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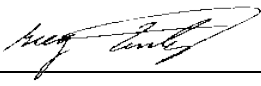
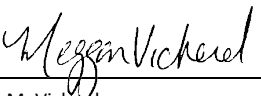
# SAFETY ASSESSMENT REPORT

## NEAR SURFACE DISPOSAL FACILITY SAFETY CASE

### NEAR SURFACE DISPOSAL FACILITY (NSDF)

**232-03610-SAR-001**

**Revision 2**

|                 |                                                                                                                                                                       |                             |
|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------|
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## Executive Summary

The Near Surface Disposal Facility (NSDF) Safety Case demonstrates that:

- The associated risk and hazards have been assessed, appropriate limits and conditions have been defined and adequate safety measures have been identified and put in place.
- The conclusions of the safety assessments meet the safety objective, safety strategy and acceptance criteria.
- The safety arguments and evidence demonstrate the safety of the NSDF.
- The management of uncertainties are appropriate to ensure safety.
- The NSDF limits, controls and conditions are appropriate to ensure safety.
- The NSDF design incorporates safety features and multiple safety functions, to ensure the protection of persons, society and the environment.
- The NSDF design has been optimized based on design iterations.
- The construction, operation, closure and post-closure activities of the NSDF can be undertaken safely.

The NSDF Safety Case covers the pre-closure period and the post-closure period of the Facility, and will be updated as required during the life of the Facility. The current NSDF lifecycle stage is a submission to the Canadian nuclear regulator, Canadian Nuclear Safety Commission (CNSC) requesting Commission approval and License to Construct. The NSDF Safety Case is part of the licencing submission to the CNSC.

The pre-closure phase includes siting, design, construction, commissioning, operations, and closure (decommissioning of the Wastewater Treatment Plant (WWTP) and support facilities) of the NSDF. The post-closure period includes the Institutional Control Period (ICP) and the post institutional control period.

This Safety Case takes the safety arguments presented in a number of technical supporting documents and integrates them into a single body of evidence, demonstrating the operational (near term) and long-term safety of the NSDF Project. Canadian Nuclear Laboratories (CNL), is proposing to construct and operate the NSDF for the disposal of solid Low-Level Waste (LLW) at Chalk River Laboratories (CRL) in Chalk River, Ontario. The purpose and urgency of the NSDF Project is rooted in the requirements established by Atomic Energy of Canada Limited (AECL), on behalf of the Government of Canada, to substantially reduce the risks associated with the CNL legacy wastes, liabilities and the cost of laboratory operations to Canadian taxpayers and to create the conditions for the revitalization of the CRL site.

Wastes generated at CNL sites are temporarily and safely contained in waste storage systems in accordance with current licence conditions that protect workers, the public and the environment; however, the practice of continuing to build additional temporary storage systems at the CRL site for radioactive waste is not consistent with modern nuclear waste management principles. In accordance with Canada's Radioactive Waste Policy Framework, the waste producers and owners of radioactive waste are responsible for the funding, organization, management and operation of disposal and other facilities required for their wastes. Responsible nuclear waste management includes full life cycle management from generation to disposal.

The main element of the NSDF design is an Engineered Containment Mound (ECM), to provide containment and isolation of the disposed LLW. The disposal facility is expected to be operational for approximately 50 years and the ECM has a design life of 550 years. The development of the ECM and the placement of low-level waste within the ECM, is completed in two phases. Phase 1 provides a total waste capacity of 525 000 m<sup>3</sup> to accommodate wastes currently in storage and wastes to be generated over the next 20 to 25 years. Phase 2 provides a total waste capacity of 475 000 m<sup>3</sup>, expanding the ECM to 1 000 000 m<sup>3</sup> for future waste disposal.

The following documents establish the frame work for the Safety Case document:

- REGDOC-2.11.1: Assessing the Long-Term Safety of Radioactive Waste Management.
- SSG-23: The Safety Case and Safety Assessment of Disposal of Radioactive Waste.
- SSG-29: Near Surface Facilities for Radioactive Waste.
- SSR-5: Disposal of Radioactive Waste.

The Nuclear Safety and Control Act (NSCA) and its regulations, are the primary legislation of CNL's main regulatory authority, the CNSC. Several regulations are made under the NSCA that are directly applicable to the NSDF and form the drivers of the overall licensing framework. The Safety Case and its supporting evidence focuses on these key drivers for the NSDF Project licensing:

- Nuclear Safety and Control Act.
- General Nuclear Safety and Control Regulations.
- Radiation Protection Regulations.
- Class I Nuclear Facility Regulations.
- Nuclear Substances and Radiation Devices Regulations.

Other Federal and Provincial legislation, such as the Canadian Environmental Assessment Act (CEAA), applies to the NSDF Project and this legislation is also part of the overall licensing framework.

The overall safety objective for the NSDF is to protect individuals, society and the environment by establishing and maintaining an effective defence against radiological and other (e.g., chemical) hazards.

The safety assessment timeframe is 10 000 years including the pre-closure phase and the post-closure phase. This assessment timeframe is consistent with the long-term assessment timeframe defined in the Post-Closure Safety Assessment (PostSA).

The System Description section of the Safety Case, describes the safety relevant aspects of the site and the facility design to align with International Atomic Energy Agency (IAEA) SSR-5 (Disposal of Radioactive Waste). Specifically, the System Description section of the Safety Case describes the:

- Site Characteristics.
- Facility Design and Engineering.
- Waste Inventory.
- Regulatory Requirements and International Guidance Addressed by the Facility Design.
- Radiological, Thermal, Hydraulic, Mechanical, Chemical and Biological Processes That May Affect the Facility.
- Possible Environmental Changes and Impacts on the NSDF.
- Interactions between System Components.
- Time Dependent Changes in Properties and Behavior of System Components and Their Interfaces.
- Radionuclide Migration Pathways (Normal Evolution and Disruptive Events).
- Data Sources Supporting Safety Assessments.
- Construction.
- Facility Operations.



The Safety Assessment section provides an evaluation of the aspects that are relevant for the safety of the NSDF including:

- Post-closure radiological impact.
- Operational safety.
- Non-radiological environmental impact.
- Site and engineering.
- Management system.
- The evaluation of the post-closure phase of the NSDF Project.

The PostSA develops models that describe the Facility's evolution through time during the post-closure phase. The Features, Events, and Processes (FEPs) are a list of all reasonable and feasible items that could affect the long-term performance and safety of the NSDF. The PostSA assesses alternative evolutions of the disposal system and its surroundings that are developed based on the FEPs that could affect the disposal facility and its evolution.

The Normal Evolution Scenario (NES) is based on a reasonable extrapolation of site and facility FEPs. Sensitivity cases are used to directly examine the effect of important uncertainties in the models and data used to represent the system. Sensitivity cases focus on using alternative parameter value choices. Disruptive Event scenarios can be considered similar to "accidents". They encompass disruptions of the site, system, or surroundings, and also encompass Inadvertent Human Intrusion scenarios. Defence-in-Depth cases are aimed at building confidence in the performance of the ECM after closure. These cases examine the extent to which the ECM depends on key engineered barriers, and what would happen if those barriers were not present. "What If?" cases represent a deliberately extreme set of assumptions that can be used to understand the absolute limits to safety performance. These scenarios are identified in a similar manner to the Disruptive Events, but are separated from them due to their low probability of occurrence.

The PostSA calculates and assesses potential impacts from non-radioactive elements or chemical species in environmental media that are relevant to human health and environmental protection. For all post-closure scenarios, there were no exceedances of the Screening Index benchmark value of 1 for any of the ecological receptors that were assessed, including species at risk, regardless of the exposure location.

The NSDF Safety Analysis Report (SAR) assesses the safety of on-site and off-site human receptors and the environment for normal operations and accident conditions. The timeframe assessed is the NSDF pre-closure phase that includes the construction period, 50 year operations period, and 30 year closure period. A Fire Hazard Analysis (FHA) was prepared in accordance with CSA N393.

Waste containment and isolation is achieved through the Facility's design, based on passive safety features and multiple barriers providing defence-in-depth and controlling the Facility's operational releases to the environment.

Principles of good engineering practice have been applied in the NSDF design, and the selection of construction materials. The construction techniques and materials foreseen for the disposal facility are well understood, and knowledge gained from similar applications confirms that these materials are well suited for the intended use.

The NSDF relies on both active and passive systems for safety during the pre-closure period and relies only on passive systems for the long-term safety.

The NSDF provides and performs the following safety functions during normal operations:

- Containment of radioactive and non-radiological materials.
- Control of operational discharges of radioactive and non-radiological materials and the limitation of accidental releases.
- Monitoring of safety critical parameters to guide worker actions.

The NSDF will provide and perform the following safety functions during the long-term:

- Isolation of radioactive and non-radiological materials.
- Retardation of migration of radioactive and non-radiological materials.
- Containment of radioactive and non-radiological materials.

The Operational Safety Analysis shows that the radiological consequences to the on-site and off-site receptors from the NSDF under normal and postulated accident conditions, meet the safety acceptance criteria and pose an acceptable risk for the public, workers and the environment.

The PostSA shows that the radiological consequences from NES, and disruptive scenarios to the critical receptors, meet the long-term safety acceptance criteria.

The overall safety objective for the NSDF has been satisfied and the design, controls and processes are adequate for the radiological protection of workers, the public and the environment.

Iteration and design optimization was completed for the NSDF. The NSDF Project applied current best practice, international and national guidelines, standards, and Research and Development (R&D) results. The project involved Subject Matter Experts (SME) from CNL, consultants and the nuclear industry, as well as SME from academic institutions to provide unbiased independent third party reviews on the project. Stakeholder feedback was considered as part of the design iteration and optimization.

The Safety Case discusses how design iteration and optimization was applied to: Site and Design Selection, Site Characterization, ECM Design Optimization, WWTP Design Optimization, Management and Administrative Measures, Waste Inventory and Waste Acceptance Criteria and Post-Closure Performance Assessment Models.

The management of uncertainties during the design phase and during safety assessment development, focuses on the use of sensitivity studies and the use of conservative assumptions.

The pre-closure and post-closure safety analyses use a conservative approach to account for the uncertainties in data and models to provide bounding results. In those cases where scientifically informed knowledge and data is available, realistic assumptions are made. Confidence in the assessment results is obtained by developing models that accurately reflect the NSDF. Further confidence is provided by ensuring data used in the models has undergone a number of iterations to minimize uncertainty and wherever assumptions have been made they have been independently validated. All software used for the NSDF Project must meet the requirements of the project Quality Assurance Plan, which include verification and validation of software. The use of software is also subject to CNL's owner surveillance activities (audits).

The waste inventory for the NSDF is referred to as the Licensed Inventory, and is a product of iteration between the Reference Inventory, the PostSA, SAR, and the Waste Acceptance Criteria (WAC). The Reference Inventory was developed through conservative estimates and extrapolations. The main sources of information was CRL's waste database: Waste Information Program (WIP). The Safety Case discusses in detail the conservatism introduced by the use of WIP to develop the Reference Inventory.

The Reference Inventory is the input into the PostSA and SAR that was developed through conservative estimates and extrapolations of CNL's current knowledge of its waste inventories. The PostSA recommended slight changes to the Facility total inventory, resulting in a proposed Licensed Inventory that is included in the SAR as an overall Facility limit.

The design of both the ECM and the WWTP are based on conventional designs to reduce uncertainty in the technology. Many other ECMs have been successfully constructed and licenced for disposal in the cleanup of similarly impacted nuclear sites. The WWTP is based on the Best Available Technology Economically Achievable. The WWTP is designed to treat the expected leachate constituents and concentrations and is flexible enough to support the addition of processes to treat unforeseen contaminants.

Uncertainty in design is managed by following an established design process and by applying good engineering practices during all phases of the design process. The design of the ECM follows industry best practice, and is being designed by a team of qualified personnel, including those responsible for the design of several other ECMs in Canada and the USA.

The NSDF is located in the Perch Lake Basin on the CRL site, which is one of the most studied and well understood plots of land at CRL. Studies on the CNL property have led to the development of sorption coefficients and distribution coefficients that form the basis of accepted industry values in Canadian Standards Association (CSA) standards. The NSDF Project has also performed borehole excavations and groundwater surveying to better understand the NSDF site characteristics.

The Ecological Risk Assessment (EcoRA), was performed to evaluate the effects of both the radiological and non-radiological contaminants on the environment and non-human biota. To address uncertainties, conservative assumptions were used throughout the assessment to ensure that the potential for a residual effect would not be underestimated.

Canadian Nuclear Laboratories follows an established Management System consistent with applicable Canadian standards such as CSA N286-12 and CNSC REGDOC-2.1.1 to ensure consistent processes are followed. Following a consistent process leads to more predictable results and less uncertainty.

Natural analogues are natural features that are similar to those features that are expected in the waste facility. These analogues can provide an understanding of how the NSDF ECM would behave over long time-scales.

Uncertainties are managed in the PostSA in the following way:

- The assessment of a range of scenarios, models and data with a suite of calculation cases.
- The adoption of conservative scenarios, models and data.
- Natural variability is taken into account.

Studying projects similar to the NSDF, and learning from them, can help build confidence. Several design and optimizations were considered as a result of the benchmarking activities, including the use of covers with sacrificial liners (geomembranes) to promote non-contact surface water runoff and minimize precipitation infiltration into the waste, and confirming that the Equalization Tanks are sized for the design basis precipitation event.

To reduce uncertainties and increase confidence in the safety assessments performed in support of the NSDF Project, several third party reviews were performed at various stages in the Project lifecycle. The findings and recommendations of the third-party reviewers were considered during the iterative development of the design and safety assessments for the project.

For the NSDF, the key uncertainties in the PostSA modelling are:

- The actual emplaced radiological inventory at the time of closure.
- The duration of institutional controls.
- How quickly contaminants move through the groundwater and the environment.
- The degradation rate of the engineered barriers.
- The effect of climate change.

For the key uncertainties, Sensitivity Analyses were performed to determine the effect of each parameter on the final outcome. For other uncertainties in the modelling, conservative assumptions are used to increase confidence that the assessment is bounding.

Uncertainties will be managed by monitoring the Facility's performance during construction, closure, and post-closure periods. Observations, site investigations, and environmental sampling results will indicate if the Facility is performing as intended, and if the assumptions used in the modelling process are consistent with reality.

The Limits, Controls and Conditions for the NSDF have been determined from the design documentation, safety analyses performed and the requirements of CNL's management systems. The limiting conditions, including systems important to safety, minimize the exposure of personnel, the public and the environment to radiological and hazardous materials at all stages of the Project.

The limits, controls and conditions are a set of rules that set parameter limits, functional capability and performance levels of equipment and personnel for the safe construction, operation and closure of the NSDF. These include safety limits, safety system settings and limiting conditions for safe operational requirements during all phases of the NSDF Project.

The post-closure phase is anticipated to include two discrete periods: institutional control and post-institutional control. The NSDF ICP is assumed to be a minimum of 300 years for planning and modelling purposes. Adequate controls are anticipated to be in place and maintained to prevent unauthorized access to the NSDF during the ICP.

The NSDF Project is designed to promote safety through passive means during post-closure but is complemented by active measures taken by CNL, such as maintenance, security and surveillance during the ICP. During institutional control, monitoring and surveillance activities will verify the integrity of the disposal facility system, while environmental monitoring activities will verify that the predicted performance continues to demonstrate compliance with the Environmental Assessment (EA) predictions.

Institutional controls include methods to preserve knowledge and to inform current and future generations of potential hazards and risks. Such administrative or legal controls help to reduce the potential for human exposure to contamination. The land use designation for the NSDF Project site is as a waste disposal facility. Upon closure, controls will be in place to limit land usage, including recognition on the property title or deed to ensure the appropriate zoning restrictions and including buffer or attenuation zones. As the enduring Federal entity, and owner of the assets and liabilities of CNL, AECL is committed to controlling and restricting the land use of the NSDF footprint for as long as necessary. While other areas of the CRL site may be re-used, the NSDF Project site will continue to be restricted as a waste disposal facility.

The key safety arguments in support of the NSDF design and radiological inventory are:

- The radiological inventory disposed of in the NSDF is only LLW.
- The Facility is designed for the radiological inventory and the physical characteristics of the site.
- The proposed site is appropriate for the NSDF.
- The NSDF supports environmental sustainability, reduces environmental risk and liability, and is protective of the Ottawa River.
- The inputs and models used in the PostSA are conservative and overestimate the risk to the public and the environment.
- The Facility will isolate the waste for hundreds of years into the future, and measures are in place to reduce the probability and limit any consequences of human intrusion to within the dose acceptance criteria of 1 mSv/a.
- Natural and anthropogenic analogues demonstrate that primitive methods of constructing earthen mounds have been used to build structures that have stood for thousands of years.

The Safety Case demonstrates that the NSDF Project meets the requirements of IAEA SSR-5 as well as all of the applicable Canadian regulations.

The waste disposed in the NSDF is contained by a multi-barrier liner and cover system designed to perform multiple safety functions for at least 550 years. The NSDF design relies on passive systems to ensure long-term safety. The safety functions fulfilled by the passive systems are containment, isolation and retardation. The NSDF design, based on multiple safety functions, ensures that safety is not dependent on a single safety function.

The ECM is designed to contain and isolate the disposed radioactivity. Over time, the total amount of radioactivity in the wastes will decrease through decay, although the activities of some radionuclides may increase through ingrowth. The results of the assessment of the NES in the PostSA shows that at the time the engineered barriers have degraded such that they no longer provide significant physical containment, 99.991% of the disposed inventory has decayed within the ECM. Only 0.005% of the disposed activity has been released from the ECM.

At the end of the assessment timeframe of 10 000 years, the total activity remaining in the ECM is equal to the local background radioactivity at the NSDF site, although the mixture of radionuclides present would be different to the background radioactivity, and hence, the radiotoxicity would be different.

After 100 years, 99.984% of the disposed activity has decayed in the ECM, and at 300 years 99.991% of the disposed activity has decayed in the ECM. A period of institutional control lasting between 100 years and 300 years will ensure the wastes are isolated from people and the environment while the hazard is greatest.

Dose assessments in the PostSA demonstrate that a person can build a home and live on top of the ECM after the institutional control period, and receive only 0.015 mSv/y, which is 1.5% of the public dose limit, and less than 1% of the natural background radiation dose in Canada.

The NSDF is an appropriate Facility for the disposal of LLW accumulated by CNL and AECL since the 1940s. The ECM provides containment and isolation of the disposed LLW from the environment for many hundreds of years, until the wastes are no longer a hazard. The NSDF allows for the clean-up and remediation of the CRL site, and removes the risk associated with wastes that are currently exposed to the environment.

## 1. INTRODUCTION

Canadian Nuclear Laboratories (CNL), is proposing to construct and operate the Near Surface Disposal Facility (NSDF) for the disposal of solid Low-Level Radioactive Waste (LLRW) at Chalk River Laboratories (CRL) in Chalk River, Ontario. The purpose and urgency of the NSDF Project is rooted in the requirements established by Atomic Energy of Canada Limited (AECL), on behalf of the Government of Canada, to substantially reduce the risks associated with the CNL legacy wastes, liabilities and the cost of laboratory operations to taxpayers and to create the conditions for the revitalization of the CRL site.

Presently, wastes generated at CNL sites are temporarily and safely contained in waste storage systems in accordance with current licence conditions that protect workers, the public and the environment. However, the practice of continuing to build additional temporary storage systems at the CRL site for radioactive waste is not consistent with modern waste management principles. In accordance with Canada's Radioactive Waste Policy Framework, the waste producers and owners of radioactive waste are responsible for the funding, organization, management and operation of disposal and other facilities required for their wastes.

Responsible nuclear waste management includes full life cycle management from generation to disposal.

Construction and operation of a new nuclear facility, NSDF, is a change that is outside the current licensing basis boundary conditions, as defined in Licence Condition G.1 [1-1] and [1-2]. Commission approval is required before proceeding with the change in accordance with CRL Licence Condition G.2, Notifications of Changes [1-1].

The NSDF design incorporates an Engineered Containment Mound (ECM), to provide containment and isolation of the disposed Low-Level Waste (LLW). The disposal Facility is expected to be operational for approximately 50 years and has a design life of 550 years. The development and the placement of waste within the ECM, is completed in a phased approach:

- Phase 1: With a total waste capacity of 525 000 m<sup>3</sup> to accommodate wastes currently in storage and wastes to be generated over the next 20 to 25 years, to facilitate the clean-up mission at AECL sites as well as create the conditions for the revitalization of the CRL site.
- Phase 2: With a total waste capacity of 475 000 m<sup>3</sup>, expands the ECM to 1 000 000 m<sup>3</sup> to accommodate wastes expected to be generated following the first Phase.

### 1.1 Purpose of this Safety Case

The purpose of this Safety Case is to present an integrated collection of safety arguments and evidence to demonstrate the safety of the NSDF. The components of the Safety Case, as shown in Figure 1-1, are:

- Safety Case Context.
- Safety strategy.
- System description.
- Safety assessment.
- Iteration and design optimization.
- Management of uncertainty.
- Limits, controls and conditions.
- Integration of safety arguments.

The NSDF Safety Case covers the pre-closure period and the post-closure period of the Facility and will be updated as required during the life of the Facility. The current NSDF lifecycle stage is submission to the Canadian nuclear regulator, Canadian Nuclear Safety Commission (CNSC) requesting Commission approval and License to Construct. The NSDF Safety Case is part of the licencing submission to the CNSC.

The pre-closure phase includes siting, design, construction, commissioning, operations, and closure (decommissioning of the Wastewater Treatment Plan (WWTP) and support facilities) of the NSDF. The post-closure period includes the ICP and the post-institutional control period.

The following documents establish the frame work for the Safety Case:

- REGDOC-2.11.1: Assessing the Long-Term Safety of Radioactive Waste Management [1-3].
- SSG-23: The Safety Case and Safety Assessment of Disposal of Radioactive Waste [1-4].
- SSG-29: Near Surface Facilities for Radioactive Waste [1-5].
- SSR-5: Disposal of Radioactive Waste [1-6].

The Safety Case will demonstrate that:

- The associated risk and hazards have been assessed, appropriate limits and conditions have been defined and adequate safety measures have been identified and put in place.
- The conclusions of the safety assessments meet the safety objective, safety strategy and acceptance criteria.
- The safety arguments and evidence demonstrate the safety of the NSDF.
- The management of uncertainties are appropriate to ensure safety.
- The NSDF limits, controls and conditions are appropriate to ensure safety.
- The NSDF design incorporates safety features and multiple safety functions, to ensure the protection of persons, society and the environment.
- The NSDF design has been optimized based on design iterations.
- The construction, operation, closure and post-closure activities of the NSDF can be undertaken safely.

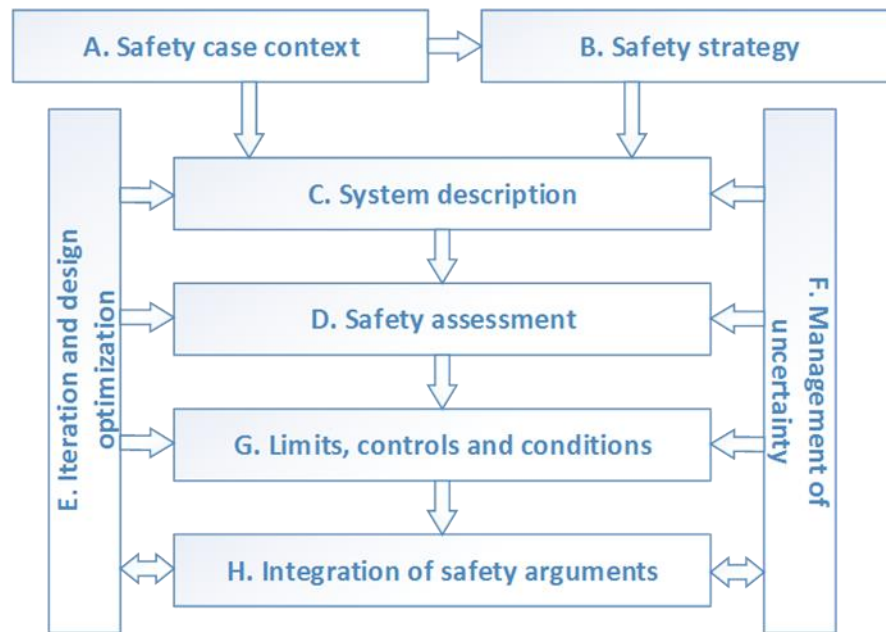


**Figure 1-1 Components of Safety Case**

## 1.2 Need for the Project

The Government of Canada's nuclear legacy liabilities have resulted from the nuclear operations, and research and development performed at CNL for approximately 70 years. The majority of these liabilities are located at CRL and consist of shutdown nuclear facilities and radioisotope laboratories, radioactive wastes in interim storage, and contaminated lands.

A nuclear facility for the disposal of LLW is required to manage the volume of LLW arising from:

- Past operations of CNL; waste dating back to the 1940s and currently placed in interim storage within the CRL Waste Management Areas (WMAs).
- Current and future operational activities of CNL's science and technology mission.
- Decommissioning and waste management activities, including the near-term campaign to decommission and demolish more than 100 obsolete facilities/buildings and to remediate contaminated lands at CRL, and to close the Whiteshell Laboratories (WL).
- Commercial waste activities where CNL offers a service to small waste volume generators (e.g., waste generated by hospitals and universities).

Approximately 90% of the LLW will originate at CRL, with 5% of the LLW coming from decommissioning at WL in Manitoba and other federal nuclear liabilities, and 5% from other Canadian sources, such as universities and hospitals.

Waste placements at CRL WMAs began in approximately 1946, and the wastes originate in part from the operation of CRL and in part from various Canadian off-site organizations such as isotope users, isotope manufactures, hospitals, government agencies, industrial plants and commercial radioactive waste brokerage firms. Currently, there are two general types of WMA facilities: operating (those facilities that are approved to receive wastes for storage), and non-operating (those facilities that are not approved to receive waste for storage, and are in a state of on-going monitoring and surveillance).



The need for a modern LLW disposal facility at CRL is imminent. Presently, safety at CRL is achieved by ensuring the wastes are temporarily contained in waste storage systems that protect workers, the public and the environment. The practice of continuing to build additional temporary storage systems at CRL for LLW is not sustainable. Canadian Nuclear Laboratories has a wealth of Operating Experience (OPEX) for LLW facilities and there is international OPEX for LLW disposal facilities.

Environmental remediation of contaminated lands is currently being assessed to ensure protection of people and the environment. The remediation of contaminated lands is anticipated to generate large volumes of LLW. Currently, large scale environmental remediation of CRL contaminated lands are deferred until the proposed NSDF is available to mitigate the need for additional storage capability.

The development of a NSDF for the disposal of LLW is an important aspect of the Statement of Work from the Site Operating Company Agreement between CNL and AECL. The baseline strategy for solid LLW at CRL, WL (excluding WR-1), and off-site prototype reactors (excluding Nuclear Power Demonstration (NPD)) is to segregate where practical, process as required and place in storage until the proposed NSDF becomes available [1-7].

The NSDF Project, addresses CNL's priority mission to provide a safe, permanent solution for the disposal of LLW, and that will provide the following benefits:

- Ensure protection, and health and safety of the public and environment.
- Provide containment and isolation of the LLW through engineered barriers.
- Reduce the nuclear liability of the Government of Canada and the Canadians.
- Improved operational efficiency.
- Meet the needs to support the CRL site clean-up mission:
  - Providing sufficient capacity to dispose of LLW generated from the decommissioning of shutdown nuclear facilities and radioisotope laboratories, which in turn eliminate the cost burden associated with the on-going maintenance of the facilities, while they remain under storage-with-surveillance.
  - Providing sufficient capacity to dispose of LLW generated from the large scale environmental remediation of contaminated lands, preventing further spread of contamination in the environment.
- Financial – reduced cost associated with the handling, size reduction, packaging and storage of LLW.
- Recovering LLW from interim storage systems suited for storage of Intermediate-Level Waste (ILW), resulting in an increased capacity for ILW storage at CRL.

### **1.3 Safety Objectives and Long-Term Safety Requirements**

The overall safety objective for the NSDF is to protect individuals, society and the environment by establishing and maintaining an effective defence against radiological and hazardous (chemical) hazards. This overall safety objective is supported by the following more detailed objectives: Radiation Protection (RP), criticality prevention, environmental protection, hazardous substance protection, and risk limitation.

In addition, four safety objectives documented in Fundamental Safety Principles [1-8], and the safety objective for a radioactive waste disposal facility documented in Disposal of Radioactive Waste [1-6], are applicable to the NSDF.

- To control the radiation exposure of people and the release of radioactive material to the environment [1-8].
- To reduce the likelihood of events that might lead to a nuclear chain reaction, or a loss of control over the radioactive material or any other source of radiation [1-8].
- To mitigate the consequences of such events if they were to occur [1-8].
- "...site, design, construct, operate, and close a disposal facility so that protection after its closure is optimized, social and economic factors being taken into account. A reasonable assurance also has to be provided that doses and risks to members of the public in the long-term will not exceed the dose limit for members of the public and other risk constraints" [1-6].

Long-term safety assessments of a facility or contaminated site, should provide reasonable assurance that the regulatory radiological dose limit for public exposure (currently 1 mSv per year) will not be exceeded [1-3]. The long-term safety requirements as documented in Assessing the Long-Term Safety of Radioactive Waste Management [1-3] are:

- Radiological protection of persons.
- Radiological protection of the environment.
- Protection of persons from hazardous substances.
- Protection of the environment from hazardous substances.

### **1.3.1 Radiological Protection of Persons**

Radiation exposure within the NSDF and any release of radioactive material from the NSDF and its associated operation activities, shall be kept As Low As Reasonably Achievable (ALARA). Any radiation exposure shall be below the established regulatory limits. These dose limits are prescribed for normal operations, although provisions must be in place to mitigate the potential exposure resulting from an accident.

Compliance with the Nuclear Safety and Control Act [1-9], the Regulations issued under the Act, as well as the CNL RP Program requirements [1-10] including the CNL ALARA standard [1-11], ensures appropriate RP and provides a system of dose limitation.

The regulatory occupational and public effective and equivalent dose limits for normal operations are stated in Section 2, Table 2-6. The action levels for occupational radiation exposure to workers are stated in Section 2, Table 2-7.

Section 2.10.1.1 presents the dose acceptance criteria for the worker and public during the pre-closure period, while Section 2.10.1.2 presents the dose acceptance criteria for the public during the post-closure period.

#### **1.3.1.1 Criticality Prevention**

Nuclear criticality in the Facility shall be prevented. The Nuclear Criticality Safety (NCS) objectives are to ensure the proper handling of Fissionable Material to render incredible or eliminate the potential of a nuclear criticality accident, to protect all persons, property and environment from the effects of a nuclear criticality accident, to protect all persons, property and environment from the effects of a nuclear criticality accident, to

comply with applicable site licence requirements, and to ensure that the use, handling, movement, and storage of Fissionable Material are controlled.

### **1.3.2 Radiological Protection of the Environment**

There shall be no significant adverse effects on the environment for all NSDF operational states and those accident scenarios accounted for in the design, the impact resulting from accident scenarios beyond the design basis, shall be mitigated to the extent practicable.

The priorities with respect to releases of radiological substances to the environment will be prevention first, then mitigation, and then accommodation such that the exposures are minimized and ALARA.

Accommodation of releases of radiological substances to the environment, implies that the release meets benchmark values and/or the acceptance criteria for the protection of persons and non-human biota.

Section 2.10.2 discusses the radiological criteria for non-human biota including a presentation of radiological dose rate benchmarks selected for both aquatic and terrestrial biota in Table 2-8.

### **1.3.3 Protection of Persons and the Environment from Hazardous Substances**

Exposure of personnel to hazardous substances in the workplace shall be minimized, taking economic and social factors into consideration, but under no circumstance shall exposure to hazardous substance exceed the Threshold Limit Values adopted by the American Conference of Governmental Industrial Hygienists [1-12], which have also been adopted by the CNL Occupational Safety and Health (OSH) Program as described in [1-13]. The acceptance criteria for the protection of persons from hazardous substances are presented in Section 2.10.3.

Canadian Nuclear Laboratories has limited the chemical characteristics of the waste inventory (including toxicity) by requiring the waste to meet the land disposal and leachate requirements of Ontario's Regulation 347, General – Waste Management [1-14] thus, constraining the hazardous substances within the waste inventory to levels not posing an unreasonable risk to the public or environment. The acceptance criteria for the protection of the environment from hazardous substances are presented in Section 2.10.4.

### **1.3.4 Risk Limitation Objective**

The acceptance criteria for frequencies and radiological consequences developed for accidents in facilities, are applied to the NSDF for the pre-closure period [1-15].

There are no non-radiological hazards within the NSDF or operations in the NSDF that pose an unreasonable risk to people outside of the NSDF. Within the NSDF, the non-radiological risks are limited to standard occupational risks related to an industrial environment. These risks are addressed by the OSH Program [1-13] and CNL work practices.

## **1.4 Safety Principles**

The safety principles to be applied in all activities for radioactive waste management are set out in the International Atomic Energy Agency (IAEA) Fundamental Safety Principles [1-8] and are:

1. Responsibility for Safety.
2. Role of Government.
3. Leadership and management for safety.

4. Justification of facilities and activities.
5. Optimization of protection.
6. Limitation of risks to individuals.
7. Protection of present and future generations.
8. Prevention of accidents.
9. Emergency preparedness (EmP) and response.
10. Protective actions to reduce existing or unregulated radiation risks.

Design principles and concepts to ensure safety in the disposal of radioactive waste based on the safety requirements defined in the IAEA Disposal of Radioactive Waste [1-6], include:

- Multiple safety functions.
- Containment of radioactive waste.
- Isolation of radioactive waste.
- Surveillance and control of passive safety features.

The safety principles applied to the design and operation of the Facility to ensure that safety functions and objectives can be met are:

- Defence-in-depth principle.
- ALARA principle.
- Nuclear Safety Culture.
- Protection of present and future generations.

#### **1.4.1 Defence-in-depth**

The defence-in-depth principle describes a system of redundant safeguards that ensures that no single human or equipment failure would result in an unacceptable hazard to the workers in the Facility, workers at the CRL site, the public, and the environment.

The key aspects of defence-in-depth are layering of defensive principles by providing multiple layers or protection against abnormal events. When defence-in-depth is applied for all activities during the life cycle of the NSDF, it provides protection against a wide range of events (e.g., Anticipated Operational Occurrences (AOO), accident conditions, equipment failure or human error within the Facility), and from events that originate outside the Facility.

Defence-in-depth follows a graded approach and consists of two components; equipment and administrative features that provide prevention or mitigation to a degree proportional to the hazard potential; and integrated safety management programs that control operations.

The level of application corresponds to the level of risk posed by the postulated event. This strategy is centred on several barriers or protection with ascending levels of importance: accommodation, mitigation and prevention. To effectively control a hazard, the same basic approach has been taken, based on the following hierarchy of hazard control principles:

- Elimination of the hazard.
- Reduce/Replace the hazard.

- Isolate the hazard.
- Control the hazard.
- Personnel Protective Equipment.
- Policies, procedures and documents.

Of these six principles, the most effective is to eliminate the hazard, and wherever possible, this is the preferred method of hazard control for the NSDF. When a hazard cannot be eliminated, then the remaining principles are implemented to various degrees to provide a significant level of defence-in-depth.

The defence-in-depth strategy is used to compensate for potential mechanical and human failures and unexpected occurrences. A series of barriers prevent, reduce, or slow down releases of radioactivity to the environment. For human errors, prevention is achieved by a combination of process design and administrative controls, e.g., training and procedures, resulting from Human Factors (HF) engineering studies, as well as by establishment of a strong safety culture.

All elements of the system design and all features of the disposal site that are primary for safety and for demonstrating defence-in-depth, are identified and assessed in a structured manner in the Safety Analysis Report (SAR) [1-16] and Post-closure Safety Assessment (PostSA) [1-17]. Assessments are performed to verify that an impairment or failure in one system classified for safety, or a decrease of performance with time of one or more systems classified for safety, is compensated for by the performance of the safety functions or by a decrease of the hazard through radioactive decay. A systematic safety assessment of the various event scenarios and evolutions of the system and its components, is conducted to demonstrate that adequate defence-in-depth will be maintained for the time frame where systems classified for safety need to be credited, including applicable uncertainties.

#### **1.4.2 As Low As Reasonably Achievable Principle**

The ALARA principle is a process of optimization to manage exposure situations. The ALARA principle is applied to activities involving radiation exposure to ensure that the magnitude of individual exposures, the number of people exposed, and the risk of unplanned exposures, are kept ALARA and economic and social factors are taken into account [1-10].

The essential elements of ALARA are [1-10]:

- Demonstrated management commitment to the ALARA principle.
- Implementation of ALARA through design, organization and management, selection and training of personnel, oversight of the RP program, resources, and documentation.
- Establishment of nuclear safety culture.
- Planning and control of non-routine work.
- Application of task-specific dose and dose-rate radiological control hold points.
- Performance of regular operational reviews.

As Low As Reasonably Achievable is achieved in the development of the NSDF through integration of design and safety activities. The NSDF development follows an iterative design process, whereby, results of the safety analysis are taken into account in the development of the design to ensure adherence to ALARA.

Protective measures against the hazards of ionizing radiation are considered to be optimized when further reductions in radiation doses are outweighed by the additional efforts and costs required for their

implementation. This principle applies to all phases throughout the life cycle of a facility, from design to decommissioning, and is a particularly important consideration when developing the operational procedures.

#### **1.4.2.1 Post-Closure As Low As Reasonably Achievable**

The ALARA principle in the NSDF post-closure phase is achieved in the optimization of the design for post-closure long-term safety, performed in compliance with the requirements of REGDOC-2.11.1 [1-3]. Specifically, a design target or dose constraint of 0.3 mSv/a, which is less than the regulatory limit of 1 mSv/a, is used in the design optimization process to ensure that long-term radiological consequences resulting from the Facility being assessed are ALARA.

#### **1.4.3 Nuclear Safety Culture**

Canadian Nuclear Laboratories has adopted the Institute of Nuclear Power Operations' nuclear safety culture definition. *"Nuclear safety culture is defined as the core values and behaviours resulting from a collective commitment by leaders and individuals to emphasize safety over competing goals to ensure protection of people and the environment."* The following principles and traits are well recognized to contribute to a healthy nuclear safety culture:

- Personal accountability: All individuals take personal responsibility for safety.
- Questioning attitude: Individuals avoid complacency and continuously challenge existing conditions and activities to identify discrepancies that might result in error or inappropriate action.
- Effective safety communication: Communications maintain a focus on safety.
- Leadership safety values and actions: Leaders demonstrate a commitment to safety in their decisions and behaviours.
- Decision-making: Decisions that support or affect nuclear safety are systematic, rigorous and thorough.
- Respectful work environment: Trust and respect permeate the organization.
- Continuous learning: Opportunities to learn about ways to ensure safety are sought out and implemented.
- Problem identification and resolution: Issues potentially impacting safety are promptly identified, fully evaluated, and promptly addressed and corrected commensurate with their significance.
- Environment for raising concerns: A safety-conscious work environment is maintained where personnel feel free to raise safety concerns without fear of retaliation, intimidation, harassment, or discrimination.
- Work processes: The process of planning and controlling work activities is implemented so that safety is maintained.

#### **1.4.4 Protection of Present and Future Generations**

The safety principle, protection of present and future generations [1-4], is applied to the NSDF pre-closure and post-closure phases. People and the environment, present and future, must be protected against radiation risks [1-4]. Application of this safety principle ensures that the LLW disposed in the NSDF does not impose an undue burden on future generations.

The NSDF design incorporates passive safety features and multiple safety functions to support this safety principle. The fundamental safety functions for the NSDF during pre-closure and post-closure phases are:

- Containment of radioactive and hazardous constituents in the radioactive waste.
- Isolation of the waste from people and from accessible biosphere.

- Retardation of the migration/dispersion of radionuclides and non-radiological contaminants in the geosphere and biosphere.
- Monitoring, surveillance and control of critical safety parameters and passive safety features credited in the post-closure period.

The NSDF SAR, provides analysis to demonstrate that the dose acceptance criteria is met for accident conditions during the pre-closure period [1-16]. The NSDF PostSA provides reasonable assurance that the regulatory radiological dose limit for public exposure (currently 1 mSv/a), will not be exceeded in the post-closure period [1-17].

## **1.5 Canadian Legislation**

The Nuclear Safety and Control Act (NSCA) [1-9] and its regulations, are the primary legislation of the main regulatory authority, the CNSC for the CRL site. Several regulations are made under the NSCA [1-9], and those that are considered directly applicable to the NSDF are identified below. The laws, regulations and guidance that are directly applicable to the NSDF Project form the drivers of the overall licensing framework. Therefore, the safety case and its supporting evidence focuses on these key drivers for the NSDF Project licensing:

- Nuclear Safety and Control Act [1-9].
- General Nuclear Safety and Control Regulations [1-18].
- Radiation Protection Regulations [1-19].
- Class I Nuclear Facility Regulations [1-20].
- Nuclear Substances and Radiation Devices Regulations [1-21].

In addition to the CNSC, the NSDF Project is also regulated by the following authorities and legislation:

- Canadian Environmental Assessment Act (CEAA) 2012.
- Environment Canada. Canadian Environmental Protection Act, 1999.
- Environment Canada. Migratory Birds Convention Act, 1994.
- Environment Canada. Species at Risk Act, 2002.
- Environment Canada. Polychlorinated Biphenyls (PCBs) Regulations, 2008.
- Fisheries and Oceans Canada. Fisheries Act, 1985.
- Canada Labour Code and Canada Occupational Health and Safety Regulations.

## **1.6 Regulatory Framework**

The Canadian nuclear regulatory framework consists of laws passed by Parliament that govern the regulation of Canada's nuclear industry, and regulations, licences and documents that the CNSC uses to regulate the industry. There are two main regulatory aspects for NSDF authorization, namely the CEAA [1-22] and the Nuclear Safety and Control Act (NSCA) [1-9]. The CNSC is the regulatory authority for the NSDF Project for both CEAA and the NSCA.

The NSDF is a designated project under the CEAA 2012 [1-22] and is subject to an Environmental Assessment (EA). The EA for the NSDF was initiated under CEAA 2012 [1-22]. The CEAA 2012 [1-22], is superseded by the Impact Assessment Act [1-23], which came into force on 2019 August 28. There is provision under the Impact Assessment Act [1-23] to grandfather projects that were initiated under CEAA 2012 [1-22]. The EA for the NSDF will be completed under CEAA 2012 [1-22] and the CNSC has provided confirmation in [1-24].

The regulatory interactions with the CNSC and the NSDF Project, are documented in the Administrative Protocol for the NSDF Project at CRL [1-25] and [1-26]. The Administrative Protocol [1-25] and [1-26], provides the administrative framework, milestones and service standards for the EA and licensing activities for the proposed NSDF. The Administrative Protocol [1-25] and [1-26], covers all activities and deliverables for the EA and licence amendment to construct, and information to be submitted to the CNSC to facilitate CNSC staff review and recommendations to the Commission. Canadian Nuclear Laboratories intent is to obtain a Licence to Construct the NSDF.

The NSDF will be a new Class 1B nuclear facility for the disposal of LLW on the CRL site. Canadian Nuclear Safety Commission staff have determined that, in accordance with the CEAA [1-22] and the NSCA [1-9] and their associated regulations, an EA and Commission approval are required to construct the Facility. Both the EA and the licence amendment will be subject to decisions made by the Commission.

When making regulatory decisions about the management of radioactive waste, the CNSC considers the extent to which the owners of the waste have addressed the following six principles [1-27]:

- The generation of radioactive waste is minimized to the extent practicable by the implementation of design measures, operating procedures and decommissioning practices.
- The management of radioactive waste is commensurate with the waste's radiological, chemical and biological hazard to the health and safety of persons, to the environment and to national security.
- The assessment of future impacts of radioactive waste on the health and safety of persons and the environment encompasses the period of time during which the maximum impact is predicted to occur.
- The predicted impacts on the health and safety of persons and the environment from the management of radioactive waste are no greater than the impacts that are permissible in Canada at the time of the regulatory decision.
- The measures needed to prevent unreasonable risk to present and future generations from the hazards of radioactive waste are developed, funded and implemented as soon as reasonably practicable.
- The trans-border effects on the health and safety of persons and the environment that could result from the management of radioactive waste in Canada, are not greater than the effects experienced in Canada.

The CNSC issues regulatory guidance documents that present general CNSC requirements and expectations, along with recommended approaches that can be followed to meet them. The regulatory documents applicable to the CRL Site are listed in CRL's Licence Conditions Handbook (LCH) [1-1].

REGDOC-2.11, Framework for Radioactive Waste Management and Decommissioning in Canada, provides overview information on the governance and regulatory framework for radioactive waste management and decommissioning in Canada [1-27].

Guidance on assessing long-term safety of radioactive waste management is set out in the regulatory document REGDOC-2.11.1, Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management [1-3]. "The purpose of this regulatory document is to assist applicants for new licences and for licence renewals in assessing the long-term safety of radioactive waste management" [1-3]. The long-term safety of waste management principles include [1-3]:

- The management of radioactive waste is commensurate with its radiological, chemical, and biological hazard to the health and safety of persons and the environment, and to national security.
- The assessment of future impacts of radioactive waste on the health and safety of persons and the environment encompasses the period of time when the maximum impact is predicted to occur.



- The predicted impact on the health and safety of persons and the environment from the management of radioactive waste is no greater than the impact that is permissible in Canada at the time of the regulatory decision.

Domestic and international standards, in particular consensus standards produced by the Canadian Standards Association (CSA) Group, are an important component of the CNSC's regulatory framework. Standards support the regulatory requirements established through the Nuclear Safety and Control Act (NSCA) [1-9], its regulations and licences by setting out the necessary elements for acceptable design and performance at a regulated facility or a regulated activity. Standards are one of the tools used by the CNSC to evaluate whether licensees are qualified to carry out licensed activities.

Appendix B of this Safety Case, maps regulatory requirements from the Class I Nuclear Facility Regulations (SOR/2000-204) [1-20], REGDOC 2.11.1 Volume III [1-3], and guidance from IAEA Safety Documents SSR-5 [1-6], SSG-23 [1-4], and SSG-29 [1-5] to the NSDF Project document(s) that provides information related to each requirement, for the purpose of demonstrating how the NSDF Project meets or exceeds regulatory requirements.

#### **1.6.1 Environmental Assessment**

The CEAA is the legal basis for the Federal EA process. Canadian Environmental Assessment Act sets out the scope, responsibilities and process for carrying out EAs that involve Federal government decision-making. Under CEAA and its regulations, the construction and operation of a disposal facility for nuclear waste qualifies as a Designated Project and therefore, requires completion of an EA. The Regulations Designating Physical Activities (2012) identify the CNSC as the Responsible Authority for projects of this type. Therefore, the CNSC is responsible for the conduct of this EA, under the CEAA.

The CNSC's Regulatory Document REGDOC-2.9.1, Environmental Protection: Environmental Principles, Assessments and Protection Measures [1-28], describes how the CNSC undertakes EAs for designated projects under the CEAA. As a designated project under CEAA (2012), the EA must be completed and an EA Decision documented prior to CNSC issuing a licensing decision.

The CNSC has delegated preparation of the technical studies (i.e., the Environmental Impact Statement (EIS)) to CNL. Guidance on preparation of the EIS is provided in REGDOC-2.9.1 [1-28], and the document Generic Guidelines for the Preparation of an EIS pursuant to the CEAA, 2012 [1-39]. The EIS [1-29] was prepared by CNL in accordance with this guidance.

The draft NSDF EIS [1-29], was submitted to the CNSC for review in 2017 March. In addition to CNSC review, the EIS was made available for review by expert Federal and Provincial departments, Indigenous groups and the public. A revised EIS will be submitted to the CNSC along with dispositions to all comments received. The CNSC will prepare the EA on the basis of the revised EIS, along with a Commission Members Document with a recommendation on an EA decision to the CNSC Commission.

#### **1.6.2 Provincial Regulations and Regulatory Documentation**

The key Provincial regulations and guidelines applicable to the NSDF Project include:

- Ontario Occupational Health & Safety Act and Regulations for Construction Projects.
- Ontario Regulation 232/98, 2011 Land-filling Sites.
- Landfill Standards 2012.

- Technical Standards and Safety Act, 2000.
- Stormwater Management Planning and Design Manual, 2003.

### **1.6.3 International Guidance**

The international guidance taken into consideration for the NSDF Project include:

- The Safety Case and Safety Assessment for the Disposal of Radioactive Waste [1-4].
- Near Surface Disposal Facilities for Radioactive Waste [1-5].
- Disposal of Radioactive Waste [1-6].
- Monitoring and Surveillance of Radioactive Waste Disposal Facilities [1-30].
- Contents and Sample Arguments of a Safety Case for Near Surface Disposal of Radioactive Waste [1-31].
- Safety Assessment Methodologies for Near Surface Disposal Facilities [1-32].
- Fundamental Safety Principles [1-8].

### **1.7 Hazard Category**

The NSDF is classified as Hazard Category 2 on the ascending scale of 1 to 4 in use by CNL [1-33]. This classification implies that the potential for significant consequences is limited to within the facility boundary of the disposal facility [1-33].

In this context, “significant consequence” is defined as a serious human injury or significant adverse impact to the environment, or a situation where a regulatory limit that defines health, safety or environmental performance is exceeded [1-34].

### **1.8 Project Lifecycle**

The NSDF Project lifecycle includes the pre-closure phase and the post-closure phase. Figure 1-2 shows the Facility lifecycle and the applicable NSDF safety documentation for the lifecycle timeframes.

The pre-closure phase activities includes the construction period, 50 year operations period, and 30 year closure period. The closure period activities include the decommissioning of redundant facilities after the ECM closure. The NSDF post-closure phase is defined by two discrete periods: Institutional Control Period and Post-Institutional Control Period. Institutional Control Period activities include surveillance, inspection and maintenance of the ECM, and groundwater monitoring. Post-Institutional Control Period occurs after the ICP and continues indefinitely.

The current NSDF Project lifecycle status is depicted in Figure 1-3. Figure 1-3 and Figure 1-4, illustrate the full life-cycle of the NSDF, the anticipated regulatory decision points, the transitions in governing documents and the graded manner in which Quality Assurance (QA) levels will be applied. Regulatory hold points, not indicated on the figures, will likely be applied at different stages to validate assumptions or confirm that the impact from uncertainties on NSDF features, credited in the safety assessments, meet the conditions used in the assessment.

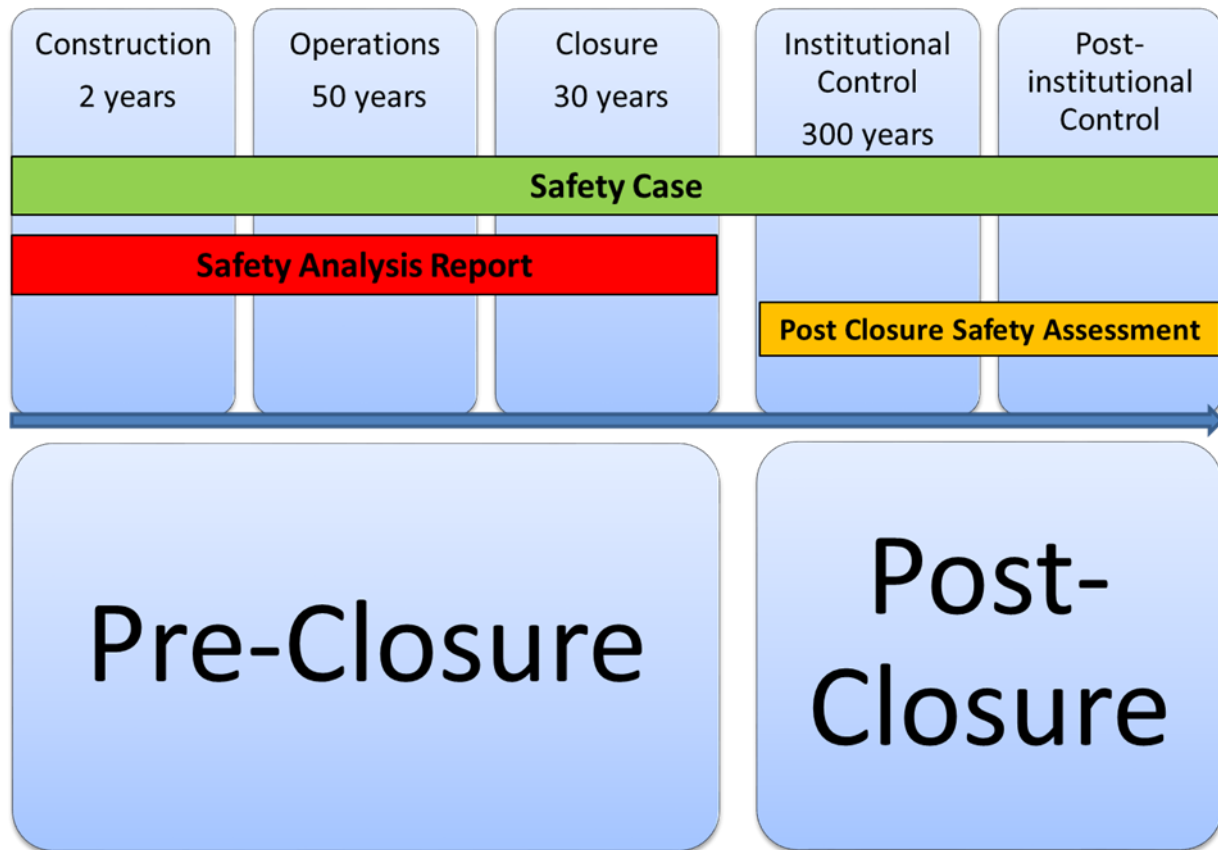


Figure 1-2 Near Surface Disposal Facility Lifecycle and Safety Documents

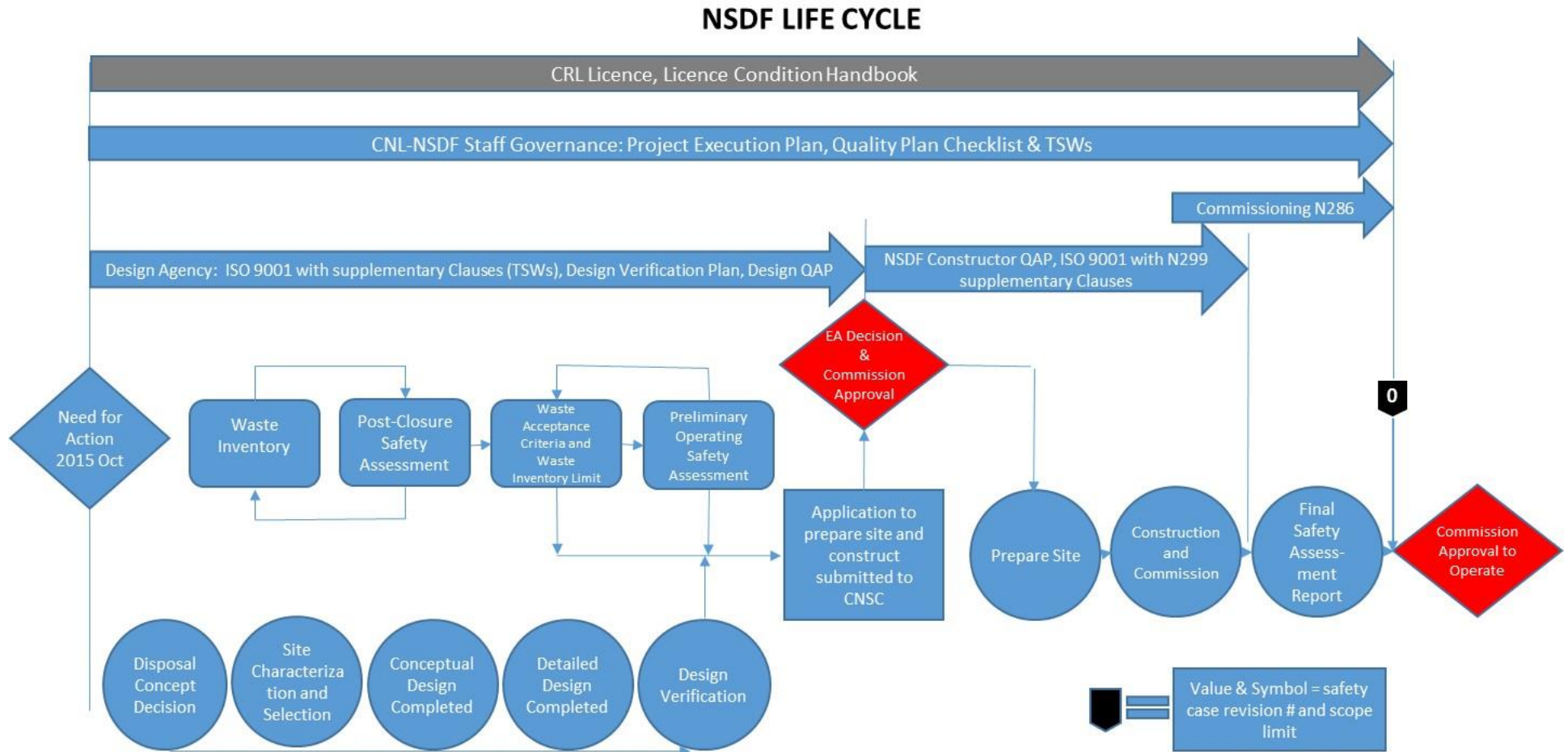


Figure 1-3 Near Surface Disposal Facility Design and Construction Phases

# NSDF LIFE CYCLE

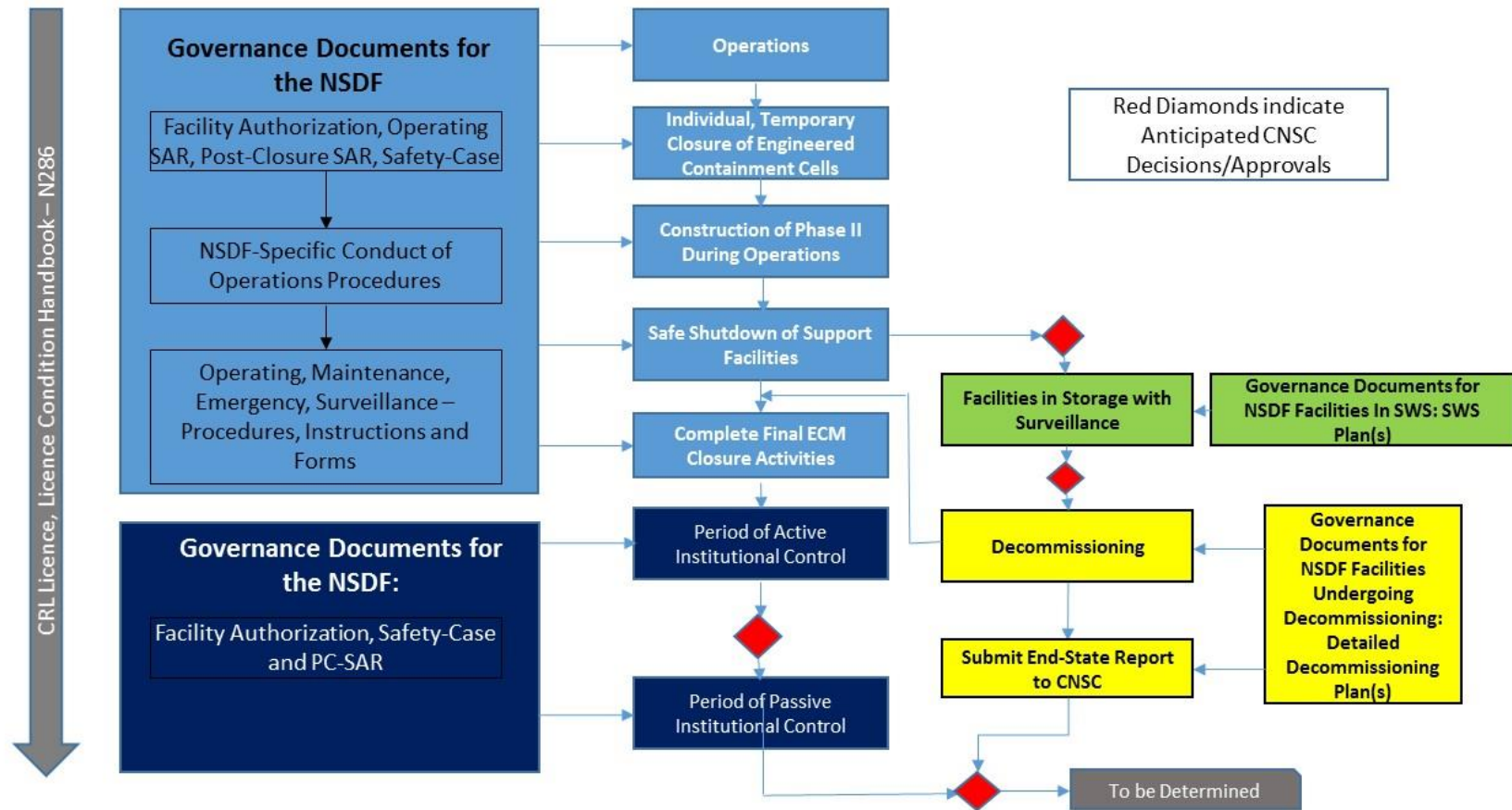


Figure 1-4 Near Surface Disposal Facility Operation, Decommissioning and Closure Phases

## 1.9 Report Structure

- Section 1, Introduction, provides the Project overview, purpose, safety objectives, safety principles, regulatory context, project lifecycle, report structure, abbreviations, and definitions.
- Section 2, Safety Strategy, provides an overview of the high-level approach that will be used to demonstrate safety. This includes regulatory requirements and acceptance criteria for both radiological and non-radiological hazards.
- Section 3, System Description, provides a description of the site, the Project at the different phases and the management system to ensure safety and the system safety functions.
- Section 4, Safety Assessment, summarizes the main aspects of pre-closure and post-closure safety assessments, which forms the scientific and technical basis for the Safety Case. The results of these assessments are compared to the acceptance criteria and safety principles identified in Section 1 and Section 2.
- Section 5, Iteration and Design Optimization, describes the optimized design and the justification for NSDF. Other sections will describe the current design iteration; this section discusses the process and justification for these decisions.
- Section 6, Management of Uncertainty, addresses uncertainties in the Safety Case. Uncertainties are identified in other sections; however, this section discusses the uncertainties in greater detail. These uncertainties are characterized with respect to their source, nature and degree, using quantitative methods, professional judgement, or both.
- Section 7, Limits Controls and Conditions, identifies the limits, controls and conditions to be applied to all work and activities that have an influence of the safety of the Facility for the complete life cycle of the Facility and to be applied to the waste that will be disposed of in the Facility.
- Section 8, Integration of Safety Arguments, is a summary of the results of the Safety Case. Since the development of the Safety Case is an integrated process, any limitations of currently available evidence and analyses are identified and will be resolved in future revisions.
- Appendices:
  - Appendix A: CNL Management System.
  - Appendix B: Concordance Tables for regulatory requirements from the Class I Nuclear Facility Regulations (SOR/2000-204), REGDOC-2.11-1 Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management [1-3], and guidance from IAEA Safety Document SSR-5 [1-6].
  - Appendix C provides information on the Public Engagement aspects of the Project.

**1.10 Abbreviations**

|         |                                                                |
|---------|----------------------------------------------------------------|
| AECL    | Atomic Energy of Canada Limited                                |
| AGCV    | Above-ground Concrete Vault                                    |
| ALARA   | As Low as Reasonably Achievable                                |
| AOO     | Anticipated Operational Occurrence                             |
| ASL     | Above Sea Level                                                |
| ASTM    | American Society for Testing and Materials                     |
| AVS     | Active Ventilation System                                      |
| BAT     | Best Available Technology                                      |
| BDATEA  | Best Demonstrated Available Technology Economically Achievable |
| BDBA    | Beyond Design Basis Accident                                   |
| BES     | Bentonite Enhanced Soil                                        |
| CAM     | Continuous Air Monitor                                         |
| CCL     | Compacted Clay Liner                                           |
| CCME    | Canadian Council of Ministers of the Environment               |
| CEAA    | Canadian Environmental Assessment Act                          |
| CGB     | Central Gneiss Belt                                            |
| CIP     | Clean in place                                                 |
| CLSM    | Controlled Low Strength Material                               |
| CNEA    | Canadian National Energy Alliance                              |
| CNL     | Canadian Nuclear Laboratories                                  |
| CNSC    | Canadian Nuclear Safety Commission                             |
| COPC    | Contaminant of Potential Concern                               |
| COSEWIC | Committee on the Status of Endangered Wildlife in Canada       |
| CQA     | Construction Quality Assurance                                 |
| CRL     | Chalk River Laboratories                                       |
| CSA     | Canadian Standards Association                                 |
| CSD     | Criticality Safety Document                                    |
| CW      | Contact Water                                                  |
| CWPS    | Contact Water Pumping Station                                  |
| DBA     | Design Basis Accident                                          |
| DBE     | Design Basis Earthquake                                        |
| DBT     | Design Basis Tornado                                           |
| DCF     | Dose Coefficient Factor or Dose Conversion Factor              |
| DD      | Design Description                                             |
| DEC     | Design Extension Condition                                     |
| DOE     | U.S. Department of Energy                                      |
| DR      | Design Requirements                                            |
| DRLs    | Derived Release Limits                                         |
| DVP     | Design Verification Plan                                       |
| EA      | Environmental Assessment                                       |
| EAMS    | Enterprise Asset Management System                             |
| EBS     | Engineered Barrier Systems                                     |
| EC      | Environment Canada                                             |

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|           |                                                       |
|-----------|-------------------------------------------------------|
| ECM       | Engineered Containment Mound                          |
| EcoRA     | Ecological Risk Assessment                            |
| EDTA      | ethylenediaminetetraacetic acid                       |
| EF        | Enhanced Fujita                                       |
| EIS       | Environmental Impact Statement                        |
| EmP       | Emergency Preparedness                                |
| EMR       | East Mattawa Road                                     |
| EnvP      | Environmental Protection                              |
| EQS       | Environmental Quality Standard                        |
| ERP       | Equipment Reliability Program                         |
| ESA       | Electrical Safety Authority (Ontario)                 |
| ESDC      | Employment and Social Development Canada              |
| FA        | Facility Authorization document or Facility Authority |
| FEP       | Features, Events and Processes                        |
| FHA       | Fire Hazard Analysis                                  |
| FM        | Facility Manager                                      |
| FPP       | Fire Protection Program                               |
| FSA       | Functional Safety Area                                |
| FS        | Factor of Safety                                      |
| GAC       | Granular Activated Carbon                             |
| GCL       | Geosynthetic Clay Liner                               |
| GDI       | Governing Document Index                              |
| GHG       | Greenhouse Gas                                        |
| GMB or GM | Geomembrane                                           |
| GPR       | Ground Penetrating Radar                              |
| GSC       | Geological Survey of Canada                           |
| GWMF      | Geologic Waste Management Facility                    |
| GWMP      | Groundwater Monitoring Program                        |
| HA        | Hazard Analysis                                       |
| HDPE      | High-Density Polyethylene                             |
| HEPA      | High Efficiency Particulate Air                       |
| HER       | Hydrological Effective Rainfall                       |
| HF        | Human Factors                                         |
| H.I.      | Human Intrusion                                       |
| HSSE      | Health, Safety, Security and Environment              |
| HSSE&Q    | Health Safety Security Environmental and Quality      |
| IAEA      | International Atomic Energy Agency                    |
| IC        | Institutional Control                                 |
| ICP       | Institutional Control Period                          |
| ICRP      | International Commission on Radiological Protection   |
| IM        | Information Management                                |
| INPO      | Institute of Nuclear Power Operations                 |
| ISAM      | Improvement of Safety Assessment Methodologies        |
| ISO       | International Organization for Standardization        |



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|--------|-----------------------------------------------------------|
| ITPR   | Independent Third Party Review                            |
| IX     | Ion Exchange                                              |
| k      | permeability with unit of $m^2$                           |
| K      | hydraulic conductivity with unit m/s                      |
| LCH    | Licence Conditions Handbook                               |
| LCS    | Leachate Collection System                                |
| LDA    | Liquid Dispersal Area                                     |
| LDS    | Leak Detection System                                     |
| LFG    | Landfill Gas                                              |
| LLW    | Low-Level Waste                                           |
| LLWR   | Low Level Waste Repository                                |
| lphd   | Liters per hectare day                                    |
| LSA    | Local Study Area                                          |
| LTWMF  | Long Term Waste Management Facility                       |
| Ma     | Megaannum, $10^6$ year                                    |
| mabh   | metres along the borehole                                 |
| mASL   | metres above sea level                                    |
| mgbs   | metres below ground surface                               |
| MCP    | Management Control Procedure                              |
| MMS    | Microseismic Monitoring Station                           |
| MNO    | Ministry of Transportation                                |
| MOEE   | Ontario Ministry of the Environment and Energy            |
| MSW    | Municipal Solid Waste                                     |
| MTO    | Ontario Ministry of Transportation                        |
| NBCC   | National Building Code of Canada                          |
| NCS    | Nuclear Criticality Safety                                |
| NEA    | Nuclear Energy Agency                                     |
| NEW    | Nuclear Energy Worker                                     |
| NM&SM  | Nuclear Materials and Safeguards Management               |
| NPD    | Nuclear Power Demonstration                               |
| NRTEOL | Nuclear Research and Test Establishment Operating Licence |
| NSCA   | Nuclear Safety and Control Act                            |
| NSDF   | Near Surface Disposal Facility                            |
| OBE    | Operating Basis Earthquake                                |
| OBG    | Ottawa- Bonnechère Graben                                 |
| OBR    | Ottawa-Bonnechère Rift                                    |
| OBT    | Organically Bound Tritium                                 |
| OLCs   | Operational Limits and Conditions                         |
| OP     | Operations                                                |
| OPEX   | Operating Experience                                      |
| OPSD   | Ontario Provincial Standards Drawings                     |
| ORNL   | Oak Ridge National Laboratories                           |
| OSC    | Operations Support Centre                                 |
| OSH    | Occupational Safety and Health                            |

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|        |                                                                             |
|--------|-----------------------------------------------------------------------------|
| PA     | Performance Assessment                                                      |
| PCB    | Poly Chlorinated Biphenyl                                                   |
| PCG    | Potential Critical Groups                                                   |
| PCO    | Perch Creek Outlet                                                          |
| PostSA | Post Closure Safety Assessment Report                                       |
| PDD    | Program Description Document                                                |
| PDF    | Probability Distribution Function                                           |
| PDP    | Preliminary Decommissioning Plan                                            |
| PGA    | Peak Ground Acceleration                                                    |
| PIE    | Postulated Initiating Event                                                 |
| PM     | Particulate Matter                                                          |
| PMP    | Probable Maximum Precipitation                                              |
| PPE    | Personal Protective Equipment                                               |
| PRD    | Program Requirements Document                                               |
| PSHA   | Probabilistic Seismic Hazard Analysis                                       |
| Pu     | Plutonium                                                                   |
| PWQO   | Provincial Water Quality Objective                                          |
| QA     | Quality Assurance                                                           |
| QAM    | Quality Assurance Manual                                                    |
| QC     | Quality Control                                                             |
| QPC    | Quality Plan Checklist                                                      |
| RMX    | Review Matrix                                                               |
| RP     | Radiation Protection                                                        |
| RSA    | Regional Study Area                                                         |
| RUSLE  | Revised Universal Soil Loss Equation                                        |
| S.A.   | Sensitivity Analysis                                                        |
| SAC    | Simple Administrative Controls or Strong Acid Cation (depending on context) |
| SAR    | Safety Analysis Report or Safety Assessment Report                          |
| SARA   | Species at Risk Act                                                         |
| SAT    | Systematic Approach to Training                                             |
| SCA    | Safety and Control Area                                                     |
| SCADA  | Supervisory Control and Data Acquisition                                    |
| SDE    | Site Design Earthquake                                                      |
| SF     | Support Facilities                                                          |
| SFM    | Special Fissionable Material                                                |
| SI     | Site Infrastructure                                                         |
| SMR    | Small Modular Reactor                                                       |
| SOCA   | Site Operating Company Agreement                                            |
| SPD    | Standard Proctor Density                                                    |
| SPM    | Suspended Particulate Matter                                                |
| SRSL   | Safety-Related Systems List                                                 |
| SSA    | Site Study Area                                                             |
| SSC    | Structures, Systems & Components                                            |
| STF    | Siting Task Force                                                           |

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|        |                                                       |
|--------|-------------------------------------------------------|
| TCLP   | Toxicity Characteristics Leaching Procedure           |
| TDG    | Transportation of Dangerous Goods                     |
| TOE    | Technical Operability Evaluation                      |
| TRV    | Toxicity Reference Value                              |
| TSS    | Total Suspended Solids                                |
| TSSA   | Technical Standards and Safety Authority              |
| TSW    | Technical Scope of Work                               |
| TSWRPA | Temporary Storage Waste Receiving and Processing Area |
| U      | Uranium                                               |
| UER    | Unexpected Event Report                               |
| VCs    | Valued Components                                     |
| VDF    | Vehicle Decontamination Facility                      |
| VLLW   | Very Low-Level Waste                                  |
| WAC    | Waste Acceptance Criteria                             |
| WIP    | Waste Information Program                             |
| WL     | Whiteshell Laboratories                               |
| WM     | Waste Management                                      |
| WMA    | Waste Management Area                                 |
| WQSZ   | Western Quebec Seismic Zone                           |
| WWTP   | Wastewater Treatment Plant                            |

## 1.11 Definitions

The following definitions used throughout this report are from the Glossary of CNSC Terminology [1-36] the IAEA Safety Glossary [1-37] and NSDF Safety Analysis Report [1-16].

|                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|-------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Accident                            | Any unintended event, including operator errors, equipment failures or other mishaps, the consequences or potential consequences of which are significant from the point of view of protection or safety. With respect to NCS, the term <b>accident or accident sequences</b> means events or event sequences, including external events, that lead to violation of the subcriticality margin (that is, to exceeding the upper subcritical limit) [1-36].           |
| Accident Conditions                 | Deviations from normal operation more severe than AOO. Accident conditions include Design Basis Accidents (DBA) and Beyond Design Basis Accidents (BDBA) [1-36].                                                                                                                                                                                                                                                                                                    |
| Active Component                    | A component whose functioning depends on an external input such as actuation, mechanical movement or supply of power [1-16].                                                                                                                                                                                                                                                                                                                                        |
| Administrative Controls             | Provisions relating to organization and management procedures, record keeping, assessment, and reporting necessary to ensure the safe operation of a Facility [1-16].                                                                                                                                                                                                                                                                                               |
| Anticipated Operational Occurrence  | An operational process deviating from normal operation, which is expected to occur once or several times during the operating lifetime of the Nuclear Facility but which, in view of the appropriate design provisions, does not cause any significant damage to items important to safety, nor lead to accident conditions [1-36]. These include events with frequencies of occurrence greater than or equal to $10^{-2}$ events per year.                         |
| As Low as Reasonably Achievable     | A principle of RP that holds that exposures to radiation are kept ALARA, social and economic factors taken into account [1-36].                                                                                                                                                                                                                                                                                                                                     |
| Barrier                             | A physical obstruction that prevents or inhibits the movement of people, radionuclides or some other phenomenon (e.g., fire), or provides shielding against radiation [1-37].                                                                                                                                                                                                                                                                                       |
| Beyond Design Basis Accident (BDBA) | Accidents falling outside the design envelope of a nuclear facility's safety systems (accident conditions more severe than those of a DBA) [1-36]. These include events with frequencies of occurrence less than $10^{-5}$ per year.                                                                                                                                                                                                                                |
| Bulk Waste                          | Waste that is a large mass, in large quantities and is not containerized nor contained within a package for final disposal [1-16].                                                                                                                                                                                                                                                                                                                                  |
| Contact Water                       | Water that has come in contact with LLW within the ECM open disposal cell [1-16].                                                                                                                                                                                                                                                                                                                                                                                   |
| Containment                         | A method or physical structure designed to prevent or control the release of nuclear or hazardous substances [1-36]. Some examples are [1-36]: <ul style="list-style-type: none"> <li>• For waste management: a barrier system that controls releases to the environment through different chemical and physical applications.</li> <li>• For packaging and transport of nuclear substances: a package or a sealed source containing nuclear substances.</li> </ul> |

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|                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Contamination                           | Radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places [1-37].                                                                                                                                                                                                                                                                                                                                                   |
| Contaminant of Potential Concern (COPC) | A term used to describe any chemical contaminant that is of particular concern to a study, either due to its toxicity, mobility, potential for increased risk, etc. In this report, COPC is used to refer to the non-radiological contaminants, where the "Reference Inventory" refers only to the radiological contaminants.                                                                                                                                                                                                                                               |
| Controlled area (CA)                    | Chalk River Laboratories site area within which normal working conditions, including unplanned events, require all personnel to follow well-established RP procedures and practices [1-16].                                                                                                                                                                                                                                                                                                                                                                                 |
| Critical Group                          | A uniform or reasonably homogeneous group of people whose characteristics (such as habits, location or age), cause them to be representative of the more highly exposed individuals, receiving the highest effective dose or equivalent dose (as applicable) than other groups in the exposed population [1-36].                                                                                                                                                                                                                                                            |
| Daily Cover                             | Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face, to control the release of fugitive dust from the surface of the waste [1-16]. The daily cover consists of 0.150 m layer of clean soil or an alternative daily cover material that is pre-approved for use including tarpaulin, fixative (crusting agent), or similar temporary cover system material [1-16].                                                                                                                                             |
| Decontamination                         | The complete or partial removal of contamination by a deliberate physical, chemical or biological process [1-37].                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Defence-in-depth                        | A hierarchical deployment of different levels of diverse equipment and procedures to prevent the escalation of AOOs and to maintain the effectiveness of physical barriers placed between a radiation source or radioactive material and workers, members of the public or the environment, in operational states and, for some barriers, in accident conditions [1-36].                                                                                                                                                                                                    |
| Design Basis                            | The range of conditions and events taken explicitly into account in the design of a Nuclear Facility, according to established criteria, such that the facility can withstand this range without exceeding authorized limits. Note: Design extension conditions are not part of the design basis [1-36].                                                                                                                                                                                                                                                                    |
| Design Basis Accident                   | Accident conditions against which the Nuclear Facility is designed according to established design criteria, and for which the damage to the fuel and/or the release of radioactive material are kept within authorized limits [1-36]. These include all events with frequencies of occurrence equal to or greater than $10^{-5}$ per year, but less than $10^{-2}$ per Facility year. This class of events also includes any events that are used as a design basis for a safety system, regardless of whether the estimated frequencies are less than $10^{-5}$ per year. |
| Design Extension Conditions             | A subset of BDBAs that are considered in the design process of the Facility in accordance with best-estimate methodology to keep releases of radioactive material within acceptable limits [1-36]. Design Extension Conditions could include severe accident conditions [1-36].                                                                                                                                                                                                                                                                                             |

|                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|---------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Design Life                                             | The period of time during which a Facility or component is expected to perform according to the technical specifications to which it was produced [1-37].                                                                                                                                                                                                                                                                                                                                                                                                                              |
| End-state                                               | With respect to decommissioning, the proposed physical, chemical and radiological condition of a Facility at the end of the decommissioning program. Note: Where a decommissioning program is to take place in discrete phases, the interim end-state objectives for each phase should be defined [1-36].                                                                                                                                                                                                                                                                              |
| Environment                                             | The component of the earth including [1-36]: <ul style="list-style-type: none"> <li>a) Land, water, and air, including all layers of the atmosphere.</li> <li>b) All organic and inorganic matter and living organisms.</li> <li>c) The interactive natural system that includes components referred to in (a) and (b).</li> </ul>                                                                                                                                                                                                                                                     |
| Event                                                   | Any unintended occurrence, including operating error, equipment failure or other mishap, or deliberate actions on part of others, the consequences or potential consequences of which are not negligible from the point of view of protection or safety [1-36].                                                                                                                                                                                                                                                                                                                        |
| Features, Events and Processes (FEP)                    | Relevant FEP relating to the site are those that might influence the long term performance of the disposal facility and thus, could affect safety [1-37].                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Graded Approach                                         | A method or process by which elements such as the level of analysis, the depth of documentation and the scope of actions necessary to comply with requirements are commensurate with [1-36]. <ul style="list-style-type: none"> <li>• The relative risks to health, safety, security, the environment and the implementation of international obligations to which Canada has agreed.</li> <li>• The particular characteristics of nuclear facility or licensed activity.</li> </ul>                                                                                                   |
| Hazardous Substance                                     | A substance, other than a nuclear substance, that is used or produced in the course of carrying on a licensed activity and that may pose a risk to the environment or the health and safety of persons [1-36].                                                                                                                                                                                                                                                                                                                                                                         |
| Interim Cover                                           | The interim cover consists of 0.3 m layer of clean soil or clean sand that is overlain by a sacrificial liner to promote non-contact surface water run-off, and minimize precipitation infiltration into the waste material [1-16]. The interim cover is applied to: 1) waste disposal areas that will remain inactive for more than 30 days; and 2) waste disposal areas that have reached the design waste fill grade [1-16].                                                                                                                                                        |
| Isolation (of radioactive waste in a disposal facility) | The physical separation and retention of radioactive waste away from people and from the environment [1-37]: <ul style="list-style-type: none"> <li>• Isolation of radioactive waste with its associated hazards in a disposal facility involves the minimization of the influence of factors that could reduce the integrity of the disposal facility; provision for a very low mobility of most long lived radionuclides to impede their migration from the disposal facility; and making access to the waste by people difficult without special technical capabilities.</li> </ul> |
| Leachate                                                | Water that has percolated through the LLW within the disposal and leached out some of the constituents [1-16].                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |

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|                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|---------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Licensed Inventory              | <p>The maximum radioactivity of significant radionuclides that the NSDF will accept [1-16].</p> <p>Note: Significant radionuclides are the radionuclides defined in the NSDF Reference Inventory [1-38].</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Low-Level Waste                 | <p>Radioactive solid waste that contains material with radionuclide content above established clearance levels and exemption quantities, but that generally has limited amounts of long-lived activity [1-36].</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Multiple Barriers               | <p>Two or more natural or engineered barriers used to isolate radioactive waste in, and to prevent or to inhibit migration of radionuclides from a repository [1-37].</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |
| Multiple Safety Functions       | <p>In the context of the fulfilment of multiple safety functions by a disposal system, the containment and isolation of waste (the confinement function), is fulfilled by two or more natural or engineered barriers of the disposal facility, by means of diverse physical and chemical properties or processes, together with operational controls [1-37].</p>                                                                                                                                                                                                                                                                                                                                        |
| Near Surface Disposal           | <p>Disposal, under an engineered cover, with or without engineered barriers, in a near surface disposal facility [1-37].</p> <p>Near surface disposal refers to a range of disposal methods, including the emplacement of solid radioactive waste in earthen trenches, above ground engineered structures, engineered structures just below the ground surface and rock caverns, silos and tunnels excavated at depths of up to a few tens of metres below ground level.</p>                                                                                                                                                                                                                            |
| Non-Contact Water               | <p>Water that has not come in contact with LLW within the ECM open disposal cell [1-16].</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Normal Evolution Scenario (NES) | <p>The NES is a reference description of the expected evolution of the ECM, its surroundings, and its resulting releases, consistent with the guidance provided in CNSC REGDOC 2.11.1 [1-3], which states that:</p> <p><i>A normal evolution scenario should be based on reasonable extrapolation of present day site features and receptor lifestyles. It should include expected evolution of the site and degradation of the waste disposal system (gradual or total loss of barrier function) as it ages. Evolution scenarios are not expected to include biological evolution of individual receptor species, which can be assumed to be static for the purposes of the safety assessment.</i></p> |

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|                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Nuclear Substance                       | <p>Means [1-36]:</p> <ul style="list-style-type: none"><li>a) deuterium, thorium, uranium or an element with an atomic number greater than 92;</li><li>b) a derivative or compound of deuterium, thorium, uranium or of an element with an atomic number greater than 92;</li><li>c) a radioactive nuclide;</li><li>d) a substance that is prescribed as being capable of releasing nuclear energy or as being required for the production or use of nuclear energy;</li><li>e) a radioactive by-product of the development, production or use of nuclear energy; and</li><li>f) a radioactive substance or radioactive thing that was used for the development or production, or in connection with the use, of nuclear energy.</li></ul> |
| Operational Limits and Conditions (OLC) | A set of rules setting forth parameter limits and the functional capability and performance levels of equipment and personnel for safe operation of a nuclear facility. This set of limits and conditions is monitored by or on behalf of the operator and can be controlled by the operator [1-36].                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Packaged Waste                          | Waste contained in rigid containers or packages for disposal [1-16].                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Passive component                       | A component that functions without depending on an external input such as actuation, mechanical movement or supply of power [1-36].                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| Passive safety                          | A design feature that functions without depending on an external input such as actuation, mechanical movement or supply of power [1-16].                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Performance testing                     | Testing done to determine whether a system meets specified acceptance criteria [1-36].                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Receptor                                | Any person or environmental entity that is exposed to radiation, or a hazardous substance, or both. A receptor is usually an organism or a population, but it could also be an abiotic entity, such as surface water or sediment [1-36].                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Repository                              | <p>An engineered facility where waste is emplaced for disposal [1-37].</p> <p>Near surface repository: A facility for radioactive waste disposal located at, or within, a few tens of metres of the Earth's surface [1-37].</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Safety Case                             | An integrated collection of arguments and evidence to demonstrate the safety of a facility and the meeting of all applicable regulatory requirements. A safety case will normally include a safety assessment, but could also typically include information (such as supporting evidence and reasoning) on the robustness and reliability of the safety assessment and the assumptions made therein [1-36].                                                                                                                                                                                                                                                                                                                                |



|                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-----------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Structures, Systems or Components (SSC) | A general term encompassing all of the elements of a Facility or activity that contribute to protection and safety. Structures are the passive elements: buildings, vessels, shielding, etc. A system comprises several components, assembled in such a way as to perform a specific (active) function. A component is a discrete element of a system. Some examples are wires, transistors, integrated circuits, motors, relays, solenoids, pipes, fittings, pumps, tanks, and valves [1-36]. |
| Wastewater                              | The product of the three waste streams; leachate, contact water and operational wastewater [1-16].                                                                                                                                                                                                                                                                                                                                                                                             |

## 1.12 References

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- [1-19] [Radiation Protection Regulations](#), SOR-2000-203.

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- [1-20] *Class I Nuclear Facilities Regulations*, SOR/2000-204.
  - [1-21] *Nuclear Substances and Radiation Devices Regulations*, SOR-2000-207.
  - [1-22] *Canadian Environmental Assessment Act*, 2012 (CEAA 2012).
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  - [1-26] CNSC, *Appendix A to the Administrative Protocol for the Near Surface Disposal Facility Project at Chalk River Laboratories*, e-Doc: 5272959, Appendix A, Revision 3, 2018 October.
  - [1-27] CNSC, *Framework for Radioactive Waste Management and Decommissioning in Canada*, REGDOC-2.11, 2018 December.
  - [1-28] CNSC, *Environmental Protection – Environmental Principles, Assessments and Protection Measures*, REGDOC-2.9.1 Version 1.1, 2017 April.
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  - [1-30] IAEA, *Monitoring and Surveillance of Radioactive Waste Disposal Facilities*, SSG-31, 2014.
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## 2. SAFETY STRATEGY

The safety strategy is the high-level approach adopted for achieving and demonstrating safety of the disposal of LLW, and the disposal system. This includes the strategies associated with overall management, siting and design, and assessments. The strategy guides key decision making in planning, developing, licensing, operating, closing, decommissioning and post-closure care of the NSDF Project. The CNL Management System [2-1] ensures that all activities during the lifecycle of the NSDF Project are conducted under a QA system.

The goals that the NSDF Project safety strategy is intended to meet are:

- A high degree of safety and protection for the public, and the environment.
- A high degree of safety and protection for the workers.
- Demonstrated compliance with safety objectives, criteria and requirements.
- Demonstrate that uncertainties are managed to the degree necessary to ensure safety.
- Achieve a high level of confidence in the long-term safety of the disposal system.

The NSDF Project safety strategy is to site, design, construct, operate and decommission a near surface disposal system for the disposal of LLW in a manner that the safety objectives, safety principles, safety requirements, and long-term safety requirements are met, and the applicable safety assessment acceptance criteria are not exceeded during the Facility's lifecycle.

The safety strategy associated with siting and design, is developing a reliable and robust disposal system that provides defence in depth and multiple safety functions, primarily containment and isolation of the waste, through the use of appropriate engineered and natural barriers at a suitable site. The siting and design strategy following good engineering principles and practices, uses an iterative process to allow for the optimization of the design and the disposal system's SSCs.

The assessments strategy takes into account regulatory requirements, and international and Canadian guidelines to assess the safety of the disposal system for normal operations, accident conditions and long-term scenarios against the applicable safety assessment acceptance criteria.

The safety strategy for the NSDF Project involves a graded approach utilizing methods to design, assess, operate, and decommission the disposal system that are suitable and sufficient to ensure safety and protection of individuals, society and the environment. To achieve this, the Safety Case will assess the following key components with the aim of producing confidence building arguments that demonstrate the overall safety of the disposal facility throughout its lifecycle:

- Evaluation of alternative design options and the site selection.
- The assessment methodology.
- The description of the disposal system.
- The development and justification of scenarios.
- The formulation and implementation of models.
- The analysis of results and building confidence in safety arguments.

A graded approach has been used to determine the scope, extent and level of detail of the Safety Case and supporting assessment. This is a method or process by which elements, such as the level of analysis, the depth of documentation and the scope of actions necessary to comply with requirements, are commensurate

with a) the relative risks to health, safety, security, the environment and the implementation of international obligations to which Canada has agreed, and b) the particular characteristics of a Facility or licensed activity [2-1]. The graded approach is explained and justified on the basis of the level or risk posed by the NSDF at the different stages of the Facility life cycle, and the associated magnitude of the possible radiation risks and the complexity of the Facility.

## **2.1 Safety Functions of the Disposal System**

The fundamental safety functions that the NSDF disposal system shall fulfill are:

- Containment of radioactive and non-radiological materials.
- Isolation of radioactive and non-radiological materials.
- Control of operational discharges of radioactive and non-radiological materials, as well as limitation of accidental releases.
- Monitoring of safety critical parameters to guide worker actions.
- Retardation of migration of radioactive and non-radiological materials.

Waste containment and isolation will be achieved through the Facility's design, based on multiple barriers providing defence-in-depth and controlling the Facility's operational releases to the environment. The layers of protection for containment and isolation include structure design/materials, and Facility inspections, supported by RP monitoring and the Environmental Monitoring Program.

The NSDF, disposal system, design relies on passive safety features to ensure long-term safety. The safety functions fulfilled by the passive safety features are containment, isolation and retardation. The NSDF design is based on multiple safety functions, which ensures that safety is not dependent on a single safety function.

## **2.2 Assessment Methodology**

The assessment methodology used in this Safety Case and the supporting documents, follows the guidance provided in IAEA SSG 23 [2-2], CNSC REGDOC-2.11-1 Volume III [2-3], Deterministic Safety Analysis [2-4], and the IAEA Safety Assessment Methodologies for Near Surface Disposal Facilities, Improving Safety Assessment Methodology (ISAM) Volume 1 [2-5] and Volume 2 [2-6].

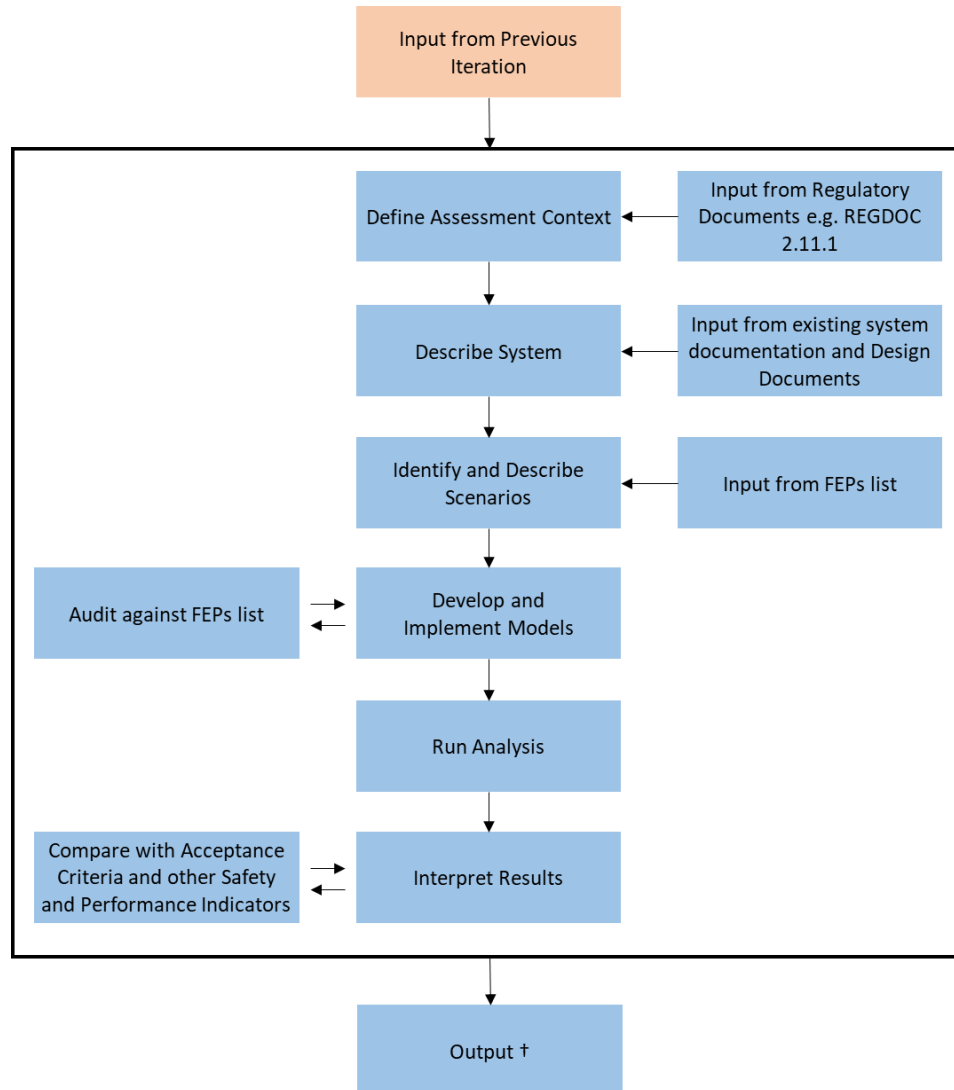
Environmental effects have been assessed in accordance with the methodology provided in REGDOC-2.9.1 - Environmental Protection: Environmental Principles, Assessments and Protection Measures [2-58], the Generic Guidelines for the Preparation of an EIS pursuant to the CEAA, 2012 [2-59], and the factors listed in subsection 19(1) of CEAA (2012).

The systematic and comprehensive methodology followed in the pre-closure safety analysis to identify all hazards and accident scenarios included [2-8]:

1. Hazard identification.
2. Identification of major hazards and Postulated Initiating Events (PIEs) associated with the NSDF design and operations.
3. Hazard analysis of the consolidated list of major hazards and PIEs for the NSDF Facilities.
4. Failure Modes Effect and Criticality Analysis of the WWTP.
5. Safety analysis of normal operations, AOO, DBA and BDBA including Design Extension Conditions (DECs) using credible/relevant scenarios.

6. The results are analysed, interpreted and discussed to inform on the performance of the system, its overall robustness, and the nature and role of key uncertainties. Particular emphasis is given to the comparison of the results for the identified safety and performance indicators against acceptance criteria.

Figure 2-1 shows the assessment methodology used to perform the PostSA [2-9].



† Includes output to EIS, Ecological Risk Assessment (EcoRA), maximum radioactive inventory, Safety Case, and next iteration (if necessary).

**Figure 2-1 Approach Used in the Post-Closure Safety Assessment [2-9]**

### 2.3 Assessment Timeframe

The Assessment Timeframe refers to the period of time that the PostSA assesses. There are several sources of CNSC and IAEA guidance on the selection of the Assessment Timeframe for long-term assessments. According to CNSC REGDOC 2.11.1 [2-3]:

*“assessments of the future impact that may arise from the radioactive waste are expected to include the period of time during which the maximum impact is predicted to occur.”*

IAEA SSG-23 [2-2] also states that:

*“In view of the complexity and variability of these factors, it is not possible to establish a universal timescale over which meaningful quantitative results from modelling can be obtained. For engineered near surface disposal facilities, which are subject to processes that may affect their integrity (e.g. erosion, human intrusion) to a lesser degree or with a smaller probability, modelling periods of a few thousand years may still be reasonable.”*

In addition to the philosophy behind the selection of the assessment timeframe, the CNSC guidance includes the following specific elements to consider from REGDOC 2.11.1, Vol. III [2-3]:

*“The assessment should provide a rationale for the assessment time frame. The approach taken to determine respective periods of time used in the assessment should take into account the following elements:*

- 1. Hazardous lifetime of the contaminants associated with the waste;*
- 2. Duration of the operational period (before the facility reaches its end state);*
- 3. Design life of engineered barriers;*
- 4. Duration of both active and passive institutional controls; and*
- 5. Frequency of natural events and human-induced environmental changes (e.g., seismic occurrence, flood, drought, glaciation, climate change, etc.).”*

The guidance was followed, and an Assessment Timeframe of 10 000 years was selected. The basis for the selection is explained in this section.

### **2.3.1 Hazardous Lifetime of the Waste**

Long-lived radionuclides are included in the NSDF inventory as they are intrinsically part of the radiological fingerprints of waste streams at CRL and other CNL sites. It is not technically or economically feasible to separate the long-lived radionuclides from the waste streams. However, the concentrations of long-lived radionuclides that are proposed in the NSDF reference inventory are in limited concentrations consistent with CSA and IAEA guidance (CSA N292.0:19 [2-10] & IAEA GSG-1 [2-11], Sections 2.2(4) and 2.24, for example). The substantial decrease of radioactivity concentrations in the first 100 years following closure of the Facility is the result of the decay of the shorter-lived radionuclides (seen in Figure 2-2). The remaining radioactivity present in the NSDF after the 300 year ICP is the limited inventory of long-lived radionuclides. The risk of the presence of these long-lived radionuclides has been studied in detail in the Post-Closure Safety Assessment [2-9]. The calculated radiological consequence and environmental concentrations meet the dose acceptance criteria and environmental quality standards, respectively, thus do not pose an unacceptable risk to the public or environment. The relative risk of the remaining long lived radionuclides contained inside the NSDF is compared with naturally occurring surficial ore bodies of the Pembroke-Renfrew region in the following Section (2.3.1.1).

From a peak risk perspective, previous iterations of the PostSA suggest that the peak dose occurs about 5 000 years after closure (as a result of barrier degradation and contaminant migration rates). Based on this, the assessment timeframe should be at least 5 000 years after closure.

While the non-radiological contaminants do not decay, the concentrations of non-radiological contaminants are being controlled via the Waste Acceptance Criteria (WAC), and via adherence to Ontario Regulation 347.

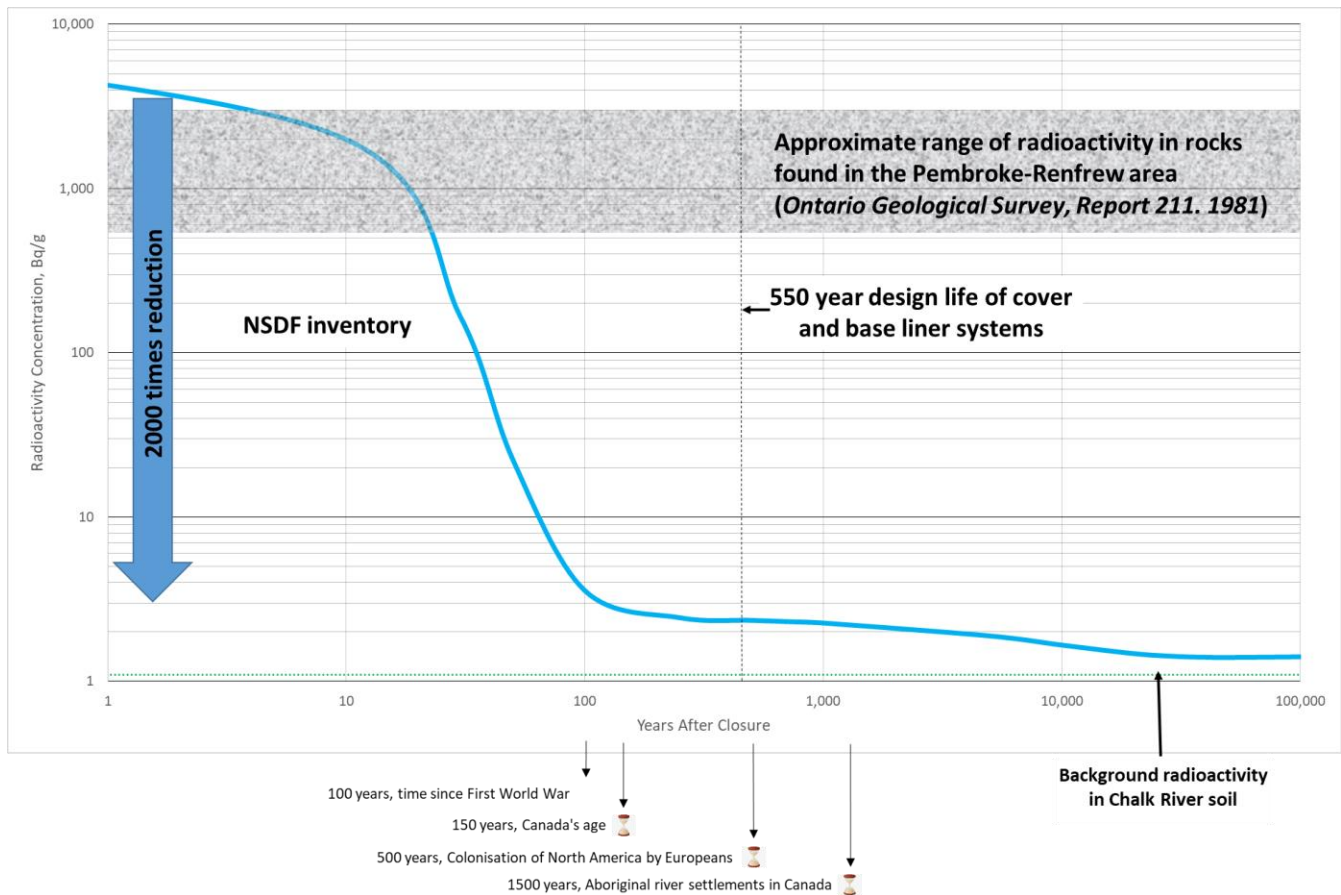


**Figure 2-2 NSDF Inventory Decay Over Time**

### 2.3.1.1 Radiotoxicity

In the above Figure 2-2, the concentration of radionuclides in the NSDF is compared to that of naturally occurring radioactive ores in the local area. The following discussion presents a related discussion, which focuses on the relative health effects, or “radiotoxicity” of the same materials.

International Atomic Energy Agency TECDOC 767 [2-12] describes radiotoxicity indices as:

*“Indices which use the inherent hazard presented by radioactive waste as a safety measure have been widely used. In particular, they have been used to indicate the time needed before the hazard presented by the waste declines to that of natural uranium ore.”*

The IAEA TECDOC 767 [2-12] discusses radiotoxicity indices in the context of comparing radioactive waste to natural materials, examples of which include:

- Total activity.
- Specific activity.
- Activity per unit volume.
- The number of Annual Limits of Intake (ALIs) by ingestion or by inhalation contained in the wastes.

When comparing quantities of radionuclides, radiotoxicity is understood to be a more useful indicator of risk than simply radioactivity or bulk mass/concentration. The selected radiotoxicity index will be a measure of dose per unit mass of material ingested, which is an equivalent way of presenting the ALI (where ALI is an example listed in IAEA TECDOC-767 [2-12]).

The relative radiotoxicity of the waste placed in the NSDF is compared to the radioactive materials contained in the naturally occurring surficial uranium ore bodies of the Pembroke-Renfrew area, as documented in the Ontario Geological Survey [2-13]. The radiotoxicity was calculated per unit mass for NSDF waste and for the ore bodies, by multiplying the radioactivity concentration of each radionuclide by the ingestion Dose Conversion Factor (DCF), and summing the values. The resulting value gives an “ingestion dose per mass” indicator of radiotoxicity, representing how much total effective dose a receptor would receive per gram of material ingested (mSv/g). Use of the ingestion DCF in the radiotoxicity comparison ensures that the relative radiological risk from the radionuclides is captured, as opposed to simply comparing radioactivity levels which only measures the quantity and rate of decay in the material.

This calculation allows a comparison of relative radiotoxicity that does not take into account any site-specific information about receptor location, or the barriers in place between the radioactive material and the environment. Radioactive progeny/ingrowth was not included in either the NSDF or ore body calculation, to maintain a fair comparison. This is conservative because the ore bodies have a higher concentration of uranium and will therefore exhibit more progeny ingrowth with time, as compared to the NSDF waste. In addition, the NSDF radioactivity was decayed, where the ore bodies were not. Only U-238 and Th-232 were included in the ore bodies’ calculation, which have half-lives of  $4.47\text{E}+09$  years and  $1.41\text{E}+10$  years, respectively. With half-lives in the billions of years, U-238 and Th-232 do not exhibit appreciable decay over the 100 000 years plotted, as seen in Figure 2-3. However, the NSDF contains mostly shorter-lived radionuclides, and therefore radioactive decay is accounted for and demonstrated in Figure 2-3. The consideration of only U-238 and Th-232 in the ore body source term is also conservative. If natural uranium was broken down into isotopes of U-238/U-235/U-234, the radiotoxicity values would actually be much higher due to the significantly larger specific activity contribution from U-234 leading to a larger ingestion dose.

The results indicate that the radiotoxicity of the NSDF waste declines quickly with time due to radioactive decay, equalling the average radiotoxicity of surficial ore deposits at approximately ten years into the post-closure phase. Therefore, the assessment timeframe for the post-closure safety assessment should assess at least ten years into the post-closure period. The 550 year design life of the Facility encompasses the timeframe where the NSDF radiotoxicity equals the radiotoxicity of natural ore bodies in the local area, and is therefore an appropriate facility lifetime.



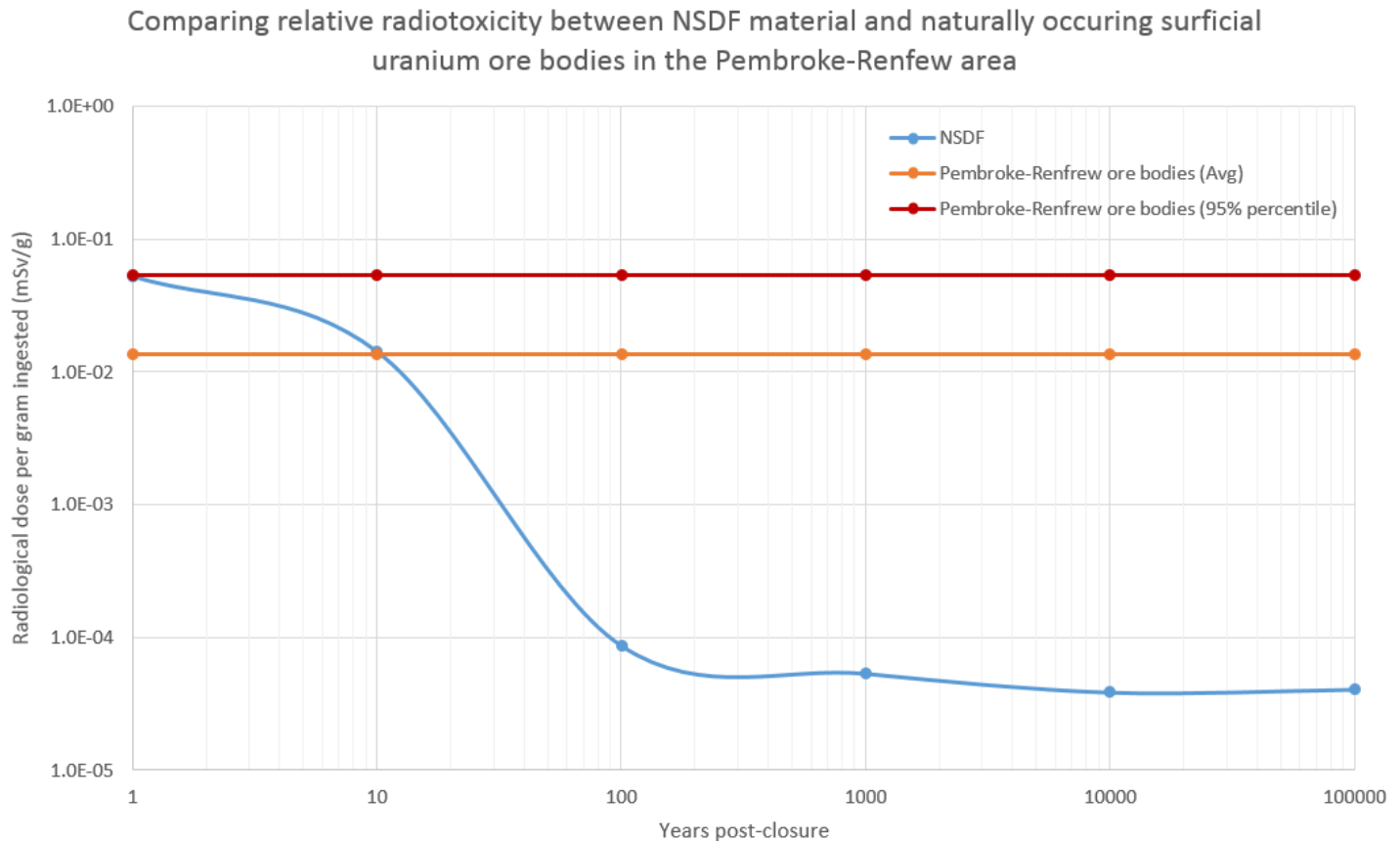


**Figure 2-3 NSDF Relative Radiotoxicity Compared to Natural Ore Bodies**

### 2.3.2 Duration of Operational Period

The operations phase of the Facility is 50 years. The safety assessment for the operations phase is covered in the SAR [2-8] and summarized in Section 4.2.

### 2.3.3 Design Life of Engineered Barriers

The engineered barriers of the NSDF include the multi-layer final cover, multi-layer base liner, and the perimeter berm. These SSCs have a 550 years design life.

The limiting material in the final cover is the High-Density Polyethylene (HDPE) geomembrane (GMB) and Geosynthetic Clay Liner (GCL) systems, described in Section 5. The GMB testing program described in Section 5, demonstrates that there are candidate GMB materials that should exceed the 550 year design life.

The base liner contains 750 mm of compacted clay, which does not have a “design life”, as a natural material. The Compacted Clay Liner (CCL) is expected to maintain its safety function for many thousands of years.

The perimeter berm is comprised entirely of natural materials, including imported fill, material excavated on-site from structure excavations, or blast rock. The perimeter berm will include aggregate materials. All aggregate materials used as perimeter berm embankment fill, will consist of granitic material (preferably rock blasted materials), capable of achieving a minimum friction angle of 45° according to a large scale direct shear test or equivalent. The exterior surface of the perimeter berm is covered with a layer of rock to protect

against erosion from wind, and precipitation. Since the perimeter berm is constructed exclusively from resilient natural materials, it is expected to remain intact and perform its function for a very long time into the future.

An examination of the engineered barriers suggests that the assessment timeframe should be at least 550 years after closure.

#### 2.3.4 Duration of Institutional Controls

In ten half-lives, a radionuclide has decayed to less than 0.1% of its original activity, and is considered to have decayed away almost completely. A 300 year period roughly aligns with ten half-lives of strontium-90 and cesium-137, which both have half-lives around 30 years, and both of which are common radionuclides found in radioactive waste. A 300 year period of institutional control is in alignment with CRL's Comprehensive Preliminary Decommissioning Plan [2-14]. In addition, IAEA GSG-1 [2-11] indicates that many member states assume that institutional controls can be relied upon for a period of 300 years.

IAEA SSG-29 [2-42], Section 7.10, discusses the relationship and decision making process related to the assumed ICP:

*An assumption in a safety assessment that, for example, active institutional controls will be effective in preventing human intrusion for 100 years, does not necessarily mean that active institutional controls will actually be removed after 100 years. The decision to release a site from regulatory control and to move from the period of active to passive institutional control is a decision that will need to be taken in the future by the operator in conjunction with the regulatory body, with account taken of the views of relevant interested parties.*

The institutional control periods used in the safety assessments of several international land disposal facilities are presented in Table 2-1 below. The institutional control periods used by these other Low-Level Waste disposal facilities are consistent with the period proposed by CNL for NSDF (i.e., at least 300 years), the only exception being the Low-Level Waste Repository (LLWR) in the UK which has a shorter ICP proposed. The NSDF has examined a shorter ICP of 100 years within the PostSA sensitivity analysis.

**Table 2-1**  
**Summary of Institutional Control Periods for Radioactive Waste Disposal Facilities**

| Country | Facility         | Institutional Control Period | Reference |
|---------|------------------|------------------------------|-----------|
| Spain   | El Cabril        | 300                          | [2-15]    |
| France  | Centre de l'Aube | 300                          | [2-15]    |
| UK      | LLWR             | 100                          | [2-15]    |
| Japan   | Rokkasho         | 300                          | [2-15]    |

Based on the above points, CNL's initial starting point for the ICP was chosen to be 300 years.

As a disposal facility, there will be land-use restrictions placed on the ECM footprint. The intention is to enforce this restriction for as long as possible. Given the uncertainty inherent to assumptions made for hundreds of years into the future, for modelling purposes, it is assumed that societal memory and institutional control fails 300 years after closure of the Facility. As a result, the assessment timeframe should be at least 300 years after closure, to capture the period where institutional controls are assumed to fail.

### **2.3.5 Frequency of Natural Events and Human-induced Environmental Changes**

Natural events, and their frequency of occurrence is assessed and screened during the FEPs process. The natural event that has the largest potential of having an adverse effect on the ECM is a large seismic event. This was an important factor in the design of the ECM. As a result, the ECM was designed to withstand the forces of a 1-in-10 000 year seismic event [2-16].

Consistent with the seismic design basis, an Assessment Timeframe of 10 000 years would capture the entire period of peak performance of the Facility.

### **2.3.6 Summary**

Although there are five factors to consider when establishing the Assessment Timeframe, the most significant for the NSDF Project was to consider the hazardous lifetime (and peak dose) from the Facility, as well as the design life of the barriers and response to seismic activity. An Assessment Timeframe of 10 000 years was selected to encompass all relevant factors.

## **2.4 Integration of Safety Arguments**

This Safety Case is intended to take the safety arguments presented in a number of technical supporting documents and integrate them into a single body of evidence, demonstrating the operational (near term) and long-term safety of the Project.

From CNSC REGDOC-2.11.1, Volume III [2-3], demonstrating long-term safety consists of providing reasonable assurance that waste management will be conducted in a manner that protects human health and the environment. This is achieved through the development of a Safety Case, which includes a safety assessment complemented by various additional arguments based on:

- Appropriate selection and application of assessment strategies. The appropriate selection and application of assessment strategies is summarized in Section 4, Safety Assessment, and discussed in more detail in the NSDF SAR [2-8], PostSA [2-9] and the EIS [2-7].
- Demonstration of system robustness. A demonstration of the system robustness is discussed throughout this Safety Case and its supporting documentation. In particular the robustness of safety arguments, is covered in Section 8, Integration of Safety Arguments.
- The use of complementary indicators of safety. Complementary indicators of safety are identified and discussed in Section 7, Limits, Controls and Conditions.
- Any other evidence that is available to provide confidence in the operational and long-term safety of radioactive waste management. Confidence building arguments and confidence in the data and models used is discussed throughout this Safety Case. In particular, the confidence in the results obtained from modelling and calculations is addressed in more detail in Section 8, Integration of Safety Arguments.

The overall approach to assessing the safety and developing the design of the NSDF, has been an iterative one, where the early iterations identified issues and tested design features and models for problems. Later, iterations were used to refine the models and data in areas where it was felt that there was considerable uncertainty in the results or that the data used required further refinement. Uncertainties in the models and data were also analyzed, and the models tested by looking at the sensitivity of the analyses to variations in the data and models. Uncertainties have also been addressed by evaluating various scenarios that have been

developed to specifically look at the consequences of that uncertainty. The management of uncertainties in the Safety Case is discussed in Section 6. The integration of safety arguments is presented in Section 8.

## **2.5 Probabilistic and Deterministic Approaches**

The goal of this Safety Case is to demonstrate that the risks associated with the creation of the NSDF are at an acceptable level. To achieve this, the Safety Case uses deterministic analysis to demonstrate that NSDF is tolerant to identified events/hazards within the design basis, thereby, defining the limits of safe operation. An additional probabilistic analysis was used to support the long-term safety assessment, where uncertainties are likely to be greater. Wherever possible, the safety of the NSDF shall be based on a deterministic design utilising the defence-in-depth concept. The safety principle of defense-in-depth is discussed further in Section 1.4.1.

### **2.5.1 The Deterministic Approach**

The deterministic approach for the safety analysis/assessment has been developed following the guidance in IAEA SSG 23 [2-2], CNSC REGDOC-2.11.1 Volume III, [2-3], Deterministic Safety Analysis [2-4] and the IAEA Safety Assessment Methodologies for Near Surface Disposal Facilities, ISAM, Volume 1, [2-5] and Volume 2 [2-6].

The safety analysis objectives of the NSDF SAR [2-8] align with the objectives defined in Deterministic Safety Analysis [2-4]. The deterministic approach for operational safety analysis comprises the following steps [2-8]:

1. Hazard identification.
2. Hazard and initiating event analysis, including risk ranking.
3. Scenario analysis and calculated radiological consequence (dose).
4. Compare calculated radiological consequence (dose) to dose acceptance criteria.

The approach used for the PostSA comprises of the following steps [2-9]:

1. The context of the assessment is defined, documenting the high-level assumptions, the constraints (reflecting the regulatory requirements), and the assessment's purpose, end points, treatment of uncertainties, and timeframes.
2. The current information on the waste, repository, geological setting and surface environment relevant to post-closure safety is reported.
3. A range of internally consistent potential future evolutions of the system (scenarios), is systematically identified, together with a suite of calculation cases that examine the performance of the disposal system under other conditions of interest and explore its sensitivity to key uncertainties.
4. Conceptual and mathematical models and data are developed for the scenarios and a range of calculation cases, which explore key areas of uncertainty, are identified and implemented in an appropriate software tool.
5. The results are analysed, interpreted and discussed to inform on the performance of the system, its overall robustness, and the nature and role of key uncertainties. Particular emphasis is given to the comparison of the results for the identified safety and performance indicators against the relevant reference levels which have been derived from guidance by REGDOC-2.11.1 Volume III [2-3].

### **2.5.2 The Probabilistic Approach**

An uncertainty analysis was performed to support the Post-Closure Safety Assessment [2-9]. The potentially most important parameters for uncertainty were identified. Suitable ranges were defined for the likely most significant parameters.

The Normal Evolution Scenario was modified to include the selected parameters. Uncertainty calculations were undertaken. For each of the sampled parameter, scatter plots and regression analysis (where appropriate) were used to illustrate the significance of the parameters to the calculated environmental concentrations and radiological dose consequence. Further detail of the uncertainty analysis is provided in Section 6.6.3.8.

### **2.6 Conservatism and Realism**

The safety analyses [2-8] and [2-9] performed, use a conservative approach to take account of uncertainties in data, and models to provide bounding results using conservative assumptions. In those cases where scientifically informed knowledge and data is available, realistic assumptions are made. In addition, where measurement data is available, the data is used as inputs to calculations, for performing a comparison between results, or to limiting the range of variants for a scenario.

Accompanying each accident analysis scenario and conceptual model is the specific information needed to describe the event. A realistic but conservative approach has been used to define parameters, noting that in many cases there are uncertainties.

Where there are high levels of uncertainty, more conservative assumptions are adopted. As such, it is acknowledged that the combined effect of many conservative assumptions can lead to unrealistic consequence estimates. To counteract this, realistic data has been used wherever possible in the safety analyses, both during the pre-closure and post-closure phases, and to determine design requirements for the NSDF.

#### **2.6.1 Pre-closure Safety Analysis**

The NSDF SAR [2-8], uses conservatism in the data, inputs and assumptions used to calculate radiological consequences for normal operations, AOO and DBA. The use of appropriate conservatism, engineering judgement and justified assumptions in the quantitative analyses, ensures that the estimates of radiological consequences are conservative.

The radiological inventories or source terms used in the radiological consequence analysis was prepared during the design phase and are documented in Waste Characterization [2-17] and WWTP Material and Energy Balance Report [2-18]. The radiological inventories in [2-17] and [2-18], were developed from NSDF Reference Inventory [2-20]. The NSDF Reference Inventory [2-20], was developed based on waste currently in storage at CRL and is intended to provide a reasonable upper bound to the radiological inventory and radionuclide concentrations in NSDF waste. The NSDF Reference Inventory [2-20], overestimates the quantities of radionuclides to be received for disposal and forms the basis for a bounding inventory used in the safety analysis.

Table 2-2 provides a summary of key assumptions used in the NSDF SAR calculations [2-8], and the reason for conservatism.

**Table 2-2**  
**Summary Key Assumptions used in the NSDF SAR [2-8]**

| Key Assumptions                                                                                                                                                                         | Reason for Conservatism                                                                                                                                                                                    |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>General</b>                                                                                                                                                                          |                                                                                                                                                                                                            |
| The average waste density is assumed to be 1.5 g/cm <sup>3</sup> .                                                                                                                      | The waste density of 1.5 g/cm <sup>3</sup> after compaction, is a design basis assumption defined in Waste Characterization [2-17].                                                                        |
| Damage ratio is 1 for airborne releases, unless otherwise stated.                                                                                                                       | The damage ratio of 1 represents that 100% of the material at risk is actually impacted by the accident generated conditions.                                                                              |
| Leak path factor is 1 for airborne releases.                                                                                                                                            | The Leak path factor of 1 represents that 100% of the radionuclides in the aerosol are transported through confinement filtration mechanism.                                                               |
| Airborne release fraction and respirable fractions are from the American National Standards Institute (ANSI) and DOE [2-8]                                                              | The ARF and RF used are bounding values for the event.                                                                                                                                                     |
| Building ventilation in WWTP not credited.                                                                                                                                              | The building ventilation provides air changes and will remove airborne contamination reducing the radiological consequence of the worker in the building.                                                  |
| The inhalation Dose Coefficient Factors (DCF), are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm activity median aerodynamic diameter (AMAD) [2-21]. | The largest value DCF is used in the calculation.                                                                                                                                                          |
| <b>Normal operations radiological consequence</b>                                                                                                                                       |                                                                                                                                                                                                            |
| Engineered Containment Mound worker dose estimates conservatively, exclude the distance and shielding provided by the heavy equipment to the receptor.                                  | The estimated worker dose is higher than the actual worker dose that would be observed in the field and still meets the normal operations dose acceptance criteria.                                        |
| Waste Water Treatment Plant maintenance activities are to occur on full tanks.                                                                                                          | This is considered conservative, since the volume assessed is greater than the working volume, and maintenance operations would likely occur on empty tanks in the non-operating train of the WWTP system. |
| For the WWTP, a distance of 30 cm is used as the average working distance for tasks.                                                                                                    | The worker may be closer for portions of a task, however, most of the time should be greater than 30 cm from the source. Radiation                                                                         |

| Key Assumptions                                                                   | Reason for Conservatism                                                                                                        |
|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------|
|                                                                                   | Protection staff support/oversight will assist in ensuring appropriate worker distance from radiological hazards during tasks. |
| Shielding provided from the tank wall of a steel tank is conservatively excluded. | The steel wall of a steel tank wall will provide shielding, dependent on the steel thickness.                                  |

### 2.6.2 Post-Closure Safety Assessment

A generally conservative approach is applied throughout the assessment where uncertainties are present [2-22]. This approach allows the uncertainties to be bounded. Best estimate values are selected where there is little uncertainty or such values are readily justified. Where possible, scientifically informed, physically realistic assumptions are made for processes that are understood and can be justified on the basis of the results of research and/or site investigation. Where there are high levels of uncertainty associated with processes and data, conservative assumptions are adopted to allow uncertainties to be bounded.

Table 2-3 provides a summary of key assumptions used in the NSDF PostSA calculations [2-22], [2-23] and the reason for conservatism.

**Table 2-3**  
**Summary of Key Assumptions used in the NSDF PostSA**

| Key Assumptions                                                                                                                                                                                                                                                                                                                                                                              | Reason for Conservatism                                                                                                                                                                                                                                                                                                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Human intrusion scenario – borehole: the borehole intersects the waste with the highest radioactivity concentration within the ECM. In other words, all of the waste brought to the surface is assumed to be from the highest-activity waste stream.                                                                                                                                         | There is inherent uncertainty about future behavior and human intrusion scenarios.<br>Conservative assumptions are adopted with regards to human intrusion scenario's to help ensure that potential exposures are not underestimated.<br>Drilling through the highest radioactivity waste will provide the highest radiological consequence (dose) to the receptor. |
| Human intrusion scenario – house with basement located on ECM: The residence building is constructed on the ECM and the building's basement is located within the select waste layer. The material excavated during the construction of the basement (clean cover material and some portion of select waste layer), is spread throughout the garden area and is used to grow garden produce. | There is inherent uncertainty about future behavior and human intrusion scenarios.<br>Conservative assumptions are adopted with regards to human intrusion scenario's, to help ensure that potential exposures are not underestimated.                                                                                                                              |
| Disruptive event – enhanced erosion: The erosion rate is assumed to be 4E-04 m/year (0.4 mm/year) [2-19].                                                                                                                                                                                                                                                                                    | This rate is chosen so that the bulk wastes within the ECM are exposed during the assessment time frame. After 10 000 years, 4 m has been eroded. For reference, the NES assumes that the cover has fully degraded at 650 years, i.e., that water ingress is unimpeded by the cover.                                                                                |
| For packaged waste, the containers or packaging are                                                                                                                                                                                                                                                                                                                                          | Excluding the protection or containment provided                                                                                                                                                                                                                                                                                                                    |

| Key Assumptions                                                                                                                                                                                                                                                                                                                          | Reason for Conservatism                                                                                                                                                                                                                                                               |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| not a barrier (i.e., provides no contaminant transport delay or containment or protection) to water contact. No credit is given to the steel liners or the grout.                                                                                                                                                                        | by the packaged waste containers, allows the waste contaminants to be available for transport when in contact with water.                                                                                                                                                             |
| The performance of the final cover has degraded to an extent at the end of the 550 year design life of the ECM. The final cover degrades quickly beyond the design life, and the final cover has fully degraded after 650 years.                                                                                                         | Even if the GMB in the final cover has significantly degraded, the GCL part of the final cover, will significantly limit infiltration into the ECM. The GMB testing program suggests that the GMB could maintain its performance for up to 2 000 years if installed correctly [2-24]. |
| Conservative values were adopted for the fraction of feed for animals from contaminated sources. All animals are assumed to obtain all their water from contaminated sources.                                                                                                                                                            | Values for dry diet conservatively adopted, given that some part of the animal's diet is taken to be from stored food during colder months.                                                                                                                                           |
| The on-site resident/farmer lives on the ECM and farms the surrounding area.                                                                                                                                                                                                                                                             | There is inherent uncertainty about future behavior and occupancy factors. Conservative assumptions are adopted with regards to human behavior and occupancy factors to help ensure that potential exposures are not under-estimated.                                                 |
| The hunter/recreational receptors and the self-sufficient indigenous receptors, use the area surrounding the ECM for hunting/gathering and consume foods from the area. The ingestion rates are based on food intake data normalized to the conservative (high) energy intakes of 4 480 kcal/d for adults and 2 879 kcal/d for children. | There is inherent uncertainty about future behavior of the hunter/recreational groups and the self-sufficient indigenous groups. Conservative assumptions are adopted with regards to human behavior and habits to help ensure that potential exposures are not under-estimated.      |
| The radon model assumes that all the wastes in the ECM are unsaturated.                                                                                                                                                                                                                                                                  | The radon flux from saturated wastes will be much lower than from unsaturated wastes, as the effective diffusivity for radon in water is approximately four orders of magnitude lower than for radon in air.                                                                          |

## 2.7 End Points for Project

An end point is defined as [2-25]: "A radiological or other measure of protection or safety that is the calculated result of an analysis or assessment". Common end points include estimates of dose or risk, estimated frequency or probability of an event or type of event (such as damage to the reactor core), expected number of health effects in a population, predicted environmental concentrations of radionuclides, etc. [2-25].

The endpoints in the NSDF SAR [2-8], are the calculated radiological consequences of normal operations, AOOs and DBAs.

The endpoints in the NSDF PostSA [2-9], are the calculated radiological consequences of the normal evolution and disruptive scenarios.

## 2.8 Identification of Future Human Activities/Intrusion with the Facility during Post-Closure

Human intrusion involving direct disturbance of disposed wastes needs to be considered, but only for inadvertent intrusion scenarios [2-3]. The probability and consequences of inadvertent intrusion are to be



considered, and that inadvertent human intrusion is more likely for near-surface disposal than for deep geological disposal [2-3].

Disposal facilities located closer to the surface, are by their nature, vulnerable to human intrusion through either inadvertent or deliberate human acts. The identification of possible human intrusion scenarios is necessary, so that measures can be taken to prevent human actions leading to a release of radioactive or other hazardous material. Human intrusion scenarios have been identified and assessed in the PostSA [2-9], using the third step of defining “scenarios” in the ISAM approach [2-5]. A key tool used in the process of defining and screening scenarios is the list of important Features, Events, and Processes (FEPS) and these are detailed in Appendix B of the PostSA [2-9]. In addition to human intrusion scenarios, this methodology allows for the identification of future human activities that may be impacted by the NSDF.

Human activities/intrusions are assumed to only occur after the ICP has ended, since sufficient controls/barriers are anticipated to be in place and maintained to prevent unauthorized access to the NSDF.

The credible human activity/intrusion scenarios, identified as disruptive events, or “What-If” scenarios, and analyzed in the PostSA are [2-9]:

- Borehole drilling: In this disruptive event scenario, a borehole is installed into the NSDF, which intersects the buried waste.
- House with basement – resident: In this disruptive event scenario, the resident/farmer is assumed to construct their residence on top of the ECM, despite the undesirable nature of its overall slope and contoured cover, and, is assumed to have excavated and built a basement for their residence.
- Well case (shallow contaminated well): In this “What-If” scenario, the receptor obtains their water from a shallow well that intersects the contaminant plume.
- Mass excavation and farming: In this “What-If” scenario, the entire inventory of the NSDF is excavated, and dispersed in surface soils with minimal dilution, which are subsequently used e.g., for cultivating foods, thereby, maximizing the number of exposure pathways to the receptor.

## **2.9 Receptors**

The human receptors are worker and public receptors. For the pre-closure phase, the worker receptors are known as on-site receptors and the public receptors are the off-site receptors.

### **2.9.1 On-site Receptors**

The workers, including contractors, are Nuclear Energy Workers (NEWs) that perform work within the fenced licensed area. Workers will only be present during the pre-closure phase and the IC phase of the post-closure phase. The radiological consequence (dose) to NEWs during the pre-closure phase is bounding, the radiological consequence (doses) to NEWs during ICP are not quantified.

### **2.9.2 Public Receptors**

During the pre-closure phase, the CRL site has access controls which restricts access to the site thus, the public receptors are off-site receptors in the pre-closure phase. The off-site receptors analyzed for the pre-closure period are an adult and a 1 year old child located at the cottages, 3 km from the NSDF, and or Chalk River, located 5 km from the NSDF [2-8].

During the post-closure phase, access restrictions to the CRL site are conservatively assumed to be in place for only a limited timeframe to demonstrate the long-term safety of the NSDF is not reliant on ICs. The public receptors in the post-closure phase are defined as the potential exposure groups [2-9]:

- On-site resident/farmer, comprising two adults, a child and an infant.
- Hunter/recreational, comprising adults and children.
- Self-sufficient Indigenous receptor, comprising adults and children.

### **2.9.3 Non-Human Biota Receptors**

Table 2-4 summarizes the representative non-human biota receptors that were selected for inclusion in the post-closure Radiological Ecological Risk Assessment [2-23]. These indicator species are appropriate because they reflect a variety of diets/feeding habits, cover a variety of trophic levels, are representative of the biota expected to be found in the study area, and are of interest to the facility and stakeholders [2-23]. The receptors selected are consistent and complementary of the Valued Components (VC) identified within the EIS [2-7].

**Table 2-4**  
**Summary of Ecological Receptors – Post-Closure**

| Major Biota Group              | Representative Receptor | Description                                                                             | Comments / Species at Risk Act Status                             |
|--------------------------------|-------------------------|-----------------------------------------------------------------------------------------|-------------------------------------------------------------------|
| <b>Aquatic Environment</b>     |                         |                                                                                         |                                                                   |
| Aquatic Vegetation             | Reed                    | Tall, grass-like wetland plant                                                          | Assessed as a generic group against environmental concentrations  |
| Pelagic Invertebrate Community | Zooplankton             | Pelagic invertebrates                                                                   | Assessed as a generic group against environmental concentrations  |
| Benthic Invertebrate Community | Benthic Invertebrates   | Sediment-dwelling macroinvertebrates                                                    | Assessed as a generic group against environmental concentrations  |
| Benthic Fish                   | Bluntnose Minnow        | Benthivorous/bottom-dwelling fish                                                       | Assessed as a generic group against environmental concentrations  |
|                                | Black Bullhead          |                                                                                         |                                                                   |
| Pelagic Fish                   | Northern Pike           | Pelagic predatory fish                                                                  | Assessed as a generic group against environmental concentrations  |
| Birds                          | Belted Kingfisher       | Mainly piscivore                                                                        | Assessed explicitly                                               |
|                                | Great Blue Heron        | Piscivore; large wading bird                                                            | Assessed explicitly                                               |
|                                | Mallard                 | Omnivore; migrating waterfowl                                                           | Assessed explicitly                                               |
| Reptiles                       | Snapping Turtle         | Omnivore                                                                                | Special concern, assessed explicitly                              |
|                                | Common Watersnake       | Carnivore                                                                               | Qualitative assessment                                            |
| Amphibians                     | Green Frog              | Insectivore                                                                             | Assessed as tadpole                                               |
| <b>Terrestrial Environment</b> |                         |                                                                                         |                                                                   |
| Terrestrial Vegetation         | Red Maple               | Upland/wetland deciduous tree                                                           | Assessed as a generic group                                       |
| Soil Invertebrates             | Earthworm               | Soil-dwelling invertebrate                                                              | Assessed explicitly                                               |
| Insects                        | Monarch Butterfly       | Flying insect                                                                           | Special concern, qualitative assessment                           |
| Birds                          | Canada Warbler          | Insectivore                                                                             | Threatened, Assessed explicitly                                   |
|                                | Eastern Whip-poor-will  | Insectivore                                                                             | Threatened, Assessed explicitly                                   |
|                                | Purple Finch            | Feeds on seeds/fruit                                                                    | Assessed explicitly                                               |
|                                | Ruffed Grouse           | Omnivore but feeds almost exclusively on vegetation; ground-dwelling non-migratory bird | Assessed explicitly                                               |
|                                | Bald Eagle              | Piscivore/carnivore                                                                     | Assessed explicitly                                               |
| Small Mammals                  | Little Brown Myotis     | Insectivore                                                                             | Endangered; also representing Northern Myotis and Tricoloured Bat |

| Major Biota Group | Representative Receptor | Description                 | Comments / Species at Risk Act Status   |
|-------------------|-------------------------|-----------------------------|-----------------------------------------|
|                   | Meadow Vole             | Herbivore; soil dwelling    | Assessed explicitly                     |
|                   | Short-tailed Shrew      | Carnivore; burrowing mammal | Assessed explicitly                     |
| Large Mammals     | Black Bear              | Omnivore                    | Assessed explicitly                     |
|                   | Eastern Wolf            | Carnivore                   | Special concern, assessed explicitly    |
|                   | White-tailed Deer       | Herbivore                   | Assessed explicitly                     |
| Reptiles          | Eastern Milksnake       | Carnivore                   | Special concern, qualitative assessment |

## **2.10 Acceptance Criteria**

The Safety Case assesses the safety of human receptors, i.e., workers and members of the public, and the environmental impact from construction, operations, closure and post-closure activities, associated with the NSDF Project. The acceptance criteria for the identified receptors and conditions are given in the sections below.

Acceptance criteria are the numerical values used to judge the results of assessment model or scenario calculations. The calculated assessment results are compared to the acceptance criteria to provide assurance that the applicable regulatory requirements are met.

The principal regulatory requirements, are those that address radiological dose and exposure to hazardous substances. These parameters are used in pre-closure and post-closure assessments as the primary indicators of safety [2-3].

The regulatory requirements for protection of persons and the environment from both radiological and non-radiological hazards of radioactive wastes lead to four areas, each with distinguishable sets of acceptance criteria for a long-term assessment [2-3]:

- Radiological protection of persons.
- Protection of persons from hazardous substances.
- Radiological protection of the environment.
- Protection of the environment from hazardous substances.

### **2.10.1 Worker and Public Radiological Criteria**

The worker and public radiological criteria has been defined for the pre-closure period and the post-closure phase.

#### **2.10.1.1 Radiological Protection of Persons during Pre-closure Period**

The dose acceptance criteria for radiological accident risks during the pre-closure period (construction, operations and closure phases), are summarized in Table 2-5 for both on-site receptors and off-site receptors, the general public [2-26]. The dose acceptance criteria for accidents in Table 2-5 is applicable to the NSDF Project and aligns with regulatory dose acceptance criteria documented in Radiation Protection Regulations [2-27], REGDOC-2.4.1 [2-4], REGDOC-2.5.2 [2-49], and Design of Small Reactor Facilities, RD-367 [2-50].

Table 2-6 shows the regulatory effective and equivalent dose limits from the Radiation Protection Regulations [2-27] for radiation exposures resulting from normal operations from a nuclear facility [2-48]. The action levels limits for radiation exposure to workers are stated in Table 2-7 [2-28]. For work activities during the pre-closure period, the action level for radiation incidents should not exceed 6 mSv to workers in a four-week period.

**Table 2-5**  
**Dose Acceptance Criteria for Accidents [2-26]**

| Frequency (event/year)        | Qualitative Event Description                      | Off-site Doses (mSv)  | On-site Doses <sup>a</sup> (mSv) |
|-------------------------------|----------------------------------------------------|-----------------------|----------------------------------|
| $\geq 10^{-2}$                | Anticipated Operational Occurrence                 | 0.5                   | 5                                |
| $\geq 10^{-5}$ to $< 10^{-2}$ | Design Basis Accident                              | 20                    | 50                               |
| $10^{-6}$ to $< 10^{-5}$      | Selected Beyond Design Basis Accident <sup>c</sup> | Assessed <sup>b</sup> | Assessed <sup>b</sup>            |

<sup>a</sup> on-site personnel, not directly involved in the accident.

<sup>b</sup> when identified, dose assessments should be performed, and if the dose exceeds the 20 mSv DBA limit, emergency procedures should be reviewed to determine if new mitigating measures can be identified.

<sup>c</sup> includes Design Extension Conditions (DECs).

**Table 2-6**  
**Regulatory Occupational and Public Effective and Equivalent Dose Limits for Normal Operations [2-27]**  
**[2-48]**

| Application                                             | Receptor Dose Limit                                                |                             |
|---------------------------------------------------------|--------------------------------------------------------------------|-----------------------------|
|                                                         | Occupational (Nuclear Energy Worker (NEW))                         | Public (non-NEW)            |
| Effective Dose (mSv) <sup>(1)</sup>                     | 50 mSv in one calendar year, and<br>100 mSv in five calendar years | 1 mSv in one calendar year  |
| <b>Equivalent Dose Limits in Organ or Tissue (mSv):</b> |                                                                    |                             |
| Lens of the eye                                         | 150 mSv in one calendar year                                       | 15 mSv in one calendar year |
| Skin <sup>(2)</sup>                                     | 500 mSv in one calendar year                                       | 50 mSv in one calendar year |
| Hands and feet                                          | 500 mSv in one calendar year                                       | 50 mSv in one calendar year |

<sup>1</sup> For pregnant NEW, the annual effective dose limit is 4 mSv for the balance of the pregnancy.

<sup>2</sup> When skin is unevenly irradiated, the equivalent dose received by the skin is the average equivalent dose over the 1 cm<sup>2</sup> area that received the highest equivalent dose.

**Table 2-7**  
**Occupational Radiation Exposures Action Levels for Chalk River Laboratories [2-28]**

| Type of Dose                                                                           | Action Level                                                     |                    |
|----------------------------------------------------------------------------------------|------------------------------------------------------------------|--------------------|
|                                                                                        | mSv (rem) per four week or longer monitoring period <sup>1</sup> | mSv (rem) per year |
| Effective Dose                                                                         | 6 (0.6) <sup>2</sup>                                             | 20 (2)             |
| Shallow Dose                                                                           | 100 (10)                                                         | 200 (20)           |
| Extremity Dose                                                                         | 100 (10)                                                         | N/A                |
| Internal Contamination                                                                 | 0.05 x Annual Limit of Intake (ALI) <sup>4</sup>                 |                    |
| Localized Area of the Skin due to a Single Skin Contamination Incident <sup>3, 5</sup> | 50 (5)                                                           |                    |

## Notes:

1. The monitoring period is normally four weeks, but may be longer if justified. The monitoring period shall not exceed three months.
2. Action levels for pregnant women shall be 0.3 mSv per four weeks to the abdomen.
3. Extremity dose action level applies in situations where an extremity Thermoluminescent Dosimeter Badge has measured a dose exceeding 100 mSv. All contamination events that result in a dose to the skin, irrespective of the location on the body of the exposed skin, will be recorded and reported as appropriate as a skin dose (with the associated action level being 50 mSv).
4. The Annual Limit of Intake (ALI) is defined as the activity of a radionuclide that, when taken into the body, will deliver an effective dose of 20 mSv over the next 50 years following the intake.
5. The averaging area shall never be less than 1 cm<sup>2</sup>, even in case of hot particles. When skin is unevenly irradiated, the equivalent dose received by the skin is the average equivalent dose over the 1 cm<sup>2</sup> area that received the highest equivalent dose. When the contamination is relatively uniform over the skin, the averaging area of 100 cm<sup>2</sup> may be used for operational convenience but not if significantly lowers the average dose.

### 2.10.1.2 Radiological Protection of Persons during Post-Closure Period

The post-closure long-term safety assessments, uses specific criteria from CNSC REGDOC-2.11.1 [2-3] for radiation exposure that may result from the expected evolution of the NSDF, referred to as “Normal Evolution Scenario” and “Alternative Strategy Cases”, and for radiation exposure that may result from events with low or uncertain probability, referred to as “Disruptive Event Scenarios”.

For the “Normal Evolution Scenario”, the criterion for radiological exposure is that the dose to the public and to workers will be ALARA, and no more than 0.3 mSv/year. This criterion is also a ‘dose constraint’ for design optimization. While the dose constraint is used as a design target in the optimization process, it is not used as a limit for compliance. The dose constraint therefore, is not used to provide margin to the 1 mSv/year dose limit to account for uncertainties; rather, these modelling uncertainties are addressed by conservatism built into the assessment model, the scenario design, and parameter choice. As such, the calculated results for these cases account for uncertainties either explicitly or through conservative assumptions, but do not account for unknowns. This dose constraint provides a factor of three margin to the regulatory dose limit of 1 mSv/year. For comparison, 0.3 mSv/year is approximately one sixth of the annual individual dose received from natural background radiation in Canada (which is about 2 mSv/y).

For the “Disruptive Event Scenarios”, the regulatory dose limit of 1 mSv/year for public exposure is used as a criterion and compliance limit. The assessment of “Disruptive Event Scenarios” account for unknowns.

There are also other scenarios included with deliberately extreme assumptions that are evaluated to understand the boundaries of the post-closure assessment. A dose criterion of 1 mSv/y is used for radiation exposure of humans for both Defence-in-Depth scenarios and “What If” cases.

The radiological dose acceptance criteria for human intrusion during the post-closure phase are assessed separately [2-29]:

- If intrusion is expected to lead to an annual dose of less than 1 mSv, then efforts to reduce the probability of intrusion, or to limit its consequences, are not warranted.
- If intrusion is expected to lead to an annual dose in the range of 1-20 mSv, reasonable efforts are warranted to reduce the probability of intrusion or limit its consequences.
- If intrusion is expected to lead to an annual dose in excess of 20 mSv, then alternative disposal options must be considered.

### **2.10.2 Radiological Criteria – Non-Human Biota**

For the protection of non-human biota from radiation exposure, the primary concern is the total radiation dose to the organisms resulting in deterministic effects (i.e., greater than the threshold below which the effect does not occur).

A benchmark value is a level of exposure (concentration or dose), below which meaningful effects are unlikely and above which there is potential for meaningful effects [2-30]. Ecological risks are assessed by estimating the total dose rate received by an ecological receptor and comparing dose rate to the selected benchmark.

Table 2-8 presents the radiological dose rate benchmarks selected for both aquatic and terrestrial biota [2-31]. A safety factor of 10 was applied to the benchmarks for Species at Risk [2-31].

The radiological dose benchmarks from CSA N288.6-12 [2-32] were used, and are based on benchmark values recommended by the National Council on RP and Measurements, the IAEA and the United Nations Scientific Committee on the Effects of Atomic Radiation. The benchmark values are used as dose acceptance criteria for non-human biota.



**Table 2-8**  
**Radiological Dose Rate Benchmarks [2-31]**

| Major Biota Group                         | Organism                                                       | Dose Rate Benchmark (mGy/day) |
|-------------------------------------------|----------------------------------------------------------------|-------------------------------|
| Aquatic Vegetation                        | Reed                                                           | 9.6                           |
| Pelagic Invertebrate Community            | Zooplankton                                                    | 9.6                           |
| Benthic Invertebrate Community            | Benthic Invertebrates                                          | 9.6                           |
| Benthic Fish                              | Bluntnose Minnow, Brown Bullhead                               | 9.6                           |
| Pelagic Fish                              | Northern Pike                                                  | 9.6                           |
| Amphibians                                | Green Frog (tadpole)                                           | 9.6                           |
| Aquatic Based Birds                       | Belted Kingfisher, Great Blue Heron, Mallard                   | 9.6                           |
| Terrestrial Vegetation                    | Red Maple                                                      | 2.4                           |
| Soil Invertebrates                        | Earthworm                                                      | 2.4                           |
| Terrestrial Based Birds                   | Purple Finch, Ruffed Grouse                                    | 2.4                           |
| Terrestrial Based Small and Large Mammals | Meadow Vole, Short-tailed Shrew, Black Bear, White-tailed Deer | 2.4                           |
| <b>Species at Risk</b>                    |                                                                |                               |
| Aquatic Reptiles                          | Snapping Turtle                                                | 0.96                          |
| Terrestrial Based Birds                   | Canada Warbler, Eastern Whip poor-will                         | 0.24                          |
| Terrestrial Based Small and Large Mammals | Little Brown Myotis, Eastern Wolf                              | 0.24                          |

### 2.10.3 Protection of Persons from Hazardous Substances

The acceptance criteria for protection of persons from hazardous substances (or non-radiological substances/constituents), applied to the safety assessment are derived from Federal and Provincial environmental objectives and guideline benchmark values. Where the Canadian Council of Ministers of the Environment's (CCME's) human health guidelines are not available for material relevant to the NSDF, human health-based provincial guidelines or other appropriate standards are used. Health Canada has established that a cancer risk in the range of  $10^{-5}$  to  $10^{-6}$  per persons exposed, is negligible for carcinogenic substances in drinking water, and that only exposure to adults needs to be determined [2-33].

#### 2.10.3.1 Airborne Acceptance Criteria

The airborne release acceptance criteria for non-radiological substances are based on Ontario ambient air quality criteria [2-34] and CCME documents [2-35] and [2-36]. The most restrictive value for each airborne release type was selected. A summary of the applicable Ontario and Federal objectives and criteria are listed in Table 2-9, where the selected values are on grey background.

**Table 2-9**  
**Provincial and Federal Regulatory Air Quality Criteria**

| Provincial and Federal Regulatory Air Quality Criteria <sup>(1)</sup> |                  |                                                                               |                                                                               |                                                                                                                           |            |
|-----------------------------------------------------------------------|------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|------------|
| Substance                                                             | Averaging Period | Ontario Ambient Air Quality Guidelines <sup>(a)</sup><br>(µg/m <sup>3</sup> ) | Canadian Ambient Air Quality Standards <sup>(b)</sup><br>(µg/m <sup>3</sup> ) | National Ambient Air Quality Objectives and Canadian Ambient Air Quality Standards <sup>(c)</sup><br>(µg/m <sup>3</sup> ) |            |
|                                                                       |                  |                                                                               |                                                                               | Desirable                                                                                                                 | Acceptable |
| SPM <sup>(d)</sup>                                                    | 24-Hour          | 120                                                                           | —                                                                             | —                                                                                                                         | 120        |
|                                                                       | Annual           | 60 <sup>(e)</sup>                                                             | —                                                                             | 60                                                                                                                        | 70         |
| PM <sub>10</sub>                                                      | 24-Hour          | 50 <sup>(f)</sup>                                                             | —                                                                             | —                                                                                                                         | —          |
| PM <sub>2.5</sub>                                                     | 24-Hour          | 30 <sup>(g)</sup>                                                             | 27                                                                            | —                                                                                                                         | —          |
|                                                                       | Annual           | —                                                                             | 8.8                                                                           | —                                                                                                                         | —          |
| NO <sub>2</sub>                                                       | 1-Hour           | 400 <sup>(h)</sup>                                                            | 113 (60 ppb) <sup>(i)</sup>                                                   | —                                                                                                                         | 400        |
|                                                                       | 24-Hour          | 200 <sup>(h)</sup>                                                            | —                                                                             | —                                                                                                                         | —          |
|                                                                       | Annual           | —                                                                             | 32 (17 ppb)                                                                   | 60                                                                                                                        | 100        |
| SO <sub>2</sub>                                                       | 1-Hour           | 690                                                                           | 183 (70 ppb) <sup>(j)</sup>                                                   | 450                                                                                                                       | 900        |
|                                                                       | 24-Hour          | 275                                                                           | —                                                                             | 150                                                                                                                       | 300        |
|                                                                       | Annual           | 55                                                                            | 13 (5 ppb)                                                                    | 30                                                                                                                        | 60         |
| CO                                                                    | 1-Hour           | 36,200                                                                        | —                                                                             | 15,000                                                                                                                    | 35,000     |

| Provincial and Federal Regulatory Air Quality Criteria <sup>(1)</sup> |                  |                                                                               |                                                                               |                                                                                                                           |            |
|-----------------------------------------------------------------------|------------------|-------------------------------------------------------------------------------|-------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|------------|
| Substance                                                             | Averaging Period | Ontario Ambient Air Quality Guidelines <sup>(a)</sup><br>(µg/m <sup>3</sup> ) | Canadian Ambient Air Quality Standards <sup>(b)</sup><br>(µg/m <sup>3</sup> ) | National Ambient Air Quality Objectives and Canadian Ambient Air Quality Standards <sup>(c)</sup><br>(µg/m <sup>3</sup> ) |            |
|                                                                       |                  |                                                                               |                                                                               | Desirable                                                                                                                 | Acceptable |
|                                                                       | 8-Hour           | <b>15,700</b>                                                                 | —                                                                             | 6,000                                                                                                                     | 15,000     |
| <b>C<sub>3</sub>H<sub>4</sub>O</b>                                    | 1-Hour           | <b>4.5</b>                                                                    | —                                                                             | —                                                                                                                         | —          |
|                                                                       | 24-Hour          | <b>0.4</b>                                                                    | —                                                                             | —                                                                                                                         | —          |
| <b>O<sub>3</sub></b>                                                  | 1-Hour           | 165                                                                           | —                                                                             | 100                                                                                                                       | 160        |
|                                                                       | 8-Hour           | —                                                                             | 122 (62 ppb) <sup>(k)</sup>                                                   | —                                                                                                                         | —          |
| <b>Pb</b>                                                             | 24-Hour          | <b>0.5</b>                                                                    | —                                                                             | —                                                                                                                         | —          |
|                                                                       | 30-Day           | <b>0.2<sup>(l)</sup></b>                                                      | —                                                                             | —                                                                                                                         | —          |
| <b>Hg</b>                                                             | 24-Hour          | <b>2</b>                                                                      | —                                                                             | —                                                                                                                         | —          |
| <b>H<sub>2</sub>S</b>                                                 | 10-Minute        | <b>13</b>                                                                     | —                                                                             | —                                                                                                                         | —          |
|                                                                       | 24-Hour          | <b>7</b>                                                                      | —                                                                             | —                                                                                                                         | —          |
| <b>C<sub>2</sub>H<sub>3</sub>Cl</b>                                   | 24-Hour          | <b>1</b>                                                                      | —                                                                             | —                                                                                                                         | —          |
|                                                                       | Annual           | <b>0.2</b>                                                                    | —                                                                             | —                                                                                                                         | —          |
| <b>Odour<sup>(m)</sup><br/>(OU/m<sup>3</sup>)</b>                     | 10-minute        | <b>1<sup>(n)</sup></b>                                                        | —                                                                             | —                                                                                                                         | —          |

Note: **Bold** = ambient air criteria retained for use in the assessment.

<sup>(1)</sup> The lowest values in the table were used in the assessment of significance although the monitoring-based CAAQS numbers are not intended to be used in this manner.

- 
- a) Ontario's Ambient Air Quality Criteria (MOE 2012).
  - b) Canadian Ambient Air Quality Standards (Government of Canada 2013). Final standard phase in date of 2020 used. For SO<sub>2</sub>, NO<sub>2</sub> and O<sub>3</sub> the reference is ppb and was converted using a pressure of 1 atmosphere and a temperature of 25°C.
  - c) Canadian National Ambient Air Quality Objectives: Process and Status (CCME 1999) [2-36].
  - d) SPM in Ontario is defined as <44 µm diameter.
  - e) Geometric mean.
  - f) Interim Ambient Air Quality Criteria and is provided as a guide for decision making (MOE 2012).
  - g) Compliance is based on the 98<sup>th</sup> percentile of the annual monitored data averaged over three years of measurements.
  - h) Standard is for nitrogen oxides (NO<sub>x</sub>), but is based on the health effects of NO<sub>2</sub>.
  - i) As described by the CCME, 3-year average of the annual 98th percentile of the NO<sub>2</sub> daily maximum 1-hour average concentrations
  - j) As described by the CCME, 3-year average of the annual 99th percentile of the SO<sub>2</sub> daily maximum 1-hour average concentrations
  - k) Ozone is not emitted directly into the atmosphere but is associated with the reaction of NO<sub>x</sub> to calculate NO<sub>2</sub> in the effects assessment.
  - l) Arithmetic mean.
  - m) Odour unit per cubic metre (OU/m<sup>3</sup>)
  - n) The Ontario Guideline is based on the 99.5<sup>th</sup> percentile on a 10-minute averaging period, in OU/m<sup>3</sup>.
- = No guideline available; SPM = suspended particulate matter; PM<sub>2.5</sub> = particulate matter less than 2.5 µm (microns) in diameter;  
PM<sub>10</sub> = particulate matter less than 10 µm (microns) in diameter; CO = carbon monoxide; NO<sub>2</sub> = nitrogen dioxide; SO<sub>2</sub> = sulphur dioxide;  
H<sub>2</sub>S = hydrogen sulfide; C<sub>2</sub>H<sub>3</sub>Cl = vinyl chloride; Pb = lead; Hg = mercury; µg/m<sup>3</sup> = microgram per cubic metre; C<sub>3</sub>H<sub>4</sub>O = acrolein; O<sub>3</sub> = Ozone; ppb = parts per billion; OU/m<sup>3</sup> = odour unit per cubic metre.

### 2.10.3.2 Waterborne Acceptance Criteria

Risk benchmark values developed for the CRL site are used as the acceptance criteria for non-radiological constituents in surface water. They were developed using a combination of values from Alberta Environment & Sustainability Resource Development [2-51], Suter and Tsao [2-52], and CCME [2-55], the Scientific Committee on Health and Environmental Risks [2-53], and SAVEX [2-54]. The risk benchmark values for non-radiological constituents in surface water are presented in Table 2-10.

**Table 2-10**  
**Risk Benchmark Values for Non-Radiological Constituents in Surface Water**

| Monitoring Parameters | Units | Risk Benchmark | Risk Benchmark Reference |
|-----------------------|-------|----------------|--------------------------|
| Aluminum              | mg/L  | 0.1            | [2-51]                   |
| Ammonia               | mg/L  | No data        | -                        |
| Antimony              | mg/L  | 0.18           | [2-52]                   |
| Barium                | mg/L  | 0.11           | [2-52]                   |
| Boron                 | mg/L  | 29             | [2-55]                   |
| Cadmium               | mg/L  | 0.001          | [2-55]                   |
| Calcium               | mg/L  | No data        | -                        |
| Chloride              | mg/L  | 640            | [2-55]                   |
| Chromium              | mg/L  | 1.7            | [2-52]                   |
| Cobalt                | mg/L  | 1.5            | [2-52]                   |
| Copper                | mg/L  | Narrative      | [2-51]                   |
| Fluoride              | mg/L  | 3              | [2-53]                   |
| Hardness              | mg/L  | No data        | -                        |
| Iron                  | mg/L  | 3.4            | [2-54]                   |
| Lead                  | mg/L  | 0.007          | [2-51]                   |
| Magnesium             | mg/L  | No data        | -                        |
| Manganese             | mg/L  | 2.3            | [2-52]                   |
| Mercury               | mg/L  | 0.0            | [2-52]                   |
| Molybdenum            | mg/L  | 16             | [2-52]                   |
| Nickel                | mg/L  | 1.4            | [2-52]                   |
| Nitrate               | mg/L  | 550            | [2-55]                   |
| Nitrite               | mg/L  | No data        | -                        |
| Phosphorus            | mg/L  | No data        | -                        |
| Potassium             | mg/L  | No data        | -                        |
| Selenium              | mg/L  | 0.02           | [2-52]                   |

| Monitoring Parameters | Units | Risk Benchmark | Risk Benchmark Reference |
|-----------------------|-------|----------------|--------------------------|
| Silver                | mg/L  | 0.0041         | [2-52]                   |
| Sodium                | mg/L  | No data        | -                        |
| Strontium             | mg/L  | 15             | [2-52]                   |
| Sulfate               | mg/L  | No data        | -                        |
| Thallium              | mg/L  | 0.11           | [2-52]                   |
| Tin                   | mg/L  | 2.7            | [2-52]                   |
| Uranium               | mg/L  | 0.033          | [2-55]                   |
| Vanadium              | mg/L  | 0.28           | [2-52]                   |
| Zinc                  | mg/L  | 0.12           | [2-52]                   |

Canadian Nuclear Laboratories also ensures the protection of the environment and public from hazardous substances through having effluent discharge targets for waterborne releases from the WWTP. The effluent discharge targets for non-radiological constituents are based on the protection of aquatic life. This is appropriate due to CRL site access restrictions, and the groundwater at the CRL site is not a source of drinking water for the public. The effluent discharge targets for non-radiological constituents are gathered from a variety of source documents including the CCME summary table [2-56] and the Ontario Provincial Water Quality Objectives (PWQO) [2-39]. If both Federal and Provincial values were available, the lower value was used to define the discharge target. The CCME water quality guidelines are for the protection of aquatic life and the Provincial Water Quality Objectives were developed to ensure that water quality is satisfactory for aquatic life and recreation. Other reference documents [2-51] and [2-52] were used when constituents were not listed in either of the primary references (i.e., CCME water quality guidelines or Provincial Water Quality Objectives). More details about the derivation of the NSDF effluent discharge limits are found in [2-57]. In comparison, the effluent discharge targets in Table 2-11 for specific constituents are lower than the risk benchmark values noted in Table 2-10 thus, demonstrating protection of the public from hazardous substances during the operational phase of the NSDF.

**Table 2-11**  
**Effluent Discharge Targets for Non-Radiological Constituents**

| Constituent               | Effluent Discharge Target (mg/L) |
|---------------------------|----------------------------------|
| 1,1,2,2-Tetrachloroethane | 0.07                             |
| 1,1,2-Trichloroethane     | 0.8                              |
| 1,4-Dichlorobenzene       | 0.004                            |
| Acetone                   | 1.5                              |
| Aluminum                  | 0.05                             |
| Ammonia                   | 0.02                             |
| Anthracene                | 8.0E-07                          |
| Antimony                  | 0.02                             |
| Arsenic                   | 0.005                            |
| Barium                    | 0.004                            |
| Benzene                   | 0.1                              |
| Benzo(a)pyrene            | 1.5E-05                          |

| <b>Constituent</b>                     | <b>Effluent Discharge Target (mg/L)</b> |
|----------------------------------------|-----------------------------------------|
| Beryllium                              | 0.011                                   |
| Bis(2-ethylhexyl) phthalate            | 6.0E-04                                 |
| Boron                                  | 0.2                                     |
| Cadmium                                | 9.0E-05                                 |
| Calcium                                | 116                                     |
| Carbon tetrachloride                   | 0.0133                                  |
| Chloride                               | 120                                     |
| Chlorobenzene                          | 0.0013                                  |
| Chloroform                             | 0.0018                                  |
| Chromium (III)                         | 0.0089                                  |
| Chromium (VI)                          | 0.001                                   |
| Chrysene                               | 1.0E-07                                 |
| Cobalt                                 | 9.0E-04                                 |
| Copper                                 | 0.002                                   |
| Dioxin                                 | 1.0E-08                                 |
| Ethylene dibromide                     | 0.005                                   |
| Fluoranthene                           | 8.0E-07                                 |
| Fluorene                               | 2.0E-04                                 |
| Fluoride (aqueous)                     | 0.12                                    |
| Furan                                  | 1.0E-08                                 |
| Iron                                   | 0.3                                     |
| Lead                                   | 0.001                                   |
| Magnesium                              | 82                                      |
| Manganese                              | 0.12                                    |
| Mercury (aqueous)                      | 2.6E-05                                 |
| Methylene chloride                     | 0.0981                                  |
| Molybdenum                             | 0.04                                    |
| Nickel                                 | 0.025                                   |
| Nitrate                                | 13                                      |
| Nitrite                                | 0.06 (as N)                             |
| Petroleum hydrocarbons, C6-C10         | 0.15                                    |
| Phenol                                 | 0.004                                   |
| Phenolic compounds,<br>non-chlorinated | 0.004                                   |
| Phosphorus                             | 0.01                                    |
| PCB                                    | 1.0E-06                                 |
| Potassium                              | 53                                      |
| Selenium                               | 0.001                                   |
| Silver                                 | 1.0E-04                                 |
| Sodium                                 | 680                                     |
| Sulphate                               | 128                                     |
| Tetrachloroethylene                    | 0.05                                    |
| Thallium                               | 3.0E-04                                 |
| Tin                                    | 0.073                                   |
| Trichloroethylene                      | 0.02                                    |
| Uranium                                | 0.005                                   |

| <b>Constituent</b>               | <b>Effluent Discharge Target (mg/L)</b> |
|----------------------------------|-----------------------------------------|
| Vanadium                         | 0.006                                   |
| Zinc                             | 0.007                                   |
| pH, standard units               | 6.5-9                                   |
| CBOD5                            | 25                                      |
| COD                              | 125                                     |
| Dissolved oxygen, >15-20 Celsius | ≥6                                      |
| Dissolved oxygen, <15-20 Celsius | ≥9.5                                    |

#### **2.10.4 Protection of the Environment from Hazardous Substances**

The Environmental Protection goals are as follows:

- Meet legal requirements, as specified by appropriate regulatory bodies, including the CNSC, Environment Canada (EC), Health Canada and/or the Department of Fisheries and Oceans.
- Minimize ecological effects, however, when necessary, allow for small structural or functional changes that may exceed natural variability of a receptor group, provided that such do not threaten the sustainability of a receptor's population.
- Avoid adverse organism-level effects on identified species at risk at CRL, where feasible.

The CCME Federal guideline derivation process, considers adverse effects from direct contact exposure and those resulting from ingestion for major land use and exposure scenarios. If no Canadian Environmental Quality Guidelines exist for a contaminant, Provincial guidelines are also considered. This approach is consistent with CSA N288.4 [2-30] and N288.6 [2-32], as required by the LCH [2-37].

The subsection that follows, Section 2.10.4.1, describes the Environmental Quality Standards that apply to the groundwater, soil, surface water, and sediment, which are used in the determination of risk to the environment and non-human biota. These Environmental Quality Standards are used as a screening tool to determine if further risk environmental assessment is required. The Ecological Risk Assessment [2-31] provides more details on the use of Environmental Quality Standards values in the calculation of risk to biota in the environment.

##### **2.10.4.1 Environmental Quality Standards**

Table 2-12 presents the environmental quality standards for non-radioactive and chemical species [2-9]. The values are based on Federal (CCME and Provincial (Ministry of Environment, Conservation and Parks) guideline concentrations for groundwater, surface water, soil and sediment. Guideline concentrations for groundwater, soil and sediment are provided primarily from MOEE [2-38], since these are the most conservative. The most conservative guideline concentrations values between MOEE [2-39] and CCME [2-40], are used for surface waters.



**Table 2-12**  
**Environmental Quality Standards for Non-Radioactive Elements and Chemical Species [2-9]**

| Species        | Groundwater<br>(µg/L) | Note | Soil<br>(µg/g) | Note | Surface Water<br>(µg/L) | Note | Sediment<br>(µg/g) | Note |
|----------------|-----------------------|------|----------------|------|-------------------------|------|--------------------|------|
| Ag             | 0.3                   | A    | 0.5            | A    | 0.1                     | H, N | 0.5                | A    |
| As             | 13                    | A    | 11             | A    | 5                       | I, N | 5.9                | G    |
| B              | 1700                  | A    | 2              | X    | 200                     | I    | -                  | B    |
| Ba             | 610                   | A    | 210            | A    | -                       | B    | -                  | B    |
| Be             | 0.5                   | A    | 2.5            | A    | 11                      | J    | -                  | B    |
| Br             | -                     | B    | -              | B    | 1700                    | R    | -                  | B    |
| Cd             | 0.5                   | A    | 1              | A    | 0.09                    | Q    | 0.6                | A    |
| Chloro-benzene | 0.5                   | A    | 0.05           | A    | 1.3                     | N    | 0.02               | C    |
| Chloro-phenol  | 8.9                   | D    | 0.05           | X    | 7                       | P    | -                  | B    |
| Co             | 3.8                   | A    | 19             | A    | 0.9                     | H    | 50                 | A    |
| Cr             | 11                    | E    | 64             | Y    | 1                       | K    | 26                 | E    |
| Cu             | 5                     | A    | 62             | A    | 1                       | J    | 16                 | A    |
| Dioxins/Furans | 1.5E-5                | F    | 7E-6           | F    | 0.3                     | L    | -                  | -    |
| Gd             | -                     | B    | -              | B    | 7.1                     | S    | -                  | B    |
| Hf             | -                     | B    | -              | B    | 4                       | T    | -                  | B    |
| Hg             | 0.1                   | A    | 0.16           | A    | 0.026                   | N    | 0.17               | G    |
| I              | -                     | B    | -              | B    | 100                     | I    | -                  | B    |
| Li             | -                     | B    | -              | B    | 2500                    | Q    | -                  | B    |
| Mn             | -                     | B    | -              | B    | 200                     | Q    | -                  | B    |
| Mo             | 23                    | A    | 2              | A    | 40                      | I    | -                  | B    |
| Nb             | -                     | B    | -              | B    | 600                     | U    | -                  | B    |
| Ni             | 14                    | A    | 37             | A    | 25                      | H    | 16                 | A    |
| PAH            | 0.1                   | G    | 0.05           | G    | 0.0008                  | M    | 0.0419             | G    |
| Pb             | 1.9                   | A    | 45             | A    | 1                       | J    | 31                 | A    |
| PCB            | 0.2                   | A    | 0.3            | A    | 0.001                   | H    | 0.0341             | G    |
| Sb             | 1.5                   | A    | 1              | A    | 20                      | I    | -                  | B    |
| Sc             | -                     | B    | -              | B    | 1.8                     | Y    | -                  | B    |
| Se             | 5                     | A    | 1.2            | A    | 1                       | P    | -                  | B    |
| Sn             | -                     | B    | -              | B    | 73                      | W    | -                  | B    |
| Sr             | -                     | B    | -              | B    | 1500                    | W    | -                  | B    |
| Te             | -                     | B    | -              | B    | 20                      | R    | -                  | B    |
| Tl             | 0.5                   | A    | 1.0            | A    | 0.3                     | I    | -                  | B    |
| U              | 8.9                   | A    | 1.9            | A    | 5                       | I    | -                  | B    |
| V              | 3.9                   | A    | 86             | A    | 6                       | I    | -                  | B    |
| W              | -                     | B    | -              | B    | 30                      | I    | -                  | B    |

| Species | Groundwater<br>(µg/L) | Note | Soil<br>(µg/g) | Note | Surface Water<br>(µg/L) | Note | Sediment<br>(µg/g) | Note |
|---------|-----------------------|------|----------------|------|-------------------------|------|--------------------|------|
| Zn      | 160                   | A    | 290            | A    | 20                      | J    | 120                | A    |
| Zr      | -                     | B    | -              | B    | 4                       | I    | -                  | B    |

**Notes:**

Ministry of Environment and Climate Change was formerly the Ontario Ministry of the Environment and Energy (MOEE) and Ontario Ministry of the Environment (MOE).

- A 'Full depth background site condition standard' (Table 1) for Ontario from MOE (2011); soil standard for agricultural land use.
- B No value available.
- C As note A; value for hexachlorobenzene used.
- D As note A; value for 2-chlorophenol used.
- E As note A; value for total chromium used.
- F As note A; values represent standard Toxic Equivalents (TEQ).
- G Freshwater sediment ISQG for the Protection of Aquatic Life from CCME [2-40].
- H Provincial Water Quality Objective (PWQO) for Ontario from MOEE [2-39].
- I Interim PWQO from MOEE [2-39].
- J Lowest PWQO/Interim PWQO conservatively adopted from MOEE [2-39].
- K PWQO for Cr (VI) from MOEE [2-39].
- L PWQO for dibenzofuran in MOEE [2-39].
- M Interim PWQO for anthracene in MOEE [2-39].
- N Freshwater Water Quality Guideline for the Protection of Aquatic Life from CCME [2-40].
- O As note N; value for water hardness of 50 mg/L CaCO<sub>3</sub>.
- P As note N; value for monochlorophenols used.
- Q Irrigation Water Quality Guidelines for the Protection of Agricultural Water Uses from CCME [2-40].
- R Calculated from minimum of Oral rate/mouse LD50s from Canadian Center for Occupational Health and Safety.
- S Maximum Permissible Concentration (MPC) for freshwater from Sneller et al. (2000).
- T Value for Zr used.
- U Lowest available from Oregon Department of Environmental Quality (2001).
- V Lowest available MPC for freshwater for all rare earth elements from Sneller et al. (2000).
- W Tier II secondary chronic value from Suter and Tsao (1996).
- X Soil quality guideline for the Protection of Environmental and Human Health, agricultural land use from CCME [2-40].
- Y As note X; value for total chromium used.

## 2.11 Assessment Context

The Safety Case has been undertaken using CNSC REGDOC-2.11.1 Volume III [2-7], and international best practice, specifically the IAEA's SSR-5 [2-29], SSG-23 [2-2] and ISAM guidance [2-5].

The assessment context includes:

- Presenting a collection arguments and evidence in support of the safety of the NSDF.
- Regulatory framework.
- Safety strategy including acceptance criteria, timeframe and receptors.
- System description including disposal system, geosphere, biosphere, and waste inventory.
- Safety assessment including endpoints, calculated radiological dose consequences and comparison of results with acceptance criteria.
- Iteration and design optimization.
- Management of uncertainties.
- Limits, controls and conditions.
- Integration of safety arguments.

## **2.12 Consistency with International Guidance and Practices**

The methodology for the Safety Case is based on international best practice, as embodied in the safety standards on the Safety Case and Safety Assessment for Radioactive Waste Disposal from the IAEA SSR-5 [2-29], SSG-23 [2-2] and the recommendations of the IAEA program for the ISAM [2-5].

The safety case and its supporting documentation has been prepared taking into account:

- Nationally and internationally accepted best practices.
- The ‘weight of evidence’ and confidence-building arguments (i.e., scientific evidence, multiple lines of reasoning, reasoned arguments, and other complementary arguments) that support the assessment and its conclusions.
- Third-party peer reviews of the submission.

International best practice that has been implemented includes:

- The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, SSG-23 [2-2].
- Disposal of Radioactive Waste, SSR-5 [2-29].
- Safety Assessment Methodologies for Near Surface Disposal Facilities, ISAM, Volume 1, [2-5] and Volume 2 [2-6].
- International Peer Reviews for Radioactive Waste Management: General Information and Guidelines [2-41].
- Compendium of Dose Coefficients based on International Commission of Radiological Protection (ICRP) Publication 60 [2-21].
- Near Surface Disposal Facilities for Radioactive Waste, SSG-29 [2-42].
- Monitoring and Surveillance of Radioactive Waste Disposal Facilities, SSG-31 [2-43].
- Safety Classification of SSC in Nuclear Power Plants, SSG-30 [2-44].

### **2.12.1 Nuclear Criticality Safety**

The Criticality Hazard Identification and Criticality Analysis Methodology used in the Criticality Safety Analysis, is based on the requirements of CNSC RD-327 Nuclear Criticality Safety [2-45] and GD-327 Guidance for Nuclear Criticality Safety [2-46].

The mass concentration of Fissionable Material disposed of in the ECM, shall be limited so that the materials remain subcritical during all phases of NSDF, including active waste disposal operation and post-closure phases.

The Criticality Safety Analysis considers the actual materials in the waste under normal conditions and the credible abnormal conditions identified in a Criticality Hazard Identification. Preliminary calculations evaluate whether an infinite array of waste packages would remain subcritical given the following conditions:

- Maximum reactivity of the Fissionable Material present is attained.
- The most reactive credible configuration consistent with the chemical and physical form of the material (e.g., lumped source, cylindrical, sphere, dispersed, etc.).

- Optimal moderation by light water.
- Full reflection of the fissionable/fissile material system.

The design ensures that materials used for the NSDF, the physical separation between wastes and the limits imposed on the quantities of Fissionable Material, shall comply with the Criticality Safety Document developed during the preparation of the Safety Case.

### **2.12.2 Pre-closure Safety Assessment**

The pre-closure SAR [2-8], follows the safety analysis objectives and guidance defined in Deterministic Safety Analysis [2-4]. In addition, the SAR [2-8] was prepared following:

- The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, SSG-23 [2-2].
- Monitoring and Surveillance of Radioactive Waste Disposal Facilities, SSG-31 [2-43].

### **2.12.3 Post-Closure Safety Assessment**

The PostSA [2-9], follows the safety analysis objectives and guidance defined in Assessing the Long-Term Safety of Radioactive Waste Management [2-3]. In addition, the PostSA [2-9] was prepared following:

- The Safety Case and Safety Assessment for the Disposal of Radioactive Waste, SSG-23 [2-2].
- Safety Assessment Methodologies for Near Surface Disposal Facilities, ISAM, Volume 1 [2-5] and Volume 2 [2-6].

## **2.13 Peer Reviews**

In addition to the CNL's internal peer review process, CNL has procured the services of multiple independent third parties to perform peer reviews on several of the key documents and analyses supporting the NSDF Project and safety case.

Reviewer comments are documented by the use of formal correspondence between the reviewer and CNL. Comments are often held in a spreadsheet listing the reviewer comment, the disposition to the comment by CNL and acceptance by the reviewer that the comment has been satisfactorily addressed.

A summary of peer reviews performed in support of the project is presented in Section 6.8.

## **2.14 Software**

A number of commercially available computer codes have been used to produce models to assess the safety of the NSDF Project. Each piece of software and subsequent revisions have been extensively tested against a broad set of verification tests. This involves implementation and analysis of a set of test cases specifically developed to check the correct functioning of the code. The results generated by the codes, are where possible, compared with those calculated by other similar tools. The software/computer codes used include:

- **AERMOD (Version 15181)** – A steady-state dispersion model designed for short-range (up to 50 km) dispersion of air pollutant emissions from stationary industrial sources, developed by the American Meteorological Society and the United States Environmental Protection Agency (U.S. EPA). The AERMOD dispersion model (Version 15181), was used to predict concentrations and deposition rates associated

with NSDF Project emissions. The AERMOD dispersion modelling system is the model recommended by the U.S. EPA for regulatory applications in the United States. This model has also been adopted in Ontario as the regulatory model recommended for permitting and regulatory applications.

- **AMBER (Version 6.3)** – AMBER is a flexible graphical-user interface based software tool that allows users to build their own dynamic compartment models to represent the migration, degradation, and fate of contaminants in environmental systems.
- **DEVEL (Version 1.0)** – DEVEL determines the number of earthquake events for each magnitude-time unit, calculates earthquake recurrence values, and was used in the seismic sensitivity analysis.
- **DUR (Version 1.0)** – DUR calculates significant duration for an acceleration time history from the normalized energy integral (Arias Intensity). DUR was used in support of HAZ38CEUS13 for the seismic analysis of the ECM and support buildings.
- **FLAC3D (Version 5.01.153)** – Fast Lagrangian Analysis of Continua (FLAC) 3D is an explicit continuum modelling computer code for advanced geotechnical analysis of soil, rock, and structural support in three dimensions. It is especially suited for non-linear material behavior modelling. The software is designed to accommodate any kind of geotechnical engineering project where continuum analysis is necessary. The fully non-linear analysis method used by FLAC3D, contrasts with the more commonly accepted “equivalent linear” method used in earthquake engineering, providing a more accurate representation of the structure’s response to earthquake loads. The FLAC3D dynamic option is used to conduct a deformation analysis of the NSDF and estimate total displacement when the ECM structure is subject to ground motion.
- **FLAC (Version 7.00.424)** – Fast Lagrangian Analysis of Continua (FLAC) is numerical modelling software for advanced geotechnical analysis of soil, rock, groundwater, and ground support in two dimensions. FLAC is used for analysis, testing, and design by geotechnical, civil, and mining engineers. It is designed to accommodate any kind of geotechnical engineering project that requires continuum analysis. FLAC utilizes an explicit finite difference formulation that can model complex behaviors, such as problems that consist of several stages, large displacements and strains, non-linear material behavior, or unstable systems (even cases of yield/failure over large areas or total collapse). The FLAC is used to assess seismic stability of the ECM.
- **FRACT38CEUS (Version 0)** – FRACT38CEUS is a program used to create fractiles, which are used to show the degree of uncertainty in the hazard analysis. FRACT38CEUS was used in support of HAZ38CEUS13 for the seismic analysis of the ECM and support buildings.
- **GeoStudio SLOPE/W (Version 8.16.2.14053)** – GeoStudio SLOPE/W is a CAD software product for computing the Factor of Safety of earth and rock slopes against slope failure. Geostudio SLOPE/W can model heterogeneous soil types, complex stratigraphic and slip surface geometry, and variable pore-water pressure and loading conditions.
- **GoldSim** – GoldSim is a graphical Windows-based simulation software developed by GoldSim Technology Group. It is used to dynamically model complex systems to support decision making and is often applied to environmental, mining, and water resource systems. The GoldSim modelling package was employed as a “graphical spreadsheet” to estimate non-radioactive contaminant concentrations at focal surface water features within the Perch Creek Basin catchment based on a mass balance approach.

- **HAZ38CEUS13 (Version 0)** – HAZ38CEUS13 is primarily designed to estimate earthquake ground-shaking hazard in a given location and site conditions. HAZ38CEUS13 was one of two main programs used to develop seismic ground motions used in engineering analyses of the ECM and building structures.
- **HELP (Version 3.07)** – Hydrologic Evaluation of Landfill Performance (HELP) is a quasi-two-dimensional hydrologic numerical model developed for landfills. The model uses a water-balance approach to model evapotranspiration and drainage through soil layers. Landfill systems, including various combinations of vegetation, cover soils, waste cells, lateral drain layers, low permeability barrier soils, and synthetic GMB liners, may be modelled.
- **LandGEM (Version 3.02)** – Landfill Gas Emissions Model (LandGEM) was used in the assessment to estimate emissions from the decomposition of waste within the landfill. The Landfill Gas Emissions Model (LandGEM) is an automated estimation tool with a Microsoft Excel interface that can be used to estimate emissions rates for total landfill gas (LFG), methane, carbon dioxide, non-methane organic compounds, and individual air pollutants from municipal solid waste landfills.
- **MAGBIAS (Version 1.0)** – MAGBIAS is based on DEVEL but can be run for multiple iterations, corrects for rounding errors and was used in the seismic sensitivity analysis.
- **MCNP** – Monte Carlo N-Particle (MCNP) is a Monte Carlo code for tracking neutrons and higher-energy photons and electrons interacting with materials. The code is used for radiation transport, criticality safety, and reactor design calculations. MCNP is a FORTRAN code developed at Los Alamos National Laboratories and used worldwide.
- **MicroShield (Version 9.02)** – MicroShield performs various shielding calculations and estimates the gamma exposure from radiation sources. There are 16 customizable geometries that can be utilized. This software is also utilized to design radiological shields and containers.
- **MOBILE6.2C** – MOBILE6 is an emission factor model for predicting gram per mile emissions of Hydrocarbons (HC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Carbon Dioxide (CO2), Particulate Matter (PM), and toxics from cars, trucks, and motorcycles under various conditions.
- **MODFLOW-2005** – MODFLOW is the U.S. Geological Survey modular finite-difference flow model, which is a computer code that solves the groundwater flow equation. The program is used by hydrogeologists to simulate the flow of groundwater through aquifers.
- **PHREEQC (PHREEQCi Version 3)** – PHREEQC produced by the United States Geological Survey (USGS), is designed to perform a wide variety of aqueous geochemical calculations and was used to undertake speciation and solubility-limit calculations.
- **RESRAD-OFFSITE (Version 3.2)** – RESRAD-OFFSITE is a computer code developed at Argonne National Laboratories for the US Department of Energy, and is an extension of the RESRAD (on-site) code, which has been widely used for calculating doses and risks from exposure to radioactively contaminated soils. The RESRAD-OFFSITE computer code evaluates the radiological dose and excess cancer risk to an individual who is exposed while located within or outside the area of initial (primary) contamination. Nine exposure pathways are considered in RESRAD-OFFSITE: direct exposure from contamination in soil, inhalation of particulates, inhalation of radon, ingestion of plant food (i.e., vegetables, grain, and fruits), ingestion of meat, ingestion of milk, ingestion of aquatic foods, ingestion of water, and ingestion (incidental) of soil.

- **RSPM Match Set (Version 1.0)** – The RSPMATCH SET software suite is used to develop site-specific spectrum compatible time histories for engineering design. The software suite includes three computational modules RPSM09 Version 12/11/2015, POLBASE2 Version 11/14/2014, and SPCTLR Version 10/21/2015. RSPMATCH SET was one of two main programs used to develop earthquake time histories used in engineering analyses of the ECM and building structures.
- **SAP 2000 (Version 18.2.0)** – SAP 2000 features a 3D object based graphical modelling environment. Complex models can be generated and meshed with built-in templates. Integrated design code features can automatically generate wind, wave, bridge, and seismic loads with automatic steel and concrete design code checks per US, Canadian and international design standards. SAP 2000 was used for analyses of the buildings' superstructures. The steel frame has been modeled, and superimposed loads applied. The program was also used to analyse the seismic load for both static and dynamic cases.
- **VARSKIN (Version 6.2.1)** – VARSKIN is used to calculate occupational dose to skin resulting from exposure to radiation emitted from hot particles or contamination on or near the skin.

## 2.15 Management Systems and Quality Assurance

The NSDF Project follows CNL Management System [2-1] and details of the CNL Management System are in Appendix A.

The CNL Management System [2-1], is implemented following the document hierarchy depicted in Figure 2-4. The CNL Management System Figure 2-4, is comprised of an integrated set of documented policies, expectations, standards, procedures, and responsibilities through which CNL is governed and managed, from the setting of direction through day-to-day operations, all within a coherent control and accountability framework.

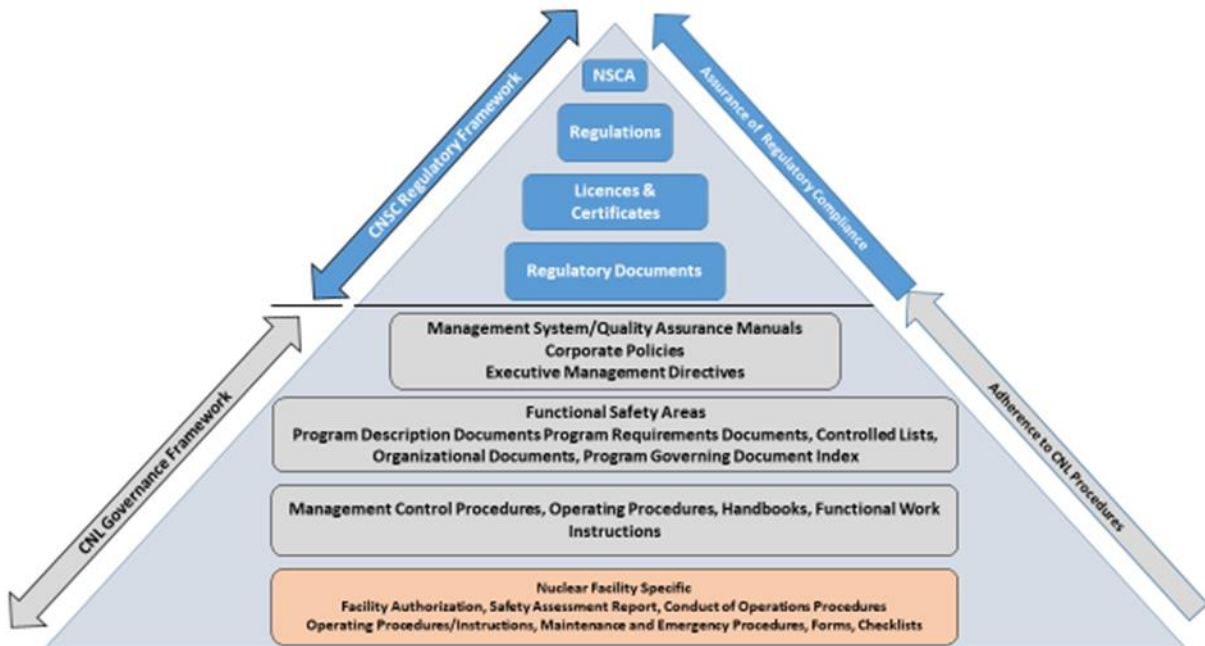


**Figure 2-4 Canadian Nuclear Laboratories Management System Document Hierarchy**

The CNL Management system [2-1] combined with CNL's QA Manual [2-47], provide the governance framework that all employees use to do their work in support of the delivery of high-value, quality products and services.

Canadian Nuclear Laboratories QA Program is based on, and meets the requirements of CSA N286 and ISO 9001. Canadian Nuclear Laboratories QA Manual [2-47]:

- Explains the CNL QA Program and identifies CNL's top level required methods for operating within the QA requirements.
- Establishes QA requirements for conducting activities, or services that affect, or may affect, nuclear safety of facilities in a graded manner to ensure that environmental, safety, and health risks/impacts are minimized.
- Ensures that safety, reliability, products, and performance are maximized by using effective management systems. Canadian Nuclear Laboratories graded approach is based on the importance to safety and safety significance of SSCs and on a specific evaluation of regulations, risks, complexity, and history of previous implementation. All requirements apply, but to varying degrees, depending upon the safety significance and complexity of the work being performed.

The management system provides the foundational framework through which the company delivers:

- Research & Development.
- Design Engineering.
- Procurement.
- Manufacturing.
- Qualification Testing.
- Construction.
- Commissioning.
- Decommissioning.
- Waste Management.
- Services, including Inspection, Maintenance and Plant Life Management.
- Project Management for Research Reactors, Nuclear Facilities and Installations, and Operation of Research Reactors and Nuclear Facilities.

Program Description Documents (PDD), Program Requirements Documents (PRD) and Program Governing Document Index (GDI), were developed for each of the fourteen Safety and Control Areas (SCA) in CRL's LCH [2-37]. Prior to 2014, these programs were internally referred to as "Compliance Programs" and have been recently renamed to Functional Support Areas or Program. Both of these terms are likely to be used in NSDF documents, depending on the timeframe in which they were prepared. Each Functional Support Area and associated top tier documents, PDD and PRD, are listed in CRL's LCH under their respective SCA, and form part of the Compliance Verification Criteria. These specific PDDs and PRDs are controlled copies, identified in the LCH as "licensee documents that require notification of change".

Program Description Documents, define roles and responsibilities and processes to be followed. The PRD maps external requirements to CNL procedural documents and forms. The Program GDI provides the list of



approved implementation documents specific to a program. Implementation documents are procedures, instructions and forms that provide the methods for implementing the program processes. Presently, there are thirty nine Functional Support Areas that form CNL's management system framework.

## 2.16 References

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### 3. SYSTEM DESCRIPTION

The system description describes the safety relevant aspects of the site and the facility design to align with SSR-5 Requirement 13 [3-1] and [3-2]:

“The safety case for a disposal facility shall describe all safety relevant aspects of the site, the design of the facility and the managerial control measures and regulatory controls”.

#### 3.1 Site Characteristics

The CRL site is operated by CNL and is located in Renfrew County, on the southern shore of the Ottawa River approximately 185 km northwest of Ottawa. The site is located within the boundaries of the Corporation of the Town of Deep River. The CRL site has an area of approximately 3 853 hectares and extends approximately 6.5 km inland from the Ottawa River. The location of the CRL site is displayed in Figure 3-1.

The NSDF site is approximately 37 hectares located within the Perch Lake Basin, approximately 1 km southwest of the CRL built-up area and south of Plant Road. A fence is proposed to surround NSDF and access is via a secondary road, East Mattawa Road (EMR), off the Plant Road. The NSDF site is located east of WMA A, north of Perch Lake and is in close proximity to the Perch Lake Wetlands. The distance from the centre of the NSDF Project site to the closest point on the Ottawa River is approximately 1.2 km. Ground surface elevations at the NSDF site range from a low of 156 mASL near the north side of Perch Lake, to a high of 197 mASL at the crest of the ridge that separates Perch Lake and Ottawa River drainage basins [3-15]. The location of the NSDF within CRL is displayed in Figure 3-2.

Aside from the nuclear operation and licensed activities undertaken by CNL, other land uses of the CRL property are prohibited due to restricted public access. No hunting or fishing is permitted on the CRL property and the property is not used for traditional purposes by Indigenous people. Land use in the region consists primarily of forestry, recreation and tourism, with limited agriculture, trapping and mining. The nearest area of considerable agriculture and dairy farming is 15 km southeast on the Quebec side of the Ottawa River and 35 km southeast on the Ontario side. The Ottawa River is an important recreational resource for swimming, sport fishing and boating; there is little commercial fishing opportunity. There are several sand beaches along both sides of the river that provide popular recreational sites. In addition, two provincial parks, Algonquin and Driftwood, are in close proximity to CRL, which offer opportunities for canoeing, hiking, fishing, and hunting. Winter recreational activities in the region include cross-country skiing, snowmobiling and ice-fishing.

Based on the information from the Ontario Mining Association [3-3], the closest active mining operations are Tatlock Quarry (calcium carbonate) located in Clayton, Ontario (~165 km from CRL) and base metal mines in Sudbury, Ontario (~310 km from CRL). There are abandoned mines within Renfrew County in the Dorset district, which were primarily quarries for granite, gneiss and feldspar [3-4].

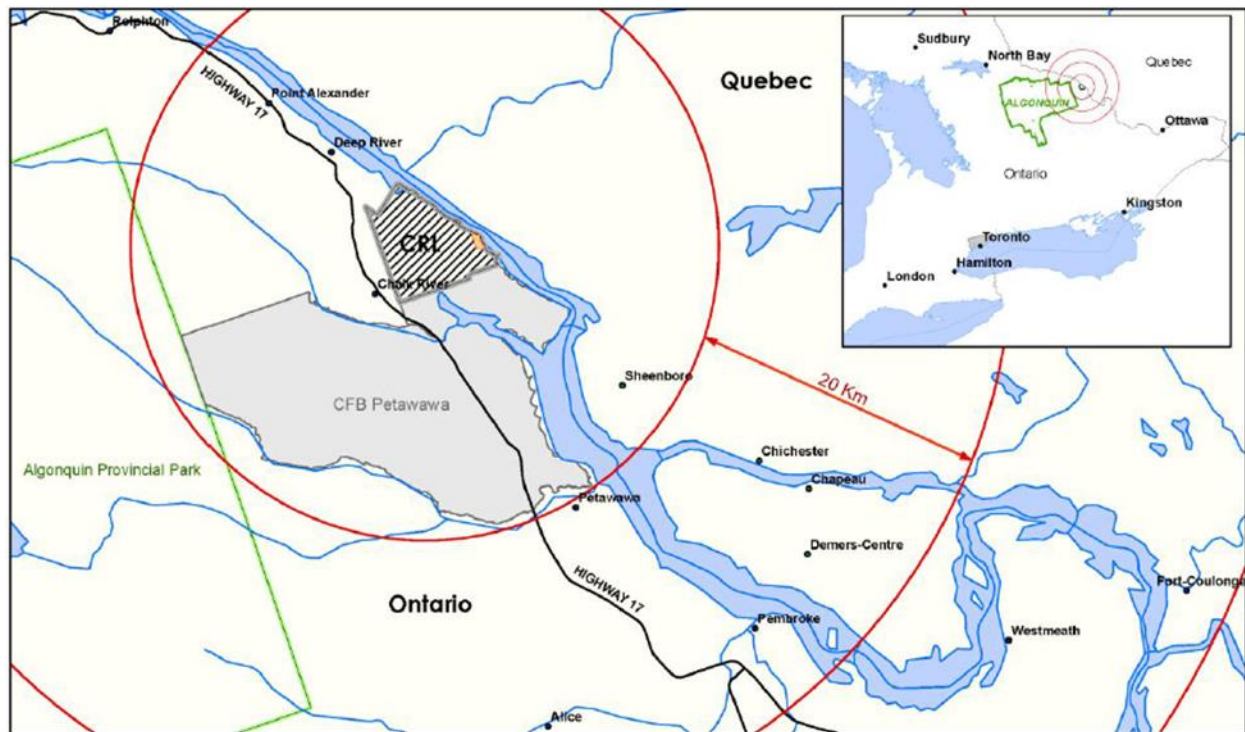


**Figure 3-1 Location of Chalk River Laboratories**

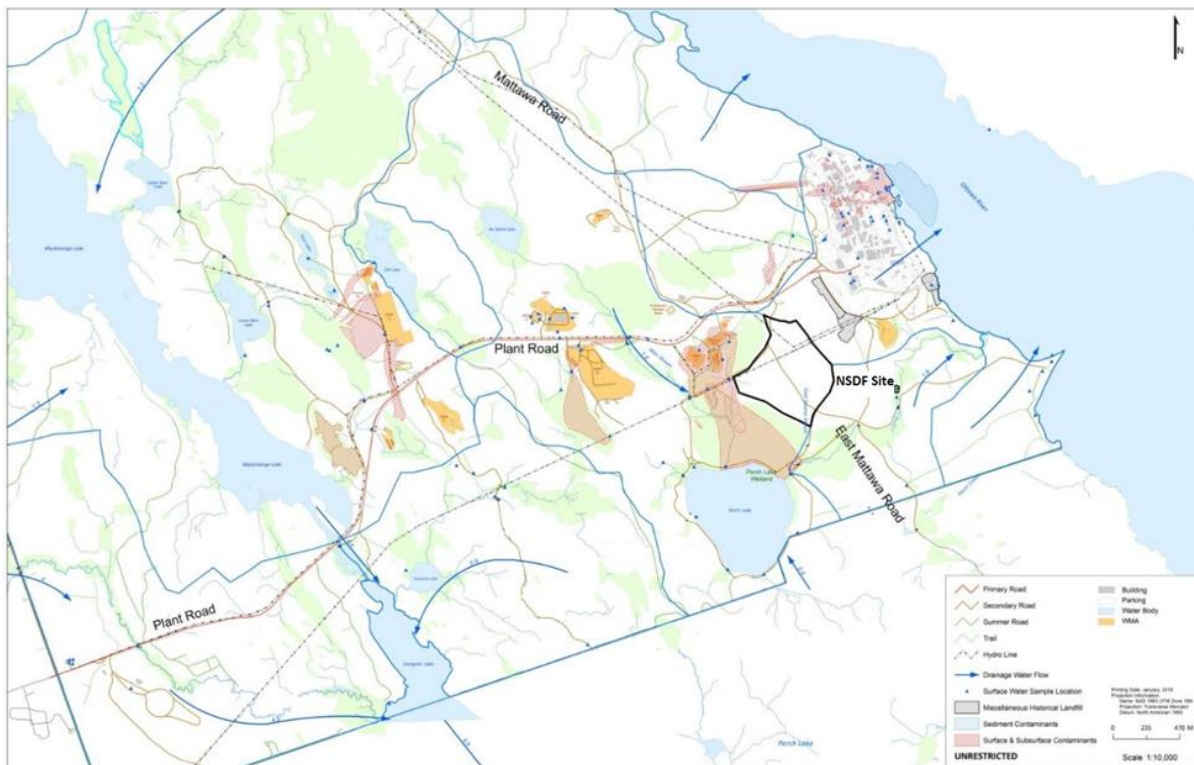


**Figure 3-2 Location of Near Surface Disposal Facility Site within Chalk River Laboratories Site**

### **3.1.1 Population Near the Chalk River Laboratories Site**

The location of population centres near the CRL site are shown in Figure 3-1.

The Federal Department of National Defence Garrison Petawawa, borders the CRL site to the southeast, and the Village of Chalk River in the Municipality of Laurentian Hills, is to the southwest.

The area population has been relatively constant, with the majority of the population surrounding CRL living in Ontario in Renfrew County with a widespread population of approximately 102 400 people, and in Quebec by sparsely populated Pontiac County, with nearly 14 250 people (2016 census data) [3-3]. The majority of local residents live close to and around the Town of Deep River and the Village of Chalk River.

The Village of Chalk River has approximately 1 200 residents and is approximately 5 km to the west of the NSDF site. Deep River, with approximately 4 100 residents, is about 10 km to the northwest. Surrounding these two population centres are Rolph, Buchanan, Wylie, and McKay, which, with Chalk River, form the town of Laurentian Hills. The total population of Laurentian Hills is nearly 3 000 residents. The Town of Petawawa, comprised of the former village of Petawawa, the amalgamated surrounding Petawawa townships and the military Garrison, is 20 km southeast of CRL and has a total combined population of approximately 17 200 residents. Another large population centre is the city of Pembroke with about 14 400 residents, 34 km southeast of CRL. Laurentian Valley Township surrounding Pembroke, has a population of approximately 10 000 residents.

The portion of Pontiac Regional County Municipality in the Province of Quebec that lies on the opposite side of the Ottawa River (i.e., the north side) is normally uninhabited, except during the summer months when seasonal cottage dwellers may be present. The closest seasonal cottage dweller is approximately 3 km from the NSDF site. The closest permanent residents in the Pontiac Regional County Municipality are located 3 km southeast of the CRL site, in the Harrington Bay area. The closest community on the Quebec side of the Ottawa River is the Municipality of Sheenboro, approximately 16 km downstream. The closest Indigenous community is the Algonquin's of Pikwàkanagàn, located at Golden Lake, approximately 50 km southeast of CRL.

### **3.1.2 Climate**

The climate of the area is classified as humid continental, with warm summers, cold winters, and no distinct dry season. The current climate for the NSDF Project was developed using the available daily meteorological data from the Chalk River AECL climate station, collected for the period of 1981 through to 2006, closely matching the current climate normal of 1981 through to 2010 [3-6]. The Chalk River AECL climate station is located approximately 3 km east-southeast of the NSDF Project centroid [3-6]. For meteorological parameters not monitored at the Chalk River AECL station, the next closest monitoring station with the required parameters is Ottawa MacDonald-Cartier International Airport (Ottawa), which was used.

The 30-year (1981 to 2010) climate normal from the Chalk River AECL station, calculates an average daily temperature of approximately 5.6°C, while the daily average temperature in the winter season is approximately -9.3°C, and the daily average temperature in the summer season is approximately 19.1°C. The extreme minimum temperature was -39°C while the extreme maximum temperature was 36°C. Temperatures below -10°C have occurred in November through April, while temperatures above 30°C occur occasionally in May through August.

The 30-year climate normal from the Chalk River AECL station, calculates an average annual precipitation of approximately 859 millimetres equivalent (mm[eq]) for the region, with the highest precipitation typically

occurring in the summer at 252 mm[eq]. The greatest extreme daily precipitation also occurs in summer at 71 mm[eq]. Winter and spring have comparable precipitation amounts but approximately 70% of the precipitation in winter is attributed to snow. Winter extreme daily precipitation is typically 35.9 mm[eq].

#### **3.1.2.1 Wind Speed and Direction**

The winds at CRL are predominantly northwest and southeast (parallel to the Ottawa River Valley). Figure 3-3 provides a wind-rose showing the annual and seasonal winds. Annual winds are predominantly from the southeast. In the winter, winds are generally from the southeast averaging 10 km/h or more. In the spring, wind speeds are similar to the winter season, but winds are generally from the northwest. In the summer, the winds shift toward the west and wind speeds are lower. In the fall season, the winds are predominantly from the southeast, increasing in speed through October and November.



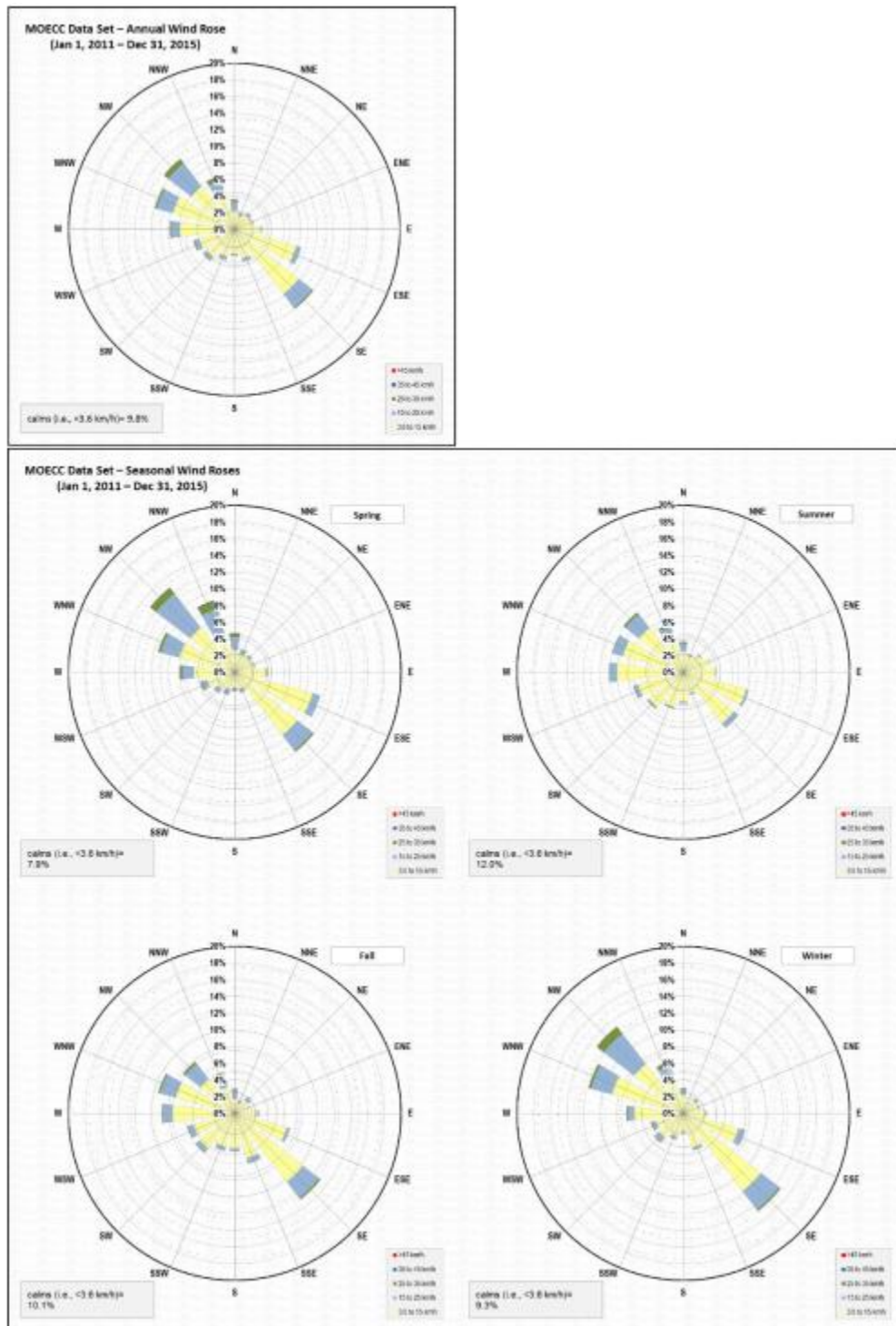


**Figure 3-3 Annual and Seasonal Wind-Rose Diagrams**



### 3.1.2.2 Tornado and Extreme Wind

The Design Basis Tornado (DBT) for the CRL site is an upper Enhanced Fujita 2 (EF2) tornado with maximum wind speed of 220 km/hr, based on the Canadian definition of an EF2 tornado [3-7]. The DBT for the CRL site was reviewed in 2018 after a series of tornadoes occurred in the Ottawa Valley, and the current choice of an upper EF2 tornado for the CRL site DBT remains an appropriate selection based on statistical probability [3-8]. Based on a map of confirmed tornadoes produced by EC, Figure 3-4, CRL is considered to be within the Eastern Canadian portion of the tornado prone zone. The DBT for the CRL has been selected based on a return frequency of 1 in 100 000 years ( $10^{-5}$ /year).

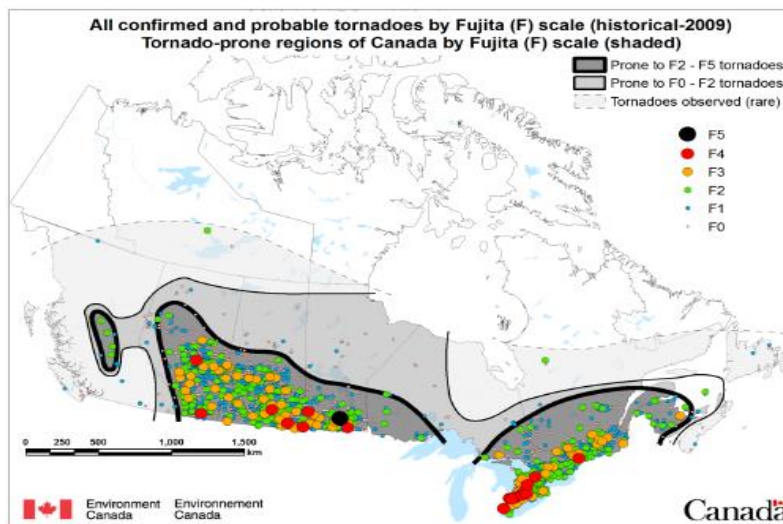


Figure 3-4 Annual Environment Canada Map of Tornado Zones in Canada

### 3.1.3 Site Characterization Program

This section describes the rationale of the site characterization program and the techniques used. A geosynthesis report documenting the geological suitability for implementation of the NSDF Project, has not been included as a site characterization requirement, since the NSDF is a near surface disposal facility. Several CNL reports including [3-9], summarize the current understanding of underground geological, hydrogeological and geomechanical conditions, and future evolution of the CRL site based on investigations previously performed to assess geological feasibility of nuclear waste geological disposal in the region.

The initial geotechnical exploration provided a broad and general evaluation of the subsurface conditions of the NSDF site [3-10]. After evaluating the data in [3-10], a data gap analysis required for the NSDF detail design was performed, and additional field exploration activities and laboratory testing were developed for the NSDF Project site characterization program [3-11] and [3-12]. The NSDF Geotechnical Report [3-12], summarizes the NSDF site characterization program.

Comprehensive site investigations were completed for the NSDF Project to provide data and information for site selection, developing detailed design and numerical models [3-10], [3-11], [3-12], [3-13], [3-14], [3-15],

[3-16], [3-17], and [3-18]. In addition, NSDF site characterization considered existing CRL site data in the Geosynthesis Report [3-9], describing site characterizations at deeper depth for up to approximately 1 000 m.

The site characterization field studies and techniques used to date included:

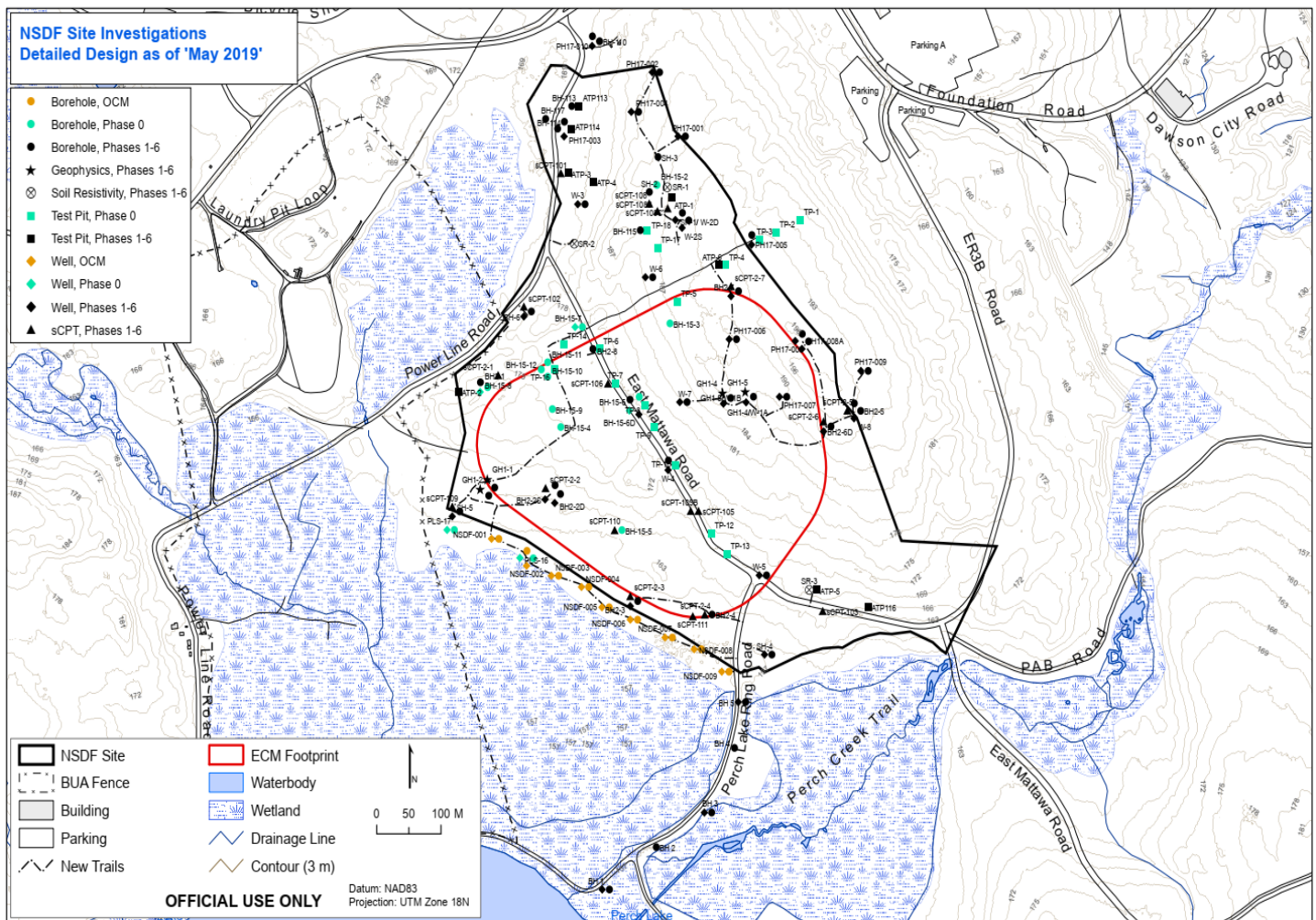
- Identification of soil types, bedrock elevations and groundwater elevations consisted of 14 test pits, seven boreholes, four auger soundings and geophysical testing - grain size distribution and moisture content [3-10].
- Phase 1 field work across the proposed ECM footprint and supporting structures, consisted of 14 Standard Penetration Test borings, 8 Cone Penetration Tests, four downhole seismic explorations, and three soil resistivity areas [3-13].
- Phase 2 field work was performed to supplement Phase 1 findings and consisted of seven borings to collect rock cores and construct monitoring wells, and 11 Cone Penetration Tests [3-14].
- Phase 3 field work was performed to supplement existing geotechnical data and field work findings, and consisted of five Standard Penetration Test borings, three test pits to conduct percolation tests to support the design of septic bed/exfiltration gallery, and Ground Penetrating Radar (GPR) survey to produce a bedrock topographic map [3-15].
- Phase 4 field work was performed to supplement existing geotechnical data and field work findings, and consisted of nine Standard Penetration Test borings and two auger borings drilled to the top of the rock [3-16].
- Phase 5 field work involved hydraulic conductivity tests using both rising and falling head single-well methodology in the monitoring wells installed during the Phase 4 field work [3-17].
- Phase 6 field work was performed to provide sufficient data/information for the design and construction of the effluent forcemain, and consisted of five Standard Penetration Test borings of which three borings were finished as monitoring wells [3-18].

The field and laboratory testing performed as part of the site characterization activities include the tests listed in Table 3-1 [3-12]. The tests were performed in accordance with the American Society for Testing and Materials (ASTM) standard testing methods. Figure 3-5 shows the field locations of the site characterization studies. The Groundwater Monitoring Program (GWMP) includes 33 groundwater monitoring wells [3-19].

A groundwater flow model was developed using the site characterization data [3-19]. The groundwater flow model numerical modelling, estimates the potential influence of the NSDF Project components (ECM, surface water management ponds, and WWTP), on local hydrogeological conditions during operations and post-closure conditions [3-19]. A deterministic approach was used where a 3D numerical (MODFLOW) groundwater model was constructed and calibrated to represent the “best estimate” of groundwater flow conditions [3-19]. To address the uncertainty associated with the “best estimate” configuration, a sensitivity analysis was completed, which involved perturbation of some of the key model input parameters and comparison to the base case results [3-19].

**Table 3-1**  
**Field and Laboratory Testing Program Summary [3-12]**

| <b>Test</b>                                                                                                                                                  | <b>ASTM Method</b> |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------|
| Laboratory Compaction Characteristics of Soil Using Standard Effort                                                                                          | D698               |
| Specific Gravity of Soil Solids by Water Pycnometer                                                                                                          | D854               |
| In-situ Measurement of Soil Bulk Density via Sand Cone                                                                                                       | D1556              |
| Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils                                                                                           | D1586              |
| Standard Practice for Rock Core Drilling and Sampling of Rock                                                                                                | D2113              |
| Laboratory Determination of Moisture Content of Soil and Rock                                                                                                | D2216              |
| Classification of Soils (Unified Soil) Classification System                                                                                                 | D2487              |
| Unconsolidated-Undrained Triaxial on Cohesive Soils                                                                                                          | D2850              |
| Direct Shear Test of Soils Under Consolidated Drained Conditions                                                                                             | D3080/D3080M       |
| Field Procedure for Instantaneous Change in Head (Slug) Tests for Determining Hydraulic Properties of Aquifers                                               | D4044/D4044M       |
| Liquid Limit, Plastic Limit, and Plasticity Index of Soils                                                                                                   | D4318              |
| Measurement of Hydraulic Conductivity of Porous Materials Using Permeameter                                                                                  | D5084              |
| Point Load Strength Index of Rock and Rock Strength Classification                                                                                           | D5731              |
| Standard for Planning and Conducting Borehole Geophysical Logging                                                                                            | D5753              |
| Electronic Friction Cone and Piezocone Penetration Testing of Soils                                                                                          | D5778              |
| Determining Rock Quality Designation of Rock Core                                                                                                            | D6032              |
| Field Measurement of Hydraulic Conductivity Using Borehole Infiltration                                                                                      | D6391              |
| Determination of the Soil Water Characteristic Curve for Desorption Using a Hanging Column, Pressure Extractor, Chilled Mirror Hygrometer, and/or Centrifuge | D6836              |
| Particle-Size Distribution (Gradation) of Soils Using Sieve Analysis                                                                                         | D6913              |
| In-Place Density and Water Content of Soil and Aggregate by Nuclear Methods                                                                                  | D6938              |
| Compressive Strength and Elastic Moduli of Intact Rock Core Specimens Under Varying States of Stress and Temperatures                                        | D7012              |
| Laboratory Determination of Density (Unit Weight) of Soil Specimens                                                                                          | D7263              |
| Downhole Seismic Testing                                                                                                                                     | D7400              |
| Particle-Size Distribution (Gradation) of Fine-Grained Soils Using the Sedimentation (Hydrometer) Analysis                                                   | D7928              |
| Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method                                                                                 | G57                |



Notes: Test Pit: TP and ATP; Boreholes & Wells: BH, BH2, PH, PLS, SH, W, and NSDF; Seismic Cone Penetration Test (sCPT): sCPT; Geophysics: GH1; Soil Resistivity: SR-1.

**Figure 3-5 Map Showing Locations of NSDF Site Characterization Investigation Locations**

### 3.1.4 Geology

#### 3.1.4.1 Geological Site Characterization

##### 3.1.4.1.1 Geological Site Characterization for the NSDF Project

Several phases of multidisciplinary site investigation were conducted at the NSDF site (e.g., [3-10], [3-20], [3-13], [3-14], [3-15], [3-16], [3-17], and [3-18]). The geotechnical aspects related to the NSDF design are summarized in [3-12], while the geological aspects are presented in [3-13] and [3-14].

Site characterization for the NSDF Project aims to support the development of the NSDF design and numerical simulations, especially the ECM. In consideration of the relatively shallow extents of the ECM and its predicted impacts, the site characterization for the NSDF Project focused on shallow depths up to approximately 30 metres below the ground surface (mbgs). At this depth, the characteristics of overburden, bedrock and shallow groundwater have the most significant impact on the development of the design and numerical simulations for the NSDF.

The scope of geological investigation at the NSDF site included characterization of ~273 m of rock core from 24 borehole locations with depth up to ~33 mbgs. The results of the geological site characterization are provided in [3-13] and [3-14]. All rock samples collected from the NSDF project are stored at the CRL site.

Field and laboratory tests were conducted to characterize “intact rock” and “rock mass” properties relevant to develop the NSDF design and numerical simulations. The definition of the terms “intact rock” and “rock mass” follows [3-21].

- The “Intact rock” is defined as rock containing no significant fractures. Properties of “intact rock” were determined from the “small” “unfractured” rock samples in laboratory tests.
- The “rock mass” properties take into account discontinuities that exist within the large volume of “rock mass”.

The results of the geological site investigation conducted for the NSDF project ([3-13], [3-14]) included:

- Intact rock properties, such as:
  - Density, elastic modulus, tensile and compressive strength; and
  - Mineralogical examination of rock core specimens using Petrographic thin section and X-ray diffraction (XRD) analyses from rock specimens.
- Rock mass properties, such as:
  - Rock Quality Designation (RQD), fracture frequency, field strength, weathering and joint properties (ASTM D6032 [3-22] and ISRM 1978 [3-23]) from rock core logging at 24 borehole locations;
  - Optical televiewer image, 3D view image and the corresponding fracture types and orientations from the photographic and acoustic televiewer survey at 4 borehole locations;
  - P-wave and S-wave velocity from downhole geophysics seismic survey at 4 borehole locations;
  - Hydraulic conductivity (or permeability) from field measurement and
  - Groundwater level and quality (e.g., chemical characteristics) from monitoring wells.

Bedrock in the vicinity of the NSDF is primarily comprised of quartzofeldspathic and diorite gneiss. Mineralogically, the rocks are comprised of quartz, potassium and plagioclase feldspars, hornblende, clinopyroxene, biotite and garnet as major minerals. These minerals are generally considered to have low potential for acid rock drainage and leachability.

Iron sulphide minerals (e.g., pyrite, pyrrhotite), which would indicate potential for acid rock drainage, have been identified through previous studies as alteration minerals formed through low-temperature fracture in filling in deep bedrock boreholes at the CRL site. One occurrence of pyrite was noted in the logs of boreholes at the NSDF site at a depth of approximately 14 m, which is approximately 2 m deeper than the excavation horizon.

Given the relatively low occurrence of the sulphide minerals and the relative stability of the constituent minerals of the rock the potential for metal leaching and acid rock drainage is anticipated to be low.

#### **3.1.4.1.2 Past Geological Site Characterization at CRL Site**

Geological site characterization at the CRL has been conducted in the past for different projects, including:

- Canadian Fuel Waste Management Program (CNFWMP) (1970s and 1980s);
- Siting Task Force (STF) (1990s) (reported in e.g., [3-24]); and

- Geologic Waste Management Facility (GWMF) feasibility study (2006-2016) (reported in [3-25], [3-26], [3-27], [3-28], and [3-9]).

The results of the geological site characterization at the CRL site from the GWMF and its predecessors have been summarized in [3-28] and [3-9].

#### **3.1.4.1.3 Data Sources**

The past studies focused on examining the feasibility of hosting a Deep Geological Repository (DGR) at the CRL site for different types of radioactive wastes. The site characterization focused on a deeper depth and longer time frame. For example, the GWMF focused investigation on ~500 to 1200 mbgs depth. Considering that geological characteristics at deeper depth will have less effects on the NSDF Project, in most cases, the results of past studies are considered as supplementary data to develop detailed design and numerical simulations.

However, integration between recent and past studies are required to understand the geological setting for the NSDF project, especially at Regional Study Area (RSA) scale. The following existing information was used to discuss the geological site characteristics for the NSDF Project:

- GWMF Descriptive Geosphere Site Model Report [3-28].
- GWMF Integrated Geosynthesis Report [3-9].
- NSDF Multidisciplinary Subsurface Investigation Phase 1 [3-13] and Phase 2 [3-14].
- NSDF EIS [3-29].
- NSDF Groundwater flow models [3-19], [3-37] and [3-38].
- NSDF PostSA [3-39].

#### **3.1.4.2 Geological Setting at CRL Site**

##### **3.1.4.2.1 Geological Maps**

The basis of the current geological and hydrostratigraphic interpretations within the NSDF RSA is provided by data from GWMF (e.g., [3-25], [3-9] and [3-28]). In principle, the geological features closest to the location of the ECM will have the most significant effects on the design and numerical models.

Figure 3-8 and Figure 3-9 show previously published geological maps of CRL site (e.g., [3-24], [3-9], and [3-28]). To facilitate further discussion, the boundaries of the NSDF Site Study Area (SSA), Local Study Area (LSA) and ECM are added to these figures. Definitions of SSA and LSA boundaries follows the NSDF EIS [3-29].

##### **3.1.4.2.2 Geological Setting of the CRL Site**

According to the Ontario Geological Survey's (OGS) Bedrock Geology of Ontario: Southern Sheet [3-57], the site is underlain predominantly by late Precambrian granitic gneisses with some amphibolitic and metasedimentary gneisses, as well as Neoproterozoic mafic (Grenville diabase dyke swarm) and felsic dykes and some discrete alkali-carbonatic complexes.

The CRL site is located within the Central Gneiss Belt (CGB) of the Grenville Province in the Canadian Shield near its contact with the structurally overlying Central Metasedimentary Belt to the southeast ([3-25], [3-9] and [3-28]). These major belts were segmented, juxtaposed and metamorphosed during the late Mesoproterozoic Grenville orogeny around 1190 to 1060 Ma. Rocks on the CRL site underlie part of the broad

Algonquin (Lac Dumoine) lithostructural domain of the CGB, which is characterized by variably migmatitic gneissic rocks intermixed with metaplutonic masses. Post-orogenic Grenville diabase dykes intrude the high grade metamorphic rocks and form at least two principal E-W trending and steeply N-dipping intrusions (i.e., the northern and southern dykes).

### 3.1.4.2.3 Lithological Descriptions of CRL Site

The rock types observed at CRL have been grouped into lithological units by mapping of the CRL site and surrounding area and in diamond drilling for the GWMF feasibility study. The seven lithological units are associated with three stratigraphically layered lithological assemblages identified on the CRL site in characterization studies ([3-25], [3-26] and [3-27]). The assemblages comprise, in descending order: (A) an upper garnet-poor gneiss assemblage, (B) a central garnet-rich gneiss assemblage, and (C) a lower garnet-poor gneiss assemblage. The seven lithological units are listed in Table 3-2 and based on the current understanding of the bedrock lithological units from the GWMF [3-9].

**Table 3-2 List of Lithological Units at CRL Site (after CNL 2016a)**

|                            |                                                                                                                                                                                                                                      |
|----------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Neoproterozoic Rock Units  | Unit 7 – Mafic Dykes (or Diabase and pyroxenite dykes in Figure 1)<br>Unit 6 – Felsic Dykes (or Granitic dykes in Figure 1)                                                                                                          |
| Mesoproterozoic Rock Units | Unit 5 – Metagabbro and Metabasite<br>Unit 4 – Granitic to granodiorite gneiss<br>Unit 3 – Quartz monzonitic, monzonitic and monzodioritic gneiss<br>Unit 2 – Dioritic and Amphibolitic gneiss<br>Unit 1 – Quartzofeldspathic gneiss |
| Minor Lithologies          | Mafic and ultramafic alkali intrusive rock<br>Calc-silicate gneiss                                                                                                                                                                   |

#### 3.1.4.2.3.1 Neoproterozoic Rock Units

##### Unit 7 - Mafic Dykes (or Diabase and pyroxenite dykes)

Diabase dykes confirmed by drilling, geo-magnetic surveys and mapping transect the CRL site as two closely-spaced, E-W striking dykes, i.e., a northern dyke and a southern dyke. Associated smaller diabase dykes (~ 0.05 m to 1.8 m) have been intersected in drilling but have not been observed in outcrop. All dip steeply north (~70°). The principal dykes range in true width between about 15 m and 40 m and are relatively continuous across the property.

The diabase is grey to greenish grey, massive, fine- to medium-grained and composed of clinopyroxene and plagioclase with accessory magnetite, the reason for the strongly magnetic character of the rock. These dykes display cm- to dm-scale, very fine-grained chilled margins. Smaller very narrow dykes are commonly highly chloritized, may contain calcite and pyrite, foliated and non-magnetic, suggesting that syn- to post-emplacement alteration has destroyed any primary titanomagnetite.



### Unit 6 - Felsic Dykes (or Granitic Dykes)

Two forms of late leucocratic granitic and, in places, tonalitic dykes cut the gneissic rocks: Two generations, earlier, weakly folded and/or foliated veins or concordant seams, and later, planar and underformed veins indicative of either episodic or protracted intrusive events including a late- to post-tectonic intrusion relative to Grenville ductile deformation, and thus are probably not Precambrian. The veins are generally coarse-grained to pegmatitic and granitic to granodioritic or quartz syenitic in composition, containing varietal accessory minerals biotite, hornblende, magnetite and locally garnet or clinopyroxene. Veins of similar texture and form that cut more mafic rocks are commonly more plagioclase rich and tonalitic or granodioritic in composition, implying probable host rock assimilation.

An uraniferous pegmatite mass is recognized by borehole gamma logging in a previous borehole (CR-13) near Lower Bass Lake [3-30] (see Figure 3-6 for borehole location). Late pegmatitic granitic veins in the Maskinonge Lake study area and in the area surrounding the CRL site display a strong preferred orientation striking NNE-SSW and dipping steeply toward the WNW.

### **3.1.4.2.3.2 Mesoproterozoic Rock Units**

#### Unit 5 - Metagabbro and Metabasite

Metagabbro and metabasite occur generally as metre- to decametre-scale lenses or bands in many boreholes and form large lenticular masses up to several hundred metres in dimension at surface. The larger masses of metagabbro commonly preserve portions displaying coarse-grained ophitic (plutonic) texture with primary clinopyroxene, plagioclase and accessory magnetite. In addition, the metagabbro generally contains metamorphic hornblende, clinopyroxene, orthopyroxene, biotite and garnet with recrystallized plagioclase.

Most of the large masses of metagabbro occur within monzonitic gneiss around contacts with quartzofeldspathic gneiss. Smaller masses are generally recrystallized and composed of ( $\pm$  garnet, clinopyroxene) biotite-hornblende-plagioclase gabbroic gneiss. Metagabbro exhibits complex corona textures with concentric mineral zones around cores of magnetite, clinopyroxene and orthopyroxene that are indicative of retrogressive metamorphic reactions of these phases with plagioclase ([3-31] and [3-32]).

Locally, the metagabbro is of troctolitic composition and contains relict olivine with well-developed corona texture [3-24]. Metabasite consists of very mafic to ultramafic rock composed mainly of hornblende and biotite with variable amounts of clinopyroxene, orthopyroxene and locally garnet. Metabasite occurs as local metre- to decametre-scale lenses intersected in several boreholes. A previously-drilled mass of metabasite (described as metapyroxenite in CR-2, CR-3 and CR-4 [3-32]) is intermixed with amphibolite around 100 mab that occurs on the hanging wall of the Upper Bass Lake Fault (see Figure 3-6 for borehole location). This rock is massive and inequigranular and contains orthopyroxene, clinopyroxene, hornblende, biotite and variable amounts of secondary chlorite.

#### Unit 4 - Granitic to granodioritic gneiss

These rocks are pink to pinkish-grey, leucocratic hornblende-biotite and garnet-biotite granitoid gneiss, characterized by abundant potassium feldspar that is either more abundant or in equal proportion to plagioclase (in contrast to Unit 1) and abundant quartz.

The rocks are generally medium- to fine-grained, equigranular and relatively massive to gneissic and contain biotite, hornblende and magnetite, with local trace amounts of clinopyroxene or garnet. The unit typically varies between (i) homogeneous and massive metagranite to granite gneiss and (ii) heterogeneous or mixed



granite to granodiorite gneiss with abundant elongate to lenticular inclusions of quartzofeldspathic gneiss, dioritic-amphibolitic gneiss and gabbroic gneiss up to several hundred metres long. Gneissic bands consist of alternations of felsic to mafic rock of variable thickness from the centimetre scale to several centimetres. Common accessory minerals are varietal garnet, biotite, hornblende and magnetite, with trace amounts of clinopyroxene. The unit forms significant components of the large map-scale assemblages.

#### Unit 3 - Quartz monzonitic, monzonitic and monzodioritic gneisses.

These are relatively massive to gneissic, leucocratic to mesocratic metaplutonic rocks with variable proportions of K-feldspar and plagioclase and relatively small amounts of quartz. The rocks are generally fine- to medium-grained inequigranular and weakly to moderately foliated. Varietal accessory minerals include hornblende, garnet, clinopyroxene and biotite, although mineralogical banding of alternating felsic and mafic mineral concentrations are common. These rocks are further intercalated with granitic to granodioritic and quartz syenitic gneiss (Unit 4) and form a main band trending NW-SE from the north end of Maskinonge Lake through the Bass Lakes area at least to an area south of Lake 233. The rocks of the unit largely correlate with the regional units of ( $\pm$  clinopyroxene) garnet-hornblende monzonitic gneiss and syenitic gneiss mapped by [3-33]. Several components of the unit are described by [3-24]:

- Light pink to white, leucocratic biotite-garnet-hornblende quartz monzonite to monzogranite and quartz syenite characterized by elongate mafic aggregates or streaks and common lenticular K-feldspar augen (megacrysts).
- Heterogeneous, leucocratic to mesocratic, quartz-poor gneisses that range widely in composition from quartz monzonite to quartz monzodiorite and quartz diorite gneiss, which generally contain hornblende-biotite ( $\pm$  clinopyroxene, garnet). More leucocratic varieties in the group contain evenly distributed mafic minerals and common thin K-feldspar rich lenses and resemble the former quartz monzonitic component.
- Greyish-pink to orange-brown hornblende-clinopyroxene-garnet quartz syenite to quartz monzonite, commonly associated with the former quartz monzonitic component.

#### Unit 2 - Dioritic and Amphibolitic Gneisses

Dioritic and amphibolitic gneiss are widespread, forming subordinate components within other rock types, occurring as local map-scale and outcrop-scale bands and lenses. These rocks range from massive to gneissose, and are generally foliated, medium- to fine-grained and subequigranular to locally porphyroblastic. Several principal mineralogical varieties of dioritic gneiss are recognized:

- (i) biotite-hornblende or hornblende-biotite dioritic gneiss
- (ii) garnet-biotite dioritic gneiss,
- (iii) garnet-hornblende dioritic gneiss. Mineralogical varieties of amphibolitic gneiss include:
  - a. undifferentiated, variably mesocratic to mafic, biotite-hornblende dioritic to amphibolitic gneiss,
  - b. hornblende-rich amphibolitic gneiss, and
  - c. garnet-bearing amphibolite, commonly containing dispersed porphyroblasts of garnet.

The biotite-hornblende rich varieties (i) of these mesocratic to mafic rocks are widespread and generally occur as concordant discontinuous lenses and/or relatively continuous bands within most principal lithological units, particularly in association with garnet-rich quartzofeldspathic gneiss or monzonitic gneiss units. The garnet-

biotite (ii) and garnet-hornblende (iii) rich varieties of dioritic gneiss occur particularly in association with garnet-rich quartzofeldspathic gneiss or monzonitic gneiss units.

#### Unit 1 - Quartzofeldspathic gneiss

This gneiss is considered to be of sedimentary origin with a semi-pelitic or pelitic affinity; hence the use of a metamorphic name, in contrast to the Streckeisen classification scheme based on modal proportions applied to other rock units. The quartzofeldspathic rock, though considered a paragneiss, spans the compositional range of basically undifferentiated granitoid rock from alkali granite to tonalite. Quartzofeldspathic gneiss contains significant quartz and plagioclase (with minor K-feldspar) and is typically relatively biotite- and garnet-rich. The rocks can be grey to pinkish-grey or greenish-grey, and variably migmatitic with common deformed seams and veins of pink syenogranite. The unit includes several intermixed components:

- (i) Grey, massive to well-layered garnet-biotite-quartz-plagioclase gneiss in which the gneissose structure is defined by variations in biotite and garnet content and by pale whitish garnet-biotite tonalitic or trondhjemitic leucosome seams and bands.
- (ii) More heterogeneous, grey to greyish-pink ( $\pm$  hornblende, garnet) biotite-quartz-Kfeldspar-plagioclase (quartzofeldspathic) gneiss containing layers, lenses or pods of dioritic and amphibolitic gneiss with layers of pink leucocratic syenogranite.
- (iii) Relatively homogeneous, greyish-pink to brownish-grey, ( $\pm$  garnet) biotite-quartz-Kfeldspar-plagioclase gneiss of granodioritic to monzogranitic composition that exhibits a weakly to moderately developed internal mineralogical layering in which narrow granitic leucosome bands define the gneissosity.

Raven Beck Environmental Ltd., [3-24] indicates that some rocks of the unit, particularly the well-layered biotite-garnet rich component, may be of either sedimentary or plutonic origin. The unit forms a broad band trending across the CRL site from the central part of its western boundary through Maskinonge Lake to the southeastern part of the property. Large segments of the unit are intersected in boreholes CRG-1, CRG-2, CRG-3 and CRG-4A. In all of these holes, the quartzofeldspathic gneiss contains local graphite-bearing intervals in which graphite occurs as disseminated mineral grains and sheaves and/or as fracture coating and fault filling material.

The quartzofeldspathic gneiss immediately hosting the faulted graphitic interval in CRG-4A is characterized by a lack of garnet and intercalated quartz-plagioclase rich and biotite-rich layers in which magnetite is locally concentrated.

The quartzofeldspathic gneiss is correlated with garnet-bearing varieties of 'biotite gneiss' ([3-44], [3-34]) in Ontario, which are associated with widespread graphite-bearing units in northern Algonquin Park [3-35] and with 'garnet gneiss' in Québec [3-36].

#### **3.1.4.2.3.3 Minor Lithologies**

##### Mafic and ultramafic alkali intrusive rock

Mafic and ultramafic alkali intrusive rock are considered as minor lithologies due to their limited intersection widths (<10 mab), limited occurrence in boreholes (<1%) and their absence in surface mapping. These rocks include lamprophyre dykes that are narrow, biotite-rich, mafic or ultramafic intrusions that are strongly foliated parallel to their discordant contacts with the host gneisses. They occur as clustered narrow dykes within garnetiferous quartzofeldspathic gneiss (unit 1) but only in boreholes CRG-4A and CRG-7. The lamprophyre dyke in CRG-7 has a relatively consistent, moderately NE dip.

### Calc-silicate gneiss

Calc-silicate gneiss has very limited distribution in the map area. The calc-silicate occurs only in CRG-4A as narrow bands of sphene-garnet-calcite-clinopyroxene-hornblende-plagioclase rock ranging from centimeter to decametre thicknesses, comprising < 5 mab intersection length.

#### **3.1.4.2.4 Ottawa- Bonnechère Graben (OBG)**

The CRL site is situated near the northern margin of the Ottawa- Bonnechère Graben (OBG). This major zone of fracturing and normal faulting ranges from about 40 km to 60 km in width and extends WNW-ESE around 700 km from Lake Nipissing to the Montréal area, where it merges with the St. Lawrence Graben. The OBG is characterized by a network of contemporaneous faults and lineaments that generally strike in two principal directions, namely: (a) E-W to ESE-WNW and (b) NW-SE.

NW-trending faults are well-developed within the central part of the graben in the Ottawa area. The Grenville diabase dykes display a strong preferred E-W orientation, related to the direction of principal crustal extension at the time of development [3-28].

The graben is believed to have been originated in the late Precambrian or early Paleozoic as a branch of the St. Lawrence rift system representing one arm of a triple junction, and later evolved as an intracratonic graben. Subsequent major normal faulting during the Mesozoic formed (a) large outliers of Paleozoic sediments and (b) prominent marginal scarps, which in part delimit the outliers.

The Paleozoic outliers are preserved in down-dropped and/or tilted blocks in the upper Ottawa valley beyond the St. Lawrence Platform, and extend to within 30 km southeast of the property. The large marginal scarps extend along the north side of the Ottawa River and include the large scarp trace along the Ottawa River adjacent to the CRL property [3-28].

Though many faults in the graben may be considered seismically active [3-40], the primary cause of the seismicity in terms of active rifting is doubtful, since most modern seismic activity occurs in Precambrian rocks to the east of the graben within the Western Québec seismic zone [3-41].

#### **3.1.4.2.5 Mattawa Fault**

The northeastern boundary of the graben is defined in part by the Coulonge Fault ([3-42], [3-43]), currently known as the Mattawa Fault [3-44]. This fault, formed as a regional scale normal fault in an extensional stress regime, underlies and controls the Ottawa River adjacent to the CRL site and dips steeply SW. According to [3-42], the fault shows a displacement of about ~244 m (800 ft.).

The southwestern boundary of the graben is marked by the Mount St. Patrick Fault scarp, located about 50 km southwest of the CRL site, for which [3-42] records a displacement of ~457 m (1500 ft.). The area of rugged relief in Québec adjacent to the CRL site comprises the up-thrown, northern margin of the graben and includes major faults (subparallel to the Mattawa Fault along the Ottawa River). In the CRL region the Mattawa Fault is oriented NW-SE with a steep, approximately 65° dip to the SW [3-28].

#### **3.1.4.2.6 Neotectonism**

Based on a literature review, it is apparent that there is general consensus on the following with regard to the Ottawa-Bonnechère Rift (OBR) and its seismic history during glaciations and to the present day [3-28]. The presence, extent and tectonic significance of the OBG have been studied since the 19th century, and while this

knowledge has been expanded the significance of the OBG with respect to neotectonism has not appreciably changed.

It is recognized that present day seismicity has only an approximate correlation with the OBR system. Instead, the distribution of seismicity defines a diffuse NW trending zone, referred to as western Quebec seismic zone, whose central axis best correlates with the trajectory of the Great Meteor hotspot. The present day state of stress and the mechanics of fault reactivation along the OBG and St. Lawrence rift system are known in a regional sense, and to some extent are known on a local scale. How the stresses interact with faults on a local scale requires further site-specific investigations. It is suspected that lithologic heterogeneities in general contribute to the focusing of past and recent seismicity. However, the specific types of heterogeneities and their influence on seismicity have not been identified.

Post-glacial faulting associated with the OBR system faults has been well documented for the regions beyond 100 km to the north and south of the CRL site, but has not been observed by any of geotechnical/geological investigations conducted in the CRL site to date. Post-glacial deformation had not been recognized in or adjacent to the CRL site in either the bedrock, or in the surficial sediments by geologists at the Ontario Geological Survey (OGS), the Geological Survey of Canada, and AECL/CNL to date. There have been no observations of post-glacial deformation in either the surficial sediments or in the bedrock at CRL and its environment [3-28].

Trench mapping on the CRL property was conducted to look for any evidence of paleoseismicity preserved in the surficial sediments and bedrock surface at the CRL site [3-28]. Faults and fractures in the surficial sandy sediments, such as those reported in the literature on other parts of the OBR system were not observed in any of the trench locations studied or their environs, or in any of the air photos or satellite images reviewed when the location for the trenches were selected [3-28]. As such, while it is likely that the CRL site was affected by prehistoric earthquakes known to have occurred in the surrounding region, these events did not leave any evidence within the bedrock [3-45], or in the surficial sediments examined.

#### **3.1.4.2.7 Apparent E-W Trending Magnetic Lineament**

Two E-W trending post-orogenic Neoproterozoic diabase dykes (i.e., the northern and southern dykes), present at the CRL site are part of the Grenville dyke swarm that extends from the Georgian Bay-Lake Timiskaming region to at least north of Montreal. The northern and southern diabase dykes are proven at the CRL site by borehole intersections, strong magnetic geophysical signature and dispersed outcrop exposures and in floats/boulders (mainly near Maskinonge Lake). The northern and southern dykes dip steeply north (~70°), range in true width between about 15 and 40 m and appear to be relatively continuous across the property.

Ground and airborne geophysical anomalies were interpreted in [3-24]. Figure 3-8 shows an airborne magnetic survey performed by the Geological Survey of Canada (GSC) as part of STF ([3-24]). This survey did not cover the NSDF SSA (see Figure 3-8 a and Figure 3-8 b). The magnetic anomaly traces show the approximate location of the two diabase dykes at the CRL site (see Figure 3-8 b). In this figure the end of the anomaly corresponding to the southern diabase dyke is located south of the NSDF SSA boundary.

#### **3.1.4.2.8 Lineament studies for CRL site**

The lineament studies for the CRL site were performed by the CNFWMP (1970s and 1980s), the STF (1990s) and GWMF (2006-2015). The results were summarized in [3-9] and [3-28]. The lineament studies performed

by the CNFWMP covered the area around the Maskinonge Lake study area. Due to the distance from the NSDF, the results will not be discussed further.

Based on analysis of air photo and linear geophysical anomalies, the lineament study for the STF (e.g., [3-24]) provided the basis for major fracture and fault zones. Interpreted fracture zones were categorized based on their confidence levels that range from “Confirmed or High Probability”, “High Probability”, “Moderate Probability” to “Probable” fracture zones corresponding to highest to lowest probability (see Figure 3-9 a).

Further site investigation was done by the GWMF (e.g., [3-9] and [3-28]). The results included the development of the conceptual 3D geological model for CRL site and surrounding area [3-46]. Confidence levels corresponding to interpreted fracture zones was reassigned by the GWMF. They range from “Confirmed or High Probability”, “Moderate Probability” and “Possible” fracture zones corresponding to highest to lowest probability (see Figure 3-9 b).

The lineament analyses performed by the STF and GWMF provide an indication for the approximate locations, orientations of fracture zones and corresponding confidence levels. However, they do not provide detailed information regarding spatial location, orientations and characteristics to be directly applied for the NSDF design and numerical simulations. Consequently, a different approach to take into account the fracture features was used in the NSDF and discussed later.

#### **3.1.4.3 Geological Features within the NSDF SSA**

This section discusses interpreted geological features within the NSDF SSA, their impacts on the NSDF project and how they are addressed by the NSDF Project.

##### **3.1.4.3.1 Selection of Key Features**

The selection of the key geological features for the NSDF SSA considers: (a) the principle that the geological features closest to ECM will have the most effects on the NSDF; and (b) confidence levels associated with the features. Figure 3-10 shows the plan view and cross-section of geological features within the NSDF SSA and confirmed geological features at CRL site, which include:

- Mattawa Fault.
- Maskinonge Lake Fracture Zone.
- Northern Diabase Dyke (Feature# 6).
- Southern Diabase Dyke (Feature#7).
- Feature #17 (Fracture Zone).

The numbers to identify the geological features are consistent with ([3-9] and [3-28]). Mattawa Fault and Maskinonge Lake Fracture Zone are identified as “Confirmed or highly probable” (see Figure 3-9) and were discussed in previous sections. Northern Diabase Dyke (Feature# 6) is identified as “probable”. Due to their distance from the NSDF SSA and their locations outside the NSDF SSA, the Mattawa fault and the Maskinonge Lake fracture zones and the Northern Diabase Dyke (Feature# 6) are anticipated to have insignificant effects on the NSDF design and analyses. The Mattawa Fault has been discussed in the previous section.

Within the NSDF SSA, in addition to Feature #7 and Feature #17 shown in Figure 3-10, two additional features were identified by previous studies by GWMF and STF (see green dash lines in Figure 3-9b). However, these

features are excluded for further discussion due to their lower probability. These features were also excluded from the GWMF hydrogeology models [3-9].

The remaining geological features within the NSDF SSA for further discussion are the Southern Diabase Dyke (Feature #7) and Fracture Zone (Feature #17) (see Figure 3-10).

#### **3.1.4.3.2 Feature # 7 (Southern Diabase Dyke)**

The southern diabase dyke (Feature # 7) was identified to potentially be located within the NSDF SSA. The existence of this feature in the surrounding of the NSDF LSA has been confirmed, but its underlying presence within the NSDF SSA has not been confirmed.

The permeability of diabase dykes was measured in the CNFWMP and GWMF (reported in [3-9] and [3-28]). Both measurements are in agreement that the diabase dykes have a decreased permeability, despite an abundance of fracturing within them ([3-9] and [3-28]). A decreased permeability of the dykes is attributed to the ubiquitous distribution of fracture fillings in most fractures ([3-9] and [3-28]).

In the GWMF, diabase dykes were observed in Boreholes CRG-3 and CRG-6 (see Figure 3-7 for the borehole locations). The diabase dykes were observed at 230-262 metres along the borehole (mabh) and 926.8 – 958.8 mabh in borehole CRG-3 and at 439 to 471 mabh in CRG-6 ([3-9] and [3-28]).

Field measurement showed that the permeability (k) of dykes is significantly lower than the rock mass [3-9]. The permeability (k) of the dykes at the CRL site was measured to be  $\sim 4 \times 10^{-21}$  to  $6 \times 10^{-18}$  m<sup>2</sup> (i.e., hydraulic conductivity (K)  $\sim 4 \times 10^{-14}$  to  $4 \times 10^{-11}$  m/s) and k of rock mass at similar depths was measured to be  $\sim 10^{-17}$  m<sup>2</sup> (i.e., K  $\sim 10^{-10}$  m/s) ([3-9], [3-28]). Given this lower k, the existence of diabase dykes is unlikely to provide additional potential contaminant flow paths. The dyke will act as relatively impermeable flow barriers (aquitards).

Based on the existing borehole observations by GWMF, Feature #7 was interpreted to be terminated at - 350 mASL or > 550 mbgs (see Figure 3-10 b). In this case, Feature #7 will have insignificant effect on the NSDF.

#### **3.1.4.3.3 Feature # 17 (Fracture Zone)**

Fracture zone (Feature #17) is located in the southern section of the NSDF SSA, but outside the ECM footprint (see Figure 3-10). The degree of confidence corresponding to this feature was categorized as a “high-probability” by the STF [3-24], but later it was re-categorized as “possible” by the GWMF [3-9].

The Feature # 17 was assigned an ESE-WNW (105/285°azimuth) trend, a length of 1,100 m and width of 10 m. A clearly defined structural control parallel to this feature was observed in the LiDAR image, air photos, and field mapping data obtained in the southern section of this feature. A dip direction of 70° towards the NE is assumed based on the field mapping data.

The hydraulic conductivity of the fracture zone is several orders of magnitude greater than the rock mass and will become the preferential groundwater flow path. However, considering that its location is outside the ECM foot print and its orientation is perpendicular to the direction of groundwater flow, this feature is anticipated to have limited potential as a preferential groundwater flow path. Conservatively, the implications of a fracture zone in the ECM foot print are further assessed in the hydrogeology numerical simulations [3-37].

#### **3.1.4.3.4 Features Observed at the NSDF Site**

The site investigations at the NSDF site ([3-13] and [3-14]), included characterization of the types and orientations of geological features at shallow depth (< 33 mbgs) by borehole logging and geophysical televiewer survey.

Rock Quality Designation (RQD) from 24 borehole locations was measured during the core logging. Rock Quality Designation is defined as the percentage of the borehole core consisting of intact rock with lengths greater than 100 mm to indicate quality of rock mass ranging from “very poor” to “excellent” [3-47]. The measured RQD of the rock cores indicates that the bedrock quality varies from “very poor” to “excellent” ([3-13] and [3-14]). The average of measured RQD from all borehole locations is ~82%, which indicates that the bedrock quality at shallow depth at the NSDF site is a “good” quality.

The geophysical televiewer survey was conducted at four borehole locations at the NSDF site [3-13]. The results included planar and 3D image of bedrock and interpretations of fracture types and orientations. The results indicate that the majority of fractures were “minor fracture”.

Currently, clear correlations between geological features from past study (e.g., Feature #7 and Feature #17) and data from the NSDF site ([3-13] and [3-14]) cannot be made due to limited borehole depth and location observation. Features #7 and #17 are likely situated deeper than 30 mbgs, which corresponds to the vertical limit of the NSDF site characterization.

To address this remaining uncertainty, a geological verification program is planned and hydrogeological models [3-37] were developed to assess potential implications of the existence of hypothetical fracture zones. The scope of the scenarios are described in [3-37]. The verification program and numerical models are discussed further below.

#### **3.1.4.4 Implications of the Geological Features to the NSDF**

##### **3.1.4.4.1 Effects on Hydrogeology Models and Post-Closure Safety Assessment**

Hydrogeology models (e.g., [3-19], [3-37], [3-38]) and Post Closure Safety Assessment (Post SA) models [3-39] have been developed for the NSDF. The hydrogeology models (e.g., [3-30], [3-19], [3-37]) evaluate groundwater flows due to the NSDF. The results of the hydrogeology models form the basis of groundwater pathways through the geosphere, as inputs to the PostSA models [3-39]. One of the purposes of the PostSA models for the NSDF is to undertake a quantitative assessment of the post closure radiological and non-radiological safety of the proposed NSDF. The PostSA models have been implemented using the AMBER code.

Hydraulic conductivity (K) is one of the key parameters to affect the hydrogeological models. The presence of geological features (e.g., fracture zones or dykes) can potentially alter hydraulic conductivity (K) values and modelling results. To facilitate the discussion, Table 3-3 compares hydraulic conductivity (K) values used to develop the models and the ones from field measurements by the NSDF, GWMF and its predecessors. Corresponding permeability (k) values are also presented in the table.

##### **3.1.4.4.1.1 Effects of Fractures at Shallow Depth**

The NSDF hydrogeology models ([3-30], [3-19] and [3-37]) assumed different hydraulic conductivity (K) for upper bedrock and lower bedrock. The hydraulic conductivity for upper bedrock, where depth up to 6 m below overburden was assumed to be  $9 \times 10^{-7}$  m/s. The hydraulic conductivity for lower bedrock, depth from

6 m to 50 m below overburden was assumed to be  $4 \times 10^{-8}$  m/s. Boundary conditions representing an impermeable layer is assumed at depth 50 m below overburden.

Selection of hydraulic conductivity (K) values for modelling was based on the field testing (e.g., [3-13] and [3-14]) (see Table 3-3). The field testing measures hydraulic conductivity (K) values of the rock mass instead of intact rock. These values have taken into account the effect of fractures within the portion of rock mass being measured. Thus, the hydrogeology models have incorporated the existence of fracture features observed at the NSDF. The models have also been calibrated with the groundwater elevation measurements at the NSDF site.

#### **3.1.4.4.1.2 Effects of Diabase Dykes**

Measured hydraulic conductivity of diabase dykes at the CRL site is  $\sim 10^{-14}$  m/s ([3-9] and [3-28]) that is significantly lower than the rock mass or model parameter ( $4 \times 10^{-8}$  m/s) ([3-30], [3-19], [3-37]). The presence of these dykes will act as a hydraulic barrier and will not likely have significant effect on the results of hydrogeology models.

#### **3.1.4.4.1.3 Effects of Fracture Zone**

Measured hydraulic conductivity of the fracture zone at CRL site was approximately  $5 \times 10^{-6}$  m/s [3-9], which is higher than the value applied to the upper bedrock used in the model ( $9 \times 10^{-7}$  m/s) ([3-30], [3-19], [3-37]). The hydraulic conductivity selected for the hydrogeology models [3-19] and [3-37] was selected based on the field measurement at the NSDF site ([3-13] and [3-14]).

Implications of the presence of additional fracture zones will be comparable to one of several sensitivity cases developed for the NSDF [3-19], identified as cases SR1 and SR2, where there is a global increase in the bedrock hydraulic conductivity of the upper 6 m of bedrock by a factor of 2. The results showed that the lateral extent of the lowering of the water table beneath the ECM was slightly decreased over the base simulation and remained below 1.5 m below the top of compacted clay liner. Additional models [3-37] were developed to assess a hypothetical fracture zone.

While there may be a potential impact to accelerate groundwater transport with the presence of a fracture zone, it is important to recognize that the fracture features at shallow depth have been indirectly incorporated in the model since field measurements were used for the model.

#### **3.1.4.4.1.4 Hydrogeology Models to Assess Hypothetical Geological Features**

Considering the long timeframe as part of PostSA [3-39], geological features may potentially evolve in the future, for example due to a significant earthquake. Additional hydrogeology models ([3-37] and [3-38]) have been developed to examine scenarios that take into account the hypothetical existence of potential geological features within the NSDF SSA. These models examined: the worst case of fracture zone conditions [3-37] and the case if undetected fracture currently exists [3-38].

Inclusion of a hypothetical bedrock fracture zone (e.g. higher permeability zone) in the EIS groundwater flow model initially simulated significantly lower (up to 7 m) groundwater elevations than those observed at groundwater monitoring locations in the vicinity of the ECM [3-37]. Recalibration of this model was reasonably achieved through a reduction in hydraulic conductivity of the bedrock units and the fracture zone, as well as an increase in the recharge rate applied in the ECM area [3-38]. The adjustments made to model input parameters were considered reasonable based on measured values thus, providing confidence in the



new model [3-38]. This recalibration resulted in simulations that are comparable to the initial model calibration completed [3-29].

A simulation of the post closure scenario with the revised model (including the hypothetical bedrock fracture zone) was completed [3-38]. This resulted in a minor change to the groundwater flow pathway, where a portion of groundwater released in the upper ECM area travelled through the fracture zone prior to reaching the overburden. The resulting groundwater travel times between the ECM and Perch Creek were similar with the hypothetical bedrock fracture zone included as compared to the base scenario (i.e., typically 7 to 10 years for the majority of groundwater particles, with the overall range of 5 to 15 years). The re-calibration and forecast simulation including the hypothetical fracture zone are documented in [3-37] and [3-38].

As discussed above, the results of the recalibrated model show that the presence of a hypothetical fracture zone in the bedrock have negligible effect on the groundwater travel times between the ECM and downgradient receptors (i.e., Perch Creek). This is because the primary groundwater flow pathway is situated in the overburden, a shallow pathway that is not significantly impacted by a fracture zone in the bedrock. The existing Normal Evolution Scenario within the 3<sup>rd</sup> iteration Post-Closure Safety Assessment [3-39] utilizes a groundwater transit time of seven years, thus is aligned with the results of [3-38]. Furthermore, the 3<sup>rd</sup> iteration PostSA also includes a sensitivity analysis of a rapid transit of five years to Perch Creek and concludes that the groundwater travel time does not have a significant impact on the fluxes of the radionuclides from the groundwater pathway to the creek.

#### **3.1.4.4.2 Effects on ECM Structural Stability**

Conservatively, even if it is assumed that all identified fracture features exist at the NSDF site, the orientations and characteristics of fracture features are not likely to effect the ECM structural stability. In general, the strength of bedrock at the NSDF site is greater than the overburden (soil) at the NSDF site. Consequently, the analyses to examine structural stability (i.e., stress-strain and slope stability analyses) of the ECM focused on overburden soil, ECM liner systems and waste ([3-48] and [3-49]).

#### **3.1.4.4.3 Effects on Seismic Hazard at the NSDF Site**

A site specific Probabilistic Seismic Hazard Assessment (PSHA) was conducted for the NSDF site to determine the level of seismic hazard for the ECM design and modelling [3-50]. The PSHA [3-50] utilized the 2015 National Building Code of Canada (NBCC) [3-51], the latest Canadian standard at the time of the design development. The analyses considered the geological features and past seismic events relevant for the NSDF site. The definition of the seismic criteria and assessment for the NSDF design is provided in [3-52].

Canadian Nuclear Laboratories has conservatively chosen a 1 in 10 000 year earthquake as the Design Basis Earthquake (DBE) for the ECM for the ECM's 550 year design life. This is the earthquake in the CSA N289.1 [3-53] standard that is to be applied to the design of a nuclear power plant. The adoption of this size of earthquake is considered conservative because the inventory of radioactive material in the NSDF is significantly less than the radioactive inventory of a nuclear power plant; thus, the consequence of exceeding the DBE at the NSDF site during the 550 year design life is much less than the consequence of exceeding a DBE at an operating power reactor if the safety and containment systems do not mitigate the event as designed. The DBE is commensurate with the design life and the risk associated with the ECM.

Within the design, to mitigate potential liquefaction due to a seismic event, the NSDF design implements the "remove and replace" ground improvement technique at the locations where potential liquefaction was identified to mitigate potential liquefaction ([3-48], [3-49] and [3-12]). While this technique is currently

limited to the overburden soil, this may be extended if in the future, it was discovered that the bedrock strength and features are not suitable during the geological verification program.

Within the PostSA, CNL demonstrates that there are no impacts to human health and the environment if more severe events than a design basis seismic event were to occur. In addition, quantitative analysis that the “Series of Landslides” scenario bounds the consequences from a more severe seismic event (i.e., 1 in 50 000-year earthquake) has been developed ([3-39] and [3-54]).

#### **3.1.4.4 Other Long-term Effects on the NSDF**

Existing studies at the CRL site (e.g., GWMF) discussed the long-term future evolution of geological conditions ([3-9] and [3-28]). Although these studies focused on a different type of disposal facility, the following conclusions are relevant for the NSDF:

- Long-term future climate predictions indicate that the next major glaciation event may not occur until 100 000 years into the future [3-55]. Therefore, the effects of glacial erosion, permafrost, and associated changes to the groundwater flow system are expected to be minimal over the NSDF assessment timeframe (10 000 years).
- The potential for fault reactivation at the NSDF site exists, but the effects are expected to be minimal on the existing system. Evidence from bedrock fractures that have been subjected to historical tectonic stresses and glacial loading and unloading indicates that the rock is inherently stable. No evidence of post-glacial structural disruption has been found.
- Volcanic activity and orogenic events are not considered to be factors that could potentially influence the geological setting over the assessment timeframe.
- The NSDF ECM will be built on the late Precambrian and/or early Paleozoic age granitic gneisses of the Ottawa-Bonnechere Graben underlying the CRL site. This region has been tectonically stable for over 100 million years, which adds confidence regarding long-term stability.
- There is no evidence of oil, gas or economic mineral deposits on the CRL site, making inadvertent human intrusion to search for such resources unlikely.

#### **3.1.4.5 Geological Verification Program**

To reduce the uncertainty in the understanding of geological characteristics at the NSDF site, a geologic verification program and seismic monitoring will be implemented for the NSDF site and is described below.

##### **3.1.4.5.1 Geologic Verification Program**

A geologic verification program will be implemented at the NSDF site during the construction phase. This program’s objective is to reduce the uncertainty with respect to the current understanding of geological characteristics and features at the NSDF site, particularly the NSDF SSA, where these characteristics and geological features have the most effect on the long-term performance of the Facility.

During the design phase, the site investigations have been limited by the access to borehole locations. During the construction phase, the upper bedrock and its geologic features will be exposed, thus providing direct access to conduct surface geological surveys.

The scope of the program will be comprised of additional field and laboratory testing to assess the presence and orientation of key geological features within NSDF SSA (e.g., Feature #7, Feature #17 or new features). The program will focus on the locations and depths where the key features will likely be observable.

### 3.1.4.5.2 On-going Monitoring

Canadian Nuclear Laboratories has recognized and assessed the potential effects of geological features. On-going monitoring programs at the CRL site are conducted which will help verify assumptions and models as well as capture any changes in environmental conditions. The environmental monitoring includes arrays of groundwater wells to monitor groundwater elevations and quality around the NSDF site as discussed in Section 3.1.3.

In addition, new geological features may be discovered or activated due to major seismic events. Presently, there are seismic monitoring stations located at CRL site that are operated by Natural Resources Canada (NRCan) and Microseismic Monitoring Stations (MMS) operated by AECL/CNL since 2008 [3-56]. Canadian Nuclear Laboratories MMS have the capability to monitor lower magnitude seismic events. The primary objective of the MMS has been to provide an analysis of the natural seismic activity of the area associated with tectonic faulting and to detect any specific active geological structures. The current seismic array consists of three surface seismic stations monitoring an area of approximately 7 km x 7 km to the west of the CRL facilities (Figure 3-11). This MMS will monitor potential activation of any new geological features, which if discovered, the impact on the NSDF performance and safety consequences will be assessed as required.

**Table 3-3**

**Comparison of Hydraulic Conductivity and Permeability for Numerical Models and Measured in the Field**

|                                                         | Hydraulic conductivity, K (m/s)***                                                    | Permeability, k (m <sup>2</sup> )**,***                                                 | References                                   |
|---------------------------------------------------------|---------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------|----------------------------------------------|
| NSDF Hydrogeologic Modelling                            |                                                                                       |                                                                                         |                                              |
| Upper bedrock, depth up to 6 m below overburden.        | Upper bedrock<br>9x10 <sup>-7</sup>                                                   | Upper bedrock<br>9x10 <sup>-14</sup>                                                    | [3-30], [3-19],<br>[3-37], [3-38],<br>[3-37] |
| Lower bedrock, depth from 6 m to 50 m below overburden. | Lower bedrock<br>4x10 <sup>-8</sup>                                                   | Lower bedrock<br>4x10 <sup>-15</sup>                                                    |                                              |
| Fracture Zone                                           | Fracture zone<br>10 <sup>-5</sup> to 10 <sup>-4</sup>                                 |                                                                                         |                                              |
| Boundary condition, depth > 50 m below overburden.      |                                                                                       |                                                                                         |                                              |
| Field Measurements                                      |                                                                                       |                                                                                         |                                              |
| Insitu measurement at the NSDF site                     | Mean : 1.4x10 <sup>-7</sup><br>Min: 2.3x10 <sup>-9</sup><br>Max: 1.5x10 <sup>-5</sup> | Mean: 1.4x10 <sup>-14</sup><br>Min: 2.3x10 <sup>-16</sup><br>Max: 1.5x10 <sup>-12</sup> | [3-13],[3-14]                                |
| Intact rock at CRL site (deeper depth)                  | 10 <sup>-10</sup>                                                                     | 10 <sup>-17</sup>                                                                       | [3-9], [3-28]                                |
| Dyke at CRL site                                        | 10 <sup>-14</sup>                                                                     | 10 <sup>-21</sup>                                                                       | [3-9], [3-28]                                |
| Fracture zone at CRL site                               | ~10 <sup>-5</sup>                                                                     | ~10 <sup>-13</sup>                                                                      | [3-9], [3-28]                                |
| FS series boreholes (depth c. 50 mbgs)                  | 10 <sup>-12</sup> to 10 <sup>-4</sup>                                                 | 10 <sup>-19</sup> to 10 <sup>-11</sup>                                                  | [3-9], [3-28]                                |

|                                              |                                  |                                   |               |
|----------------------------------------------|----------------------------------|-----------------------------------|---------------|
| STF series boreholes (depth c. 200 mbgs)     | $10^{-10}$ to $10^{-4}$          | $10^{-17}$ to $10^{-11}$          | [3-9], [3-28] |
| CRG series boreholes (depth up to 1200 mbgs) | $10^{-14}$ to $5 \times 10^{-3}$ | $10^{-21}$ to $5 \times 10^{-10}$ | [3-9], [3-28] |

\* High permeability in regions with open fractures; low permeability in regions of intact rock; \*\* Assuming water as pore fluid, conversion of from k to K is done using the following equation:

$k = K \left( \frac{\mu}{\rho \cdot g} \right)$ , where: k is the permeability,  $m^2$ ; K is the hydraulic conductivity, m/s;  $\mu$  is the dynamic viscosity of the fluid, Pa·s ( $8.90 \times 10^{-4}$  Pa·s at 25°C);  $\rho$  is the density of the fluid,  $kg/m^3$  ( $1000 kg/m^3$ ); g is the acceleration due to gravity,  $m/s^2$  ( $9.81 m/s^2$ ).  $k = K / 10^{-7}$

\*\*\* Values presented in this table are rounded value for the purpose of discussion. More accurate values can be found in [3-9] and [3-28].

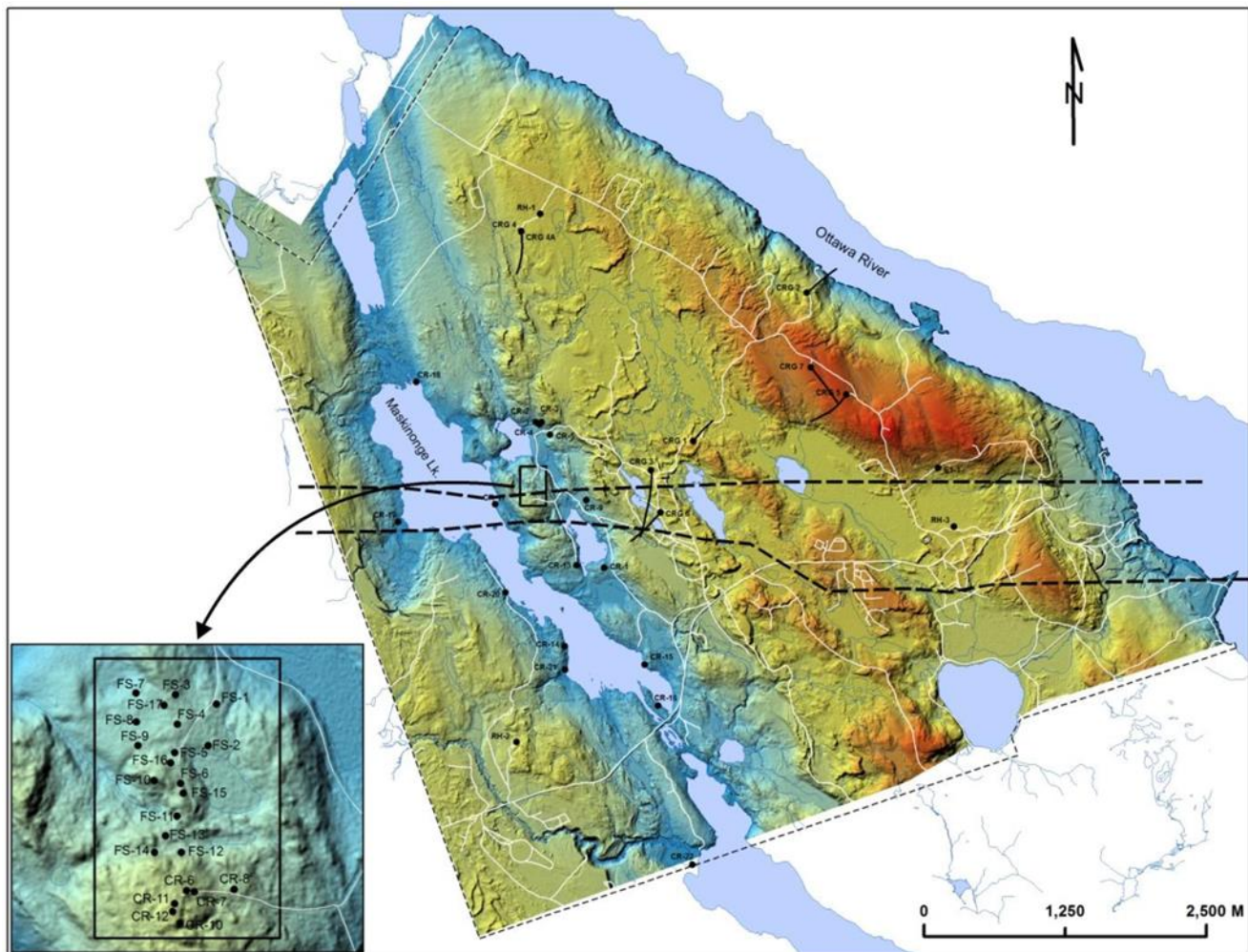
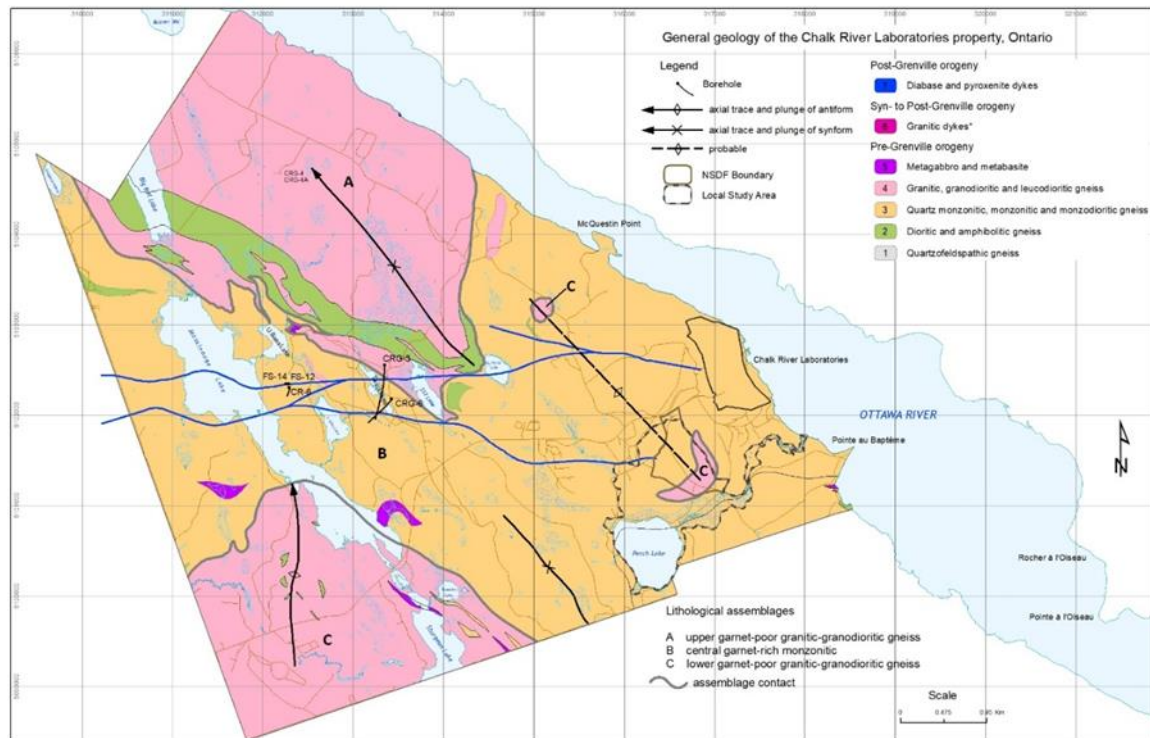


Figure 3-6 Deep Borehole Locations at CRL Site [3-9])

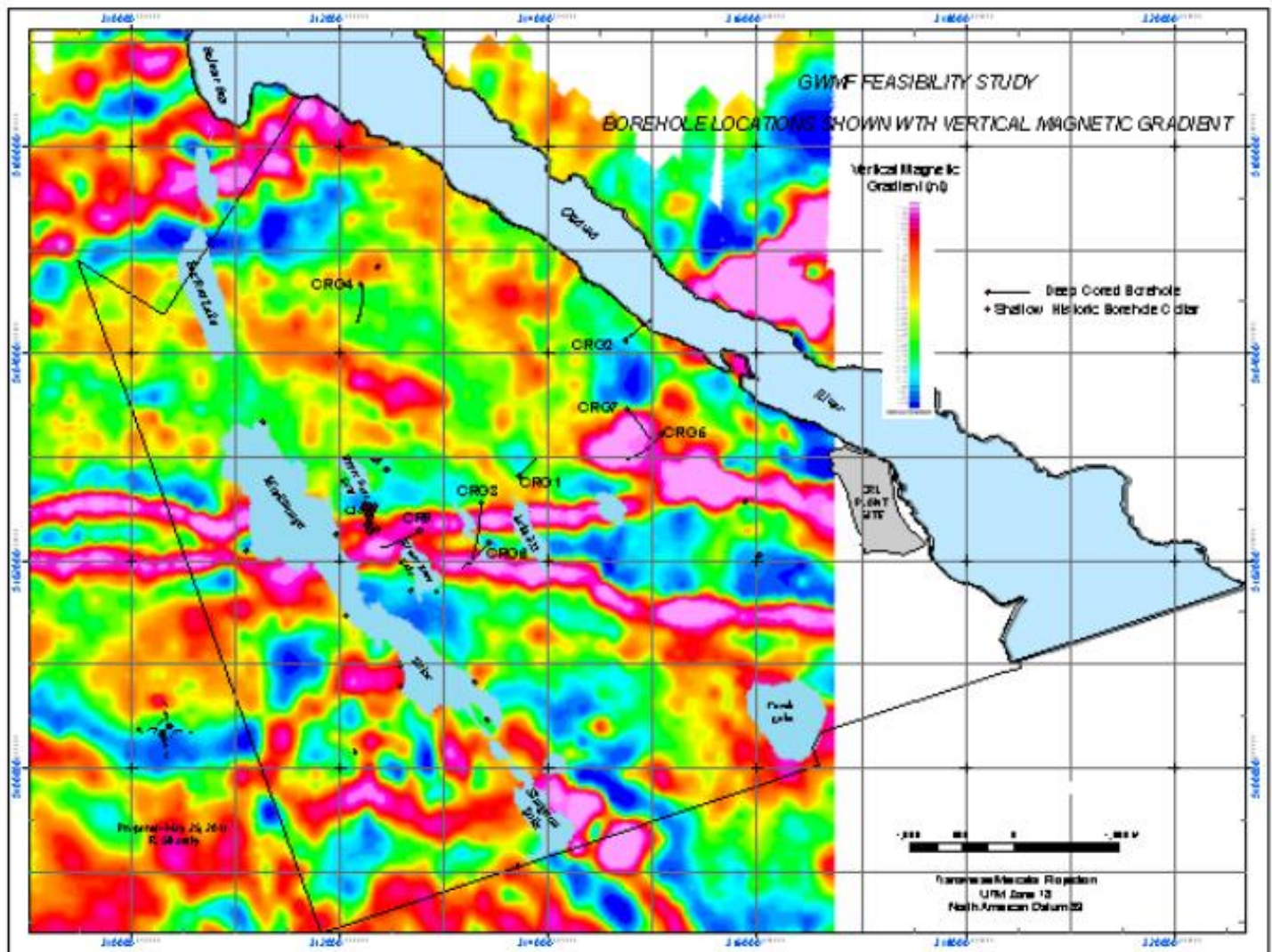


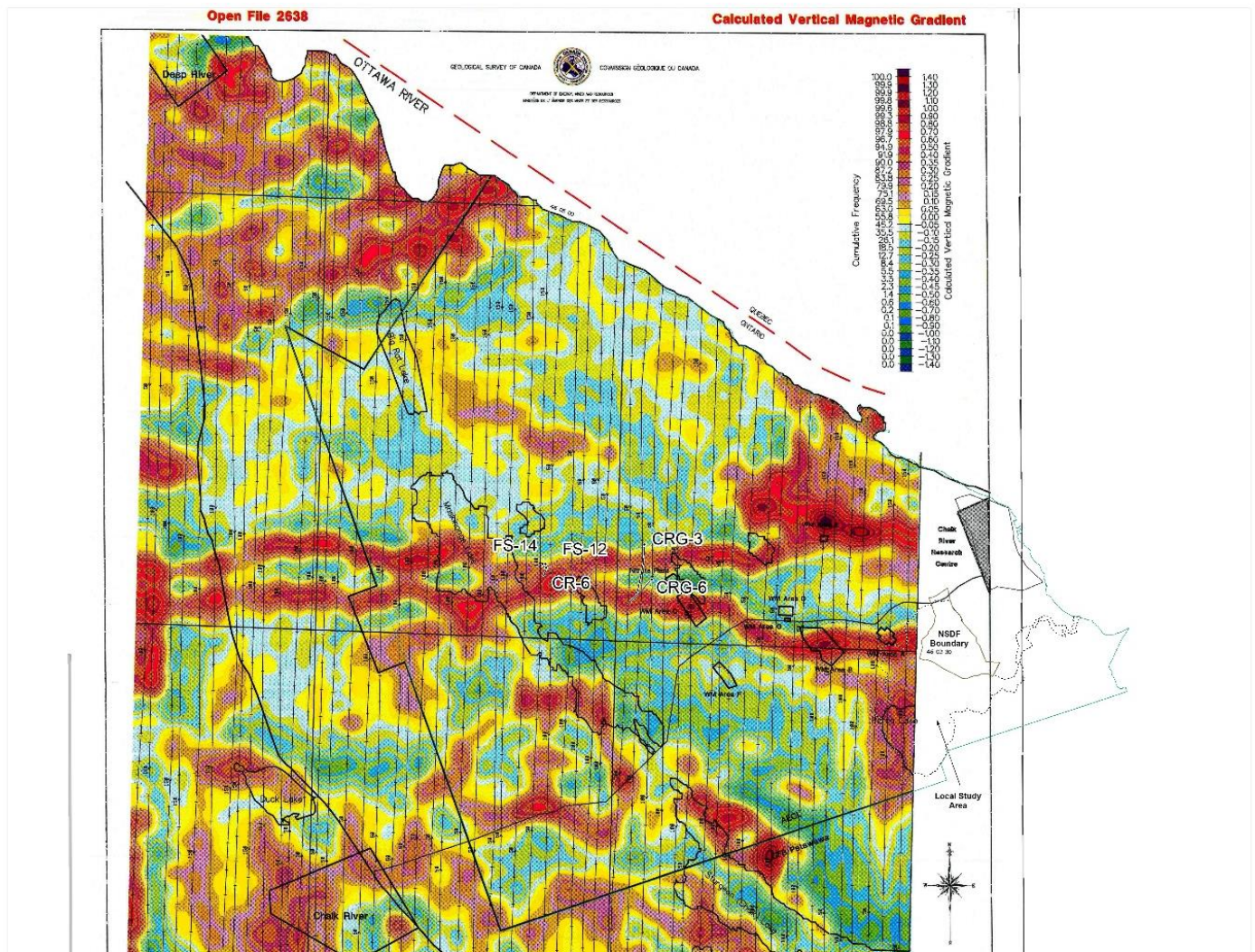
Note: The following features are shown in the figure:

- Three lithological assemblages A, B and C;
- Seven lithological units;
- Borehole locations; and
- NSDF SSA is shown as “NSDF Boundary” and LSA is shown as “Local Study Area”.

**Figure 3-7 General Geology of the CRL Property Defined by the GWMF  
 (From Figure 2-16 of [3-9])**





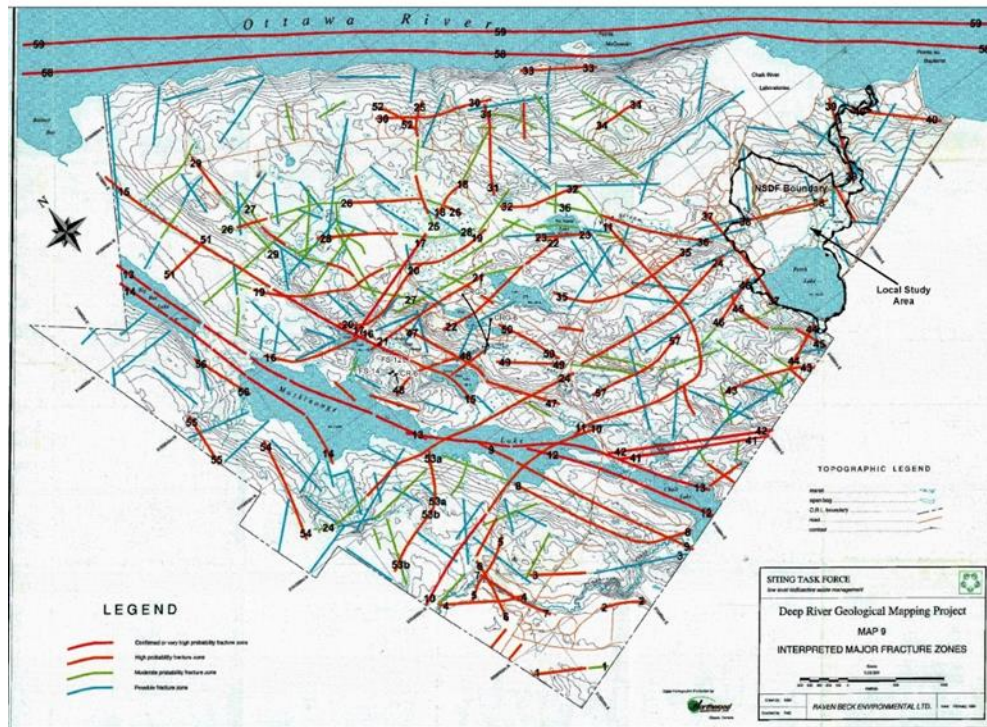


(b) After STF [3-24].

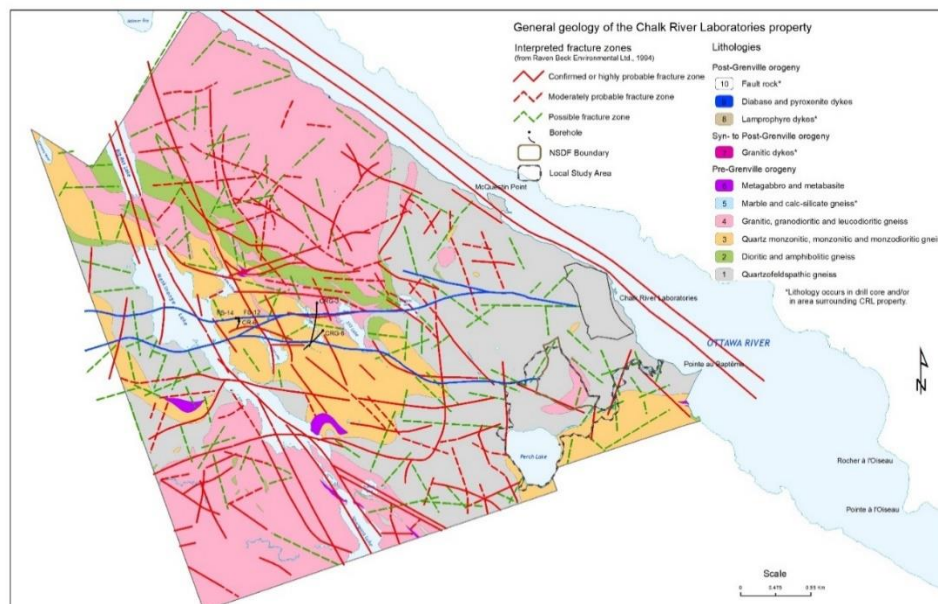
Note: NSDF SSA is shown as "NSDF Boundary" and LSA is shown as "Local Study Area".

**Figure 3-8 Vertical Magnetic Gradient with Locations of NSDF SSA and LSA**





(a) Interpreted major fracture zones from STF [3-24]

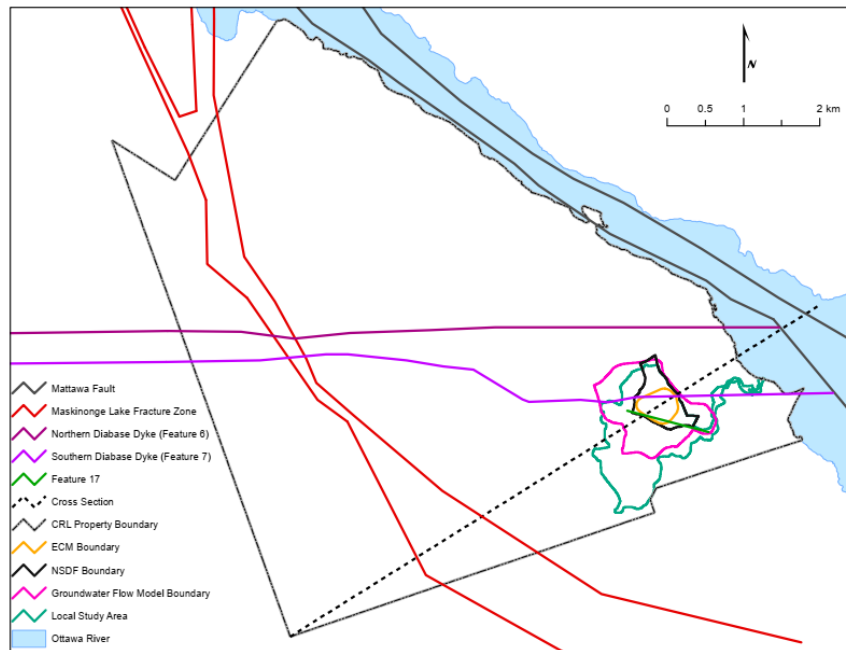


(b) Interpreted major fracture zones from GWMF ([3-9], [3-28])

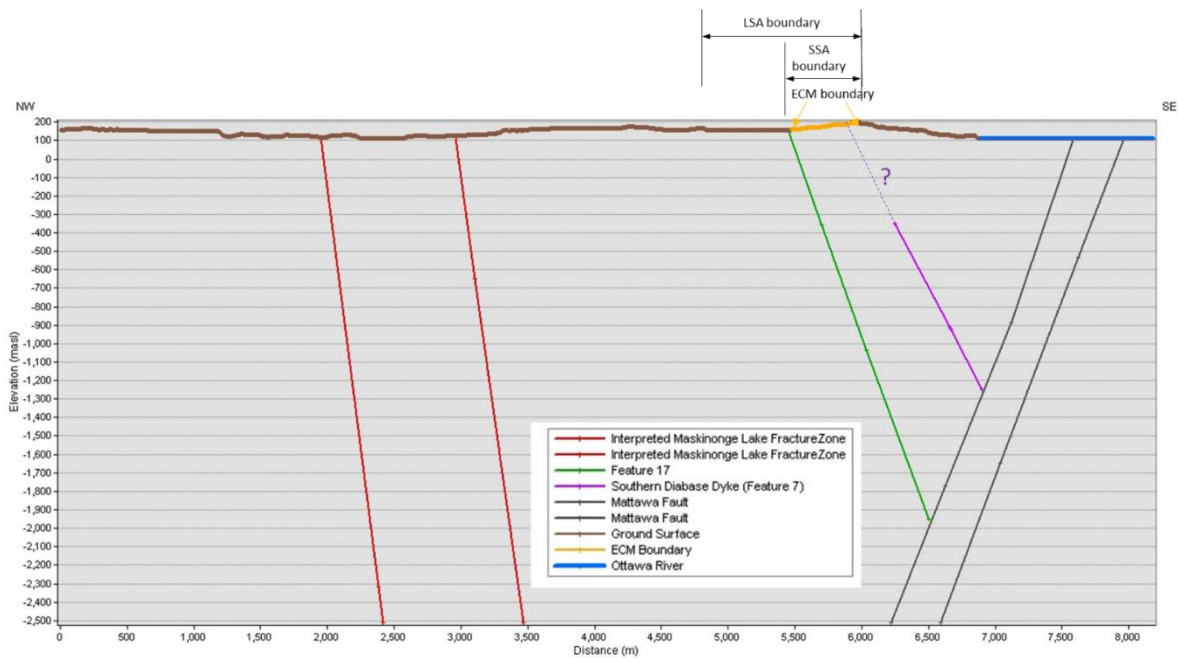
Note: NSDF SSA is shown as "NSDF Boundary" and LSA is shown as "Local Study Area".

**Figure 3-9 Fracture Zones at CRL site interpreted by STF and GWMF with Locations of NSDF SSA and LSA**





(a) Plan View of the Key Geological Features in the proximity of the NSDF SSA



(b) Cross-section of the key geological features in the proximity of the NSDF SSA.

Note: Feature # 7 was terminated at -350 masl (i.e., ~550 mbgs) based on the borehole observation.

**Figure 3-10 Geological Features in the Proximity of the NSDF SSA**



Note: Only S1, S2 and S3 are currently operating, as of 2020.

**Figure 3-11 Microseismic Monitoring Stations at CRL site [3-56]**

### 3.1.4.6 Surficial Geology

The bedrock outcrops at the surface as well as large areas are overlain by four basic types of glacial and post-glacial sediments (the overburden or Quaternary-age deposits): till, water deposited sands, wind deposited sands, and organic (mainly peat) deposits [3-12].

To date, a total of 108 explorations have been performed across the NSDF site to characterize the surface conditions and the subsurface soil and rock. In general, the explorations encountered the following subsurface profile across the site (from highest to lowest): surficial materials, sand deposits, granular till soils, and bedrock [3-12]. Measurements from across the site indicate the depth to bedrock ranges from 0 m to 11.4 m [3-12].

#### Surface Materials

Topsoil surficial materials were encountered as a majority of the borings advanced across the project limits. The remainder of the borings encountered native sandy soils or bedrock at the ground surface. The topsoil was typically described as organic silt or sandy silt material, and was generally observed to be a mixture of organic and mineral soil components; none were purely organic [3-12]. Thickness of the topsoil materials was found to vary from 0.025 m to 0.600 m, with an average thickness near 0.130 m [3-12].

#### Sand Deposits

A granular deposit generally described as dark brown to brown, poorly-graded fine sand (SP) to silty sand (SM), was encountered directly below surficial materials or at the ground surface in a majority of the borings. Note that SP and SM are group symbols from Modified Unified Classification System for Soils. The sand was generally underlain by granular till materials, except for the locations where the sand layer extends directly to the top of the rock. This layer is likely of fluvial and aeolian origin due to the lack of large gravel, cobbles, and boulders within the soil matrix. Trace amounts of organics (mostly in the uppermost samples) and varying amounts of gravel were noted in some of the representative samples. The sand deposit was first encountered at the ground surface and extended to a maximum depth of 6 mbgs [3-12]. Thickness of the layer generally

varied from less than 1 m to 6 m with an average near 2 m [3-12]. Measurements indicate a medium-dense average condition. In some cases, elevated measurement results may have indicated a large gravel or cobble zone within the layer. Moisture content results in the sand deposit ranged from 2% to 65% with an average near 14% [3-12].

#### Granular Till

Underlying the sand deposits and overlying bedrock, a granular soil deposit was encountered in a majority of the exploration locations. Glacial till consisted of well-graded boulders, cobbles, and gravel sized particles in a matrix of silty sand to sandy silt [3-12]. Moisture contents throughout this layer ranged from 1% to 24% with an average near 10% [3-12]. Thickness of the till was found to vary from less than 0.3 m to 29.2 m thick [3-12]. Thicker regions of the till were encountered in the northeastern portion of the site [3-12].

#### Bedrock

Bedrock on the CRL site consists predominantly of highly metamorphosed gneisses of the Precambrian Grenville province [3-9]. Topography on the CRL site (Figure 3-12) has a pronounced northwest-southeast lineation character, the combined result of faulting in the bedrock associated with the major tectonic feature of the region – the Ottawa-Bonnechere Graben or rift valley – and with fluvial erosion and sediment deposition arising from high flow stages of the Ottawa River in early post-glacial time. The ridges that form the western and eastern boundaries of the Lower Perch Lake Basin are bedrock-controlled, with localized bedrock outcrop, but also frequently feature a thin cover of glacial till and/or fluvial and Aeolian sand. Superimposed on the regional bedrock topography, exposed bedrock surfaces are frequently very irregular, with local relief of several meters over lateral distances of a few to a few tens of meters. Subsurface investigations show that this knobby character is a common feature of buried bedrock surfaces across the CRL site.

The bedrock contours of the NSDF site (see Figure 3-13) indicate that the buried bedrock surface generally mimics the surface topography and forms a bench along the southwest side of the ridge that defines the eastern limit of the NSDF site. In this area, bedrock occurs at depths of 0.5 m to 4.5 m. Field investigations across the CRL site, and within the proposed NSDF study area, have found that the degree of fracturing and fracture interconnections possess substantial spatial variability. Hydraulic conductivities in the bedrock, which are entirely controlled by the fracture network, are consequently also highly variable in both magnitude and in spatial distribution ([3-29] and [3-19]).

Representative rock cores collected during the exploration activities were generally described as quartzfeldspathic gneiss or gneiss, diorite, schist, and mafic intrusive bedrock. The Rock Quality Designation (RQD) varied between 10% and 100%, indicating a very poor to excellent rock quality. Bedrock was generally encountered beneath the glacial till materials and sand deposits at depths varying from less than 1 mbgs to more than 30 mbgs.

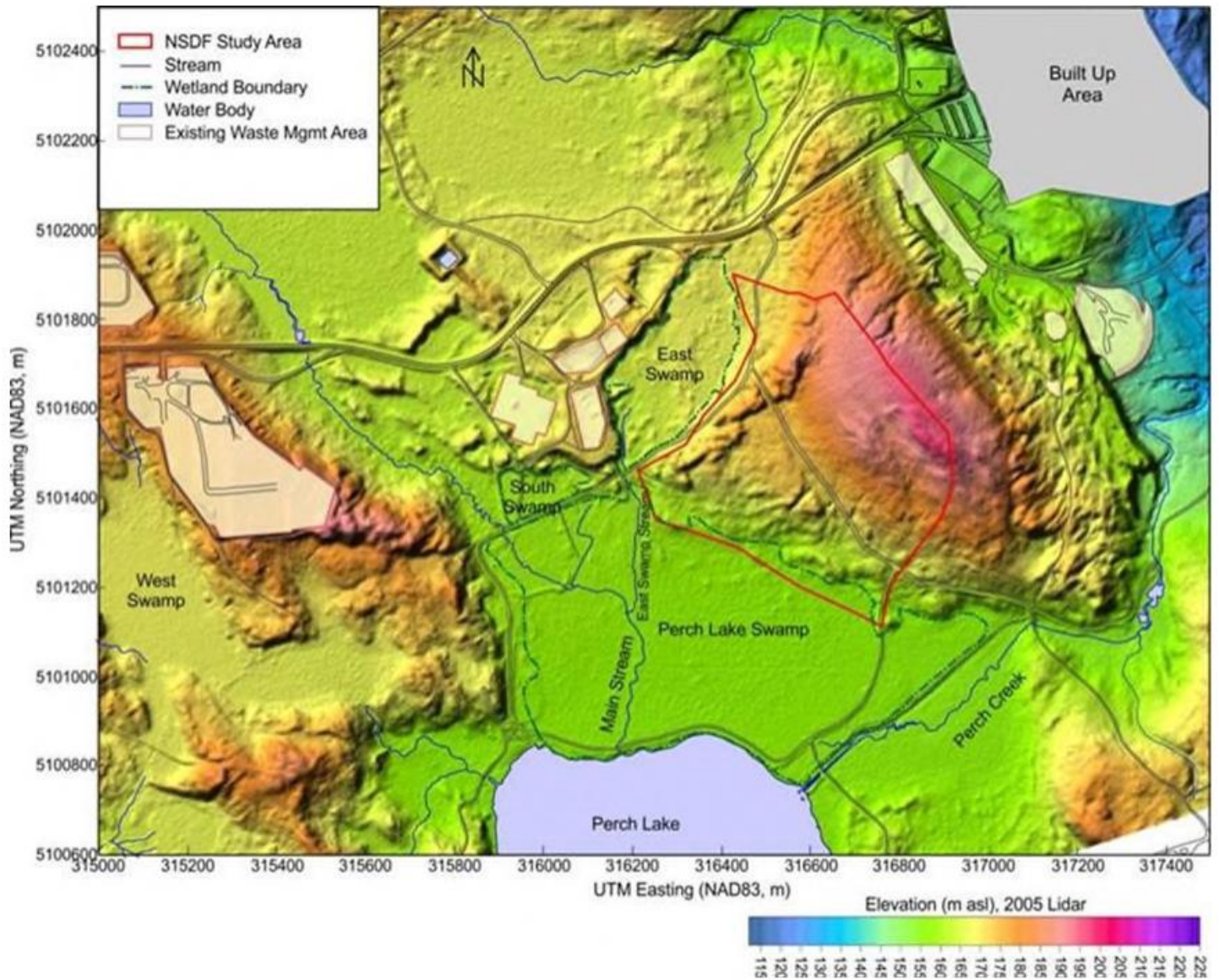


Figure 3-12 Perch Lake Basin Surface Elevation



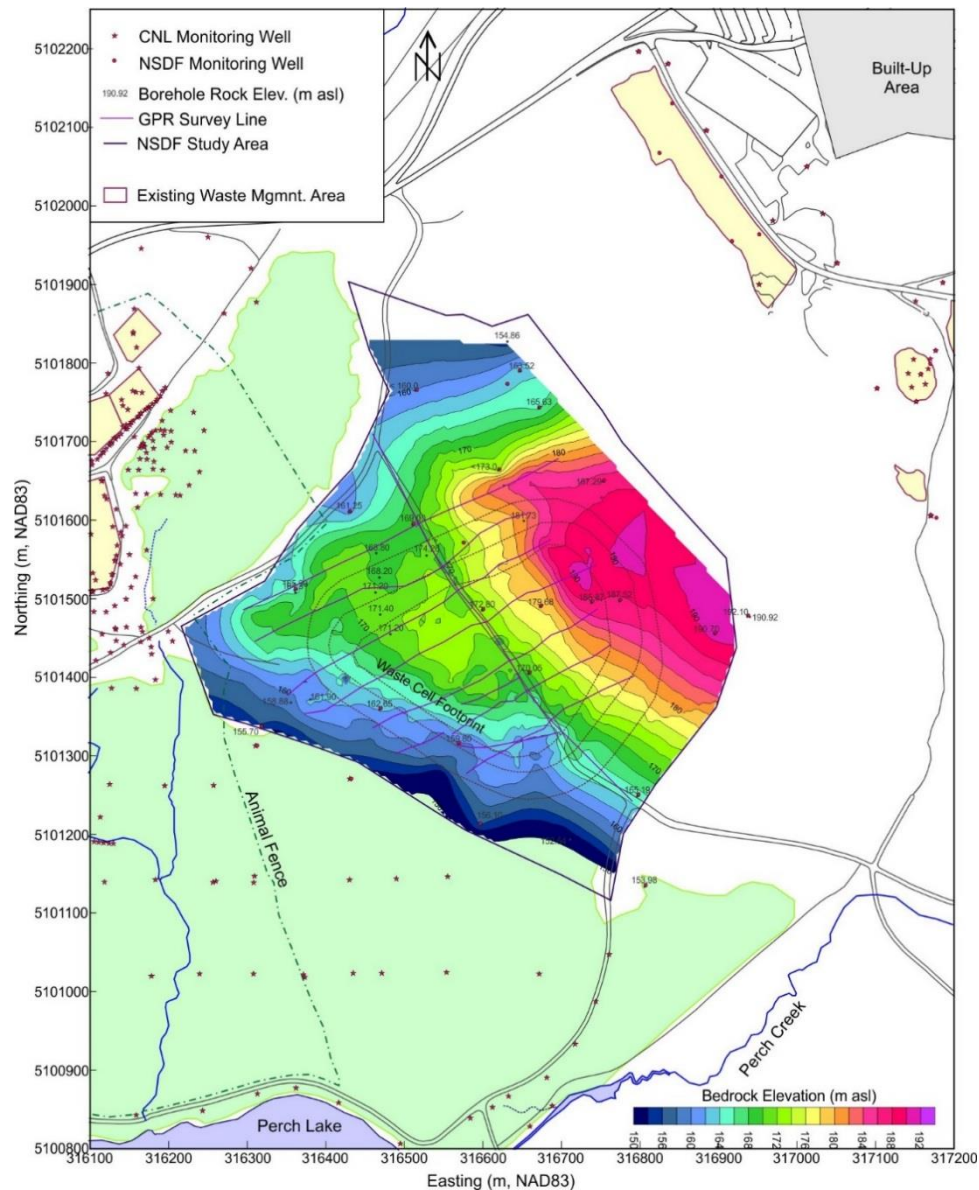


**Figure 3-13 NSDF Study Area Bedrock Topography**

### 3.1.5 Surface Hydrology

Chalk River Laboratories site and the surrounding area are within the Ottawa River watershed. Ottawa River flow rates have been measured approximately 30 km upstream of CRL at the Des Joachims Generating Station. The measured flow in the Ottawa River is summarized in the following points [3-10]:

- The highest flow rate on record is 400 million cubic metres per day ( $\text{m}^3/\text{d}$ ), occurring on 1970 May 8.
- The lowest flow rate on record is 7.9 million  $\text{m}^3/\text{d}$  (91  $\text{m}^3/\text{s}$ ), occurring on 1955 October 9.
- Average flows in the river range between 50 million and 100 million  $\text{m}^3/\text{d}$ .

The water level in the Ottawa River along the CRL property boundary is controlled by a set of rapids at Cotnam Island, located approximately 40 km downstream, and by adjustments to the discharge rate at the

Des Joachims hydroelectric dam, approximately 30 km upstream of the CRL property boundary on the Ottawa River. The mean monthly Ottawa River water levels measured at Pembroke Monitoring Station (36 km downstream of CRL), have ranged from 110.8 mASL in 2005 August to 113.1 mASL in 1960 May. The average water elevation recorded at this station is 111.5 mASL.

The Design Basis Flood level for the CRL site, for both precipitation events and for complex events involving random (or seismically related), failure of both the upstream dams (and of the control works at the exit from Lake Temiskaming), is 122 mASL, which includes a margin of 2 m [3-7].

Several waterbodies exist within the CRL site, and the on-site waterbodies and drainage basins are shown in Figure 3-14. The NSDF site is located within the Perch Lake basin. The Perch Lake Basin includes the Perch Creek catchment, and drains 15% of the CRL site. The wetland immediately to the west of the NSDF site is called East Swamp, which is connected to Perch Lake via East Swamp Stream and Main Stream. Perch Lake Swamp is located between the NSDF and Perch Lake. These wetlands are predominantly forested swamps, which contain small, wetter areas where in some locations shallow open water is present. The wetlands have been impacted by strontium and tritium plumes, emanating from legacy waste management operations.

Table 3-4 provides the annual average flows at Perch Lake Outlet and the Perch Creek Weir [3-58]. Table 3-5 lists the quantities of water entering the segment of Perch Creek between the lake outlet and the weir from the north and south side of the creek, and the total, which is  $3.32\text{E}+05 \text{ m}^3/\text{y}$ .

**Table 3-4**  
**Annual Average Flows at Perch Lake Outlet and the Perch Creek Weir [3-58]**

| Location          | Measurement Period |      | Annual Flow<br>( $\text{m}^3/\text{y}$ ) |
|-------------------|--------------------|------|------------------------------------------|
|                   | From               | To   |                                          |
| Perch Lake Outlet | 1966               | 1988 | 1.70E+06                                 |
| Perch Creek Weir  | 1992               | 2016 | 2.04E+06                                 |
| Difference:       |                    |      | 3.40E+05                                 |

**Table 3-5**  
**Perch Lake Basin Catchment Areas and Annual Average Volumes of Recharge/Runoff from Precipitation [3-58]**

| Catchment Area                                   | Area ( $\text{m}^2$ ) | Recharge/Runoff ( $\text{m}^3/\text{year}$ ) |
|--------------------------------------------------|-----------------------|----------------------------------------------|
| Perch Creek Upstream Segment Catchment, North    | 558 900               | 2.01E+05                                     |
| Perch Creek Upstream Segment Catchment, South    | 362 400               | 1.30E+05                                     |
| Perch Creek Upstream Segment Catchment, Total    | 921 300               | 3.32E+05                                     |
| Perch Creek Downstream Segment Catchment, Total  | 497 100               | 1.79E+05                                     |
| Perch Creek Total Catchment                      | 1 418 400             | 5.11E+05                                     |
| Total Discharge from Perch Creek to Ottawa River | NA                    | 2.21E+06                                     |

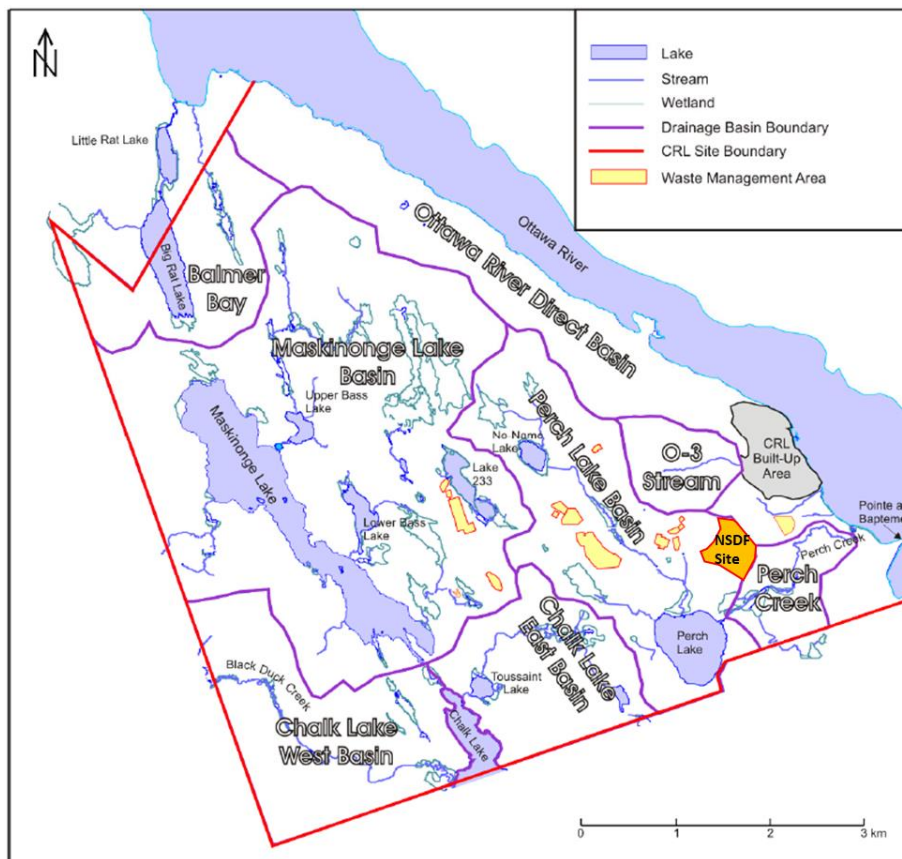


**Figure 3-14 Chalk River Laboratories Drainage Basins**

### 3.1.6 Hydrogeology

Groundwater flow primarily occurs through the sandy overburden units (the Upper Sand, Middle Sand, and Basal Sand/Till), whereas the bedrock is considered to be of low transmissivity. Groundwater flow patterns generally follow topography, with recharge occurring in the upland areas and with the ultimate discharge location at Perch Lake or Perch Creek [3-19]. Within the northern area of the NSDF Project site (north of a power line cut which runs along Power Line Road as indicated on Figure 3-5), groundwater flow is generally to the northwest towards East Swamp [3-19]. In this area hydraulic gradients are low, and minor variations in groundwater elevations can result in a component of groundwater flow towards the northeast for the northernmost portion of the NSDF study area. The PH-series of monitoring wells were installed for an NSDF-specific campaign to confirm groundwater depths in the ECM footprint. Based on transducer records from the PH-series monitoring wells, these reversals in groundwater flow direction are sustained for a period of less than a month [3-19]. For the area of the NSDF Project site south of the Powerline Cut (which includes the ECM), groundwater flow is generally to the southwest and south towards the Perch Lake Swamp and Perch Creek [3-19]. Within the southern portion of the Perch Lake Basin, groundwater flow is generally towards Perch Lake to the south with a component of flow to the southeast towards Perch Creek [3-19].

The bedrock ridges and topographic highs at the eastern and western boundaries of the Perch Lake Basin act as groundwater (and surface water) divides. The shallow groundwater flow system is expected to be recharged through precipitation at these topographic highs. Groundwater discharge generally occurs at the

surface water features within the low-lying portions of the Perch Lake Basin. Groundwater springs are observed in the East Swamp stream to the north of Powerline Road and in Perch Creek, downstream of the Perch Lake Outlet Weir. Based on stream gauge data, groundwater discharge to the East Swamp stream to the north of Powerline Road was observed to range from 25 m<sup>3</sup>/day to 770 m<sup>3</sup>/day during low-flow periods [3-19]. Groundwater discharge to Perch Creek during low-flow periods (i.e., September, when run-off is minimized and flows in the streams are dominated by groundwater discharge), is estimated to be approximately 790 m<sup>3</sup>/day, based on the difference in average flow measurements between the Perch Lake Outlet Weir and the Perch Creek Weir [3-19].

The water table elevation within the NSDF Project site, and throughout the lower Perch Lake Basin is shown on Figure 3-15. There is up to 2 to 3 m variability in seasonal and long-term annual water table elevations in unconsolidated sediments (sand and till) [3-19]. The variability in water table elevation in bedrock is up to several meters in places due to much lower porosity of the bedrock. However, once the ECM final cover is in place, infiltration will be significantly reduced and the variability in water table elevations will be significantly reduced [3-19].

The thickness of the unsaturated zone in the footprint of the proposed NSDF facility range are shown in Figure 3-16. The total thickness of the overburden is generally lowest on the eastern bedrock ridge in the vicinity of the NSDF Project site. The thickness of these sediments increases to the west and is highest in the bedrock valley, reaching over 36 m in the bedrock below [3-19]. Within the area of the NSDF Project site, unconsolidated deposits are locally thicker in the area to the north and east, reaching over 26 m thick at the northern terminus of the bedrock ridge [3-19].

In large part, the unsaturated zone thickness in the upland portions of the study area is controlled by the thickness of the sands and till that overlie the bedrock. In the southwest portion of the study area footprint the water table is controlled by the water level in the Perch Lake Swamp. Measurements of hydraulic heads for the region to the west and south of the proposed NSDF footprint have been collected as part of evaluations and monitoring of the groundwater flow system affected by existing WMAs since the 1960s. For monitoring wells located in the wetland, seasonal variations in hydraulic heads and water table elevations have typically been on the order of 1 m, with ranges of up to 2 m in recharge areas and smaller variations in portions of the flow system adjacent to or below wetlands, where surface water levels are the primary control on subsurface heads.

The hydraulic conductivities of the geological materials at the NSDF Project site are presented in Table 3-6.





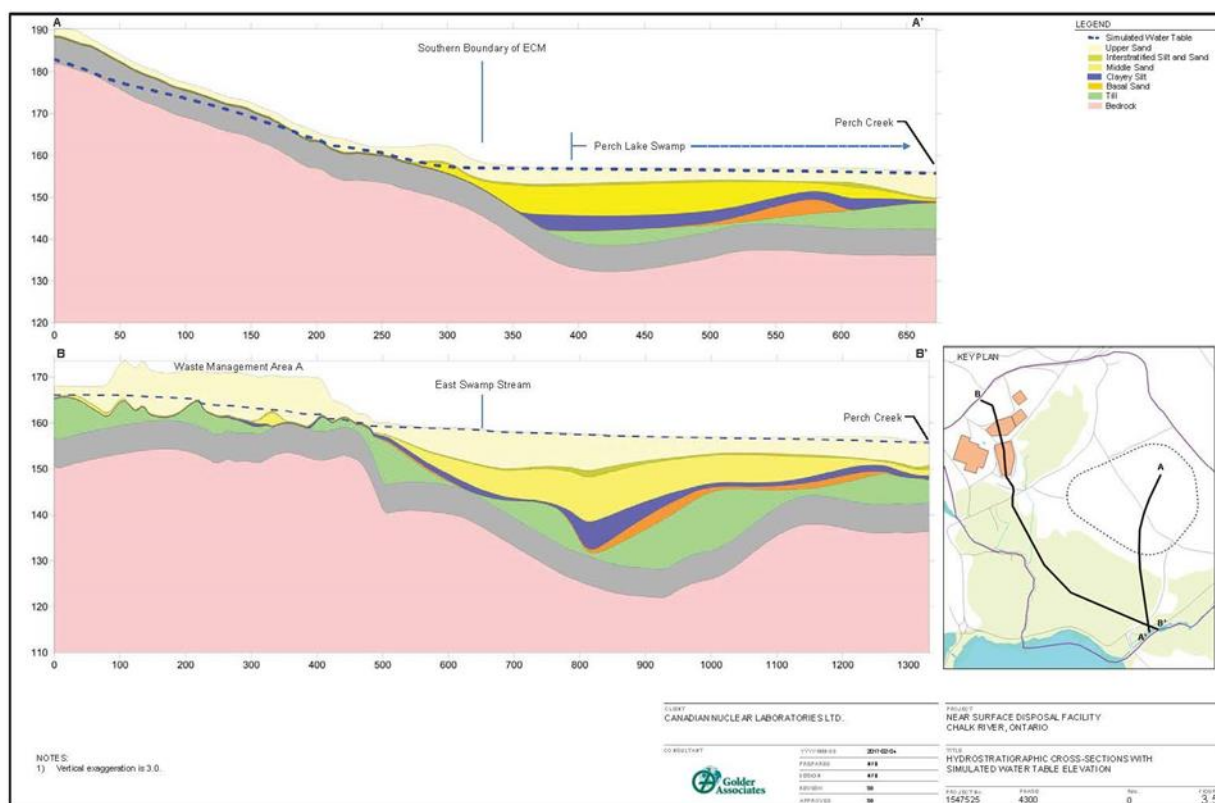


**Figure 3-16 Hydrostratigraphic Cross Sections from the NSDF site to Perch Creek [3-19]**

**Table 3-6**  
**Hydraulic Conductivity of NSDF Geological Materials [3-19]**

| Material                      | Hydraulic Conductivity (m/s) |          | Kh:Kv | Porosity |           |
|-------------------------------|------------------------------|----------|-------|----------|-----------|
|                               | Horizontal                   | Vertical |       | Total    | Effective |
| Upper Sand (Zone 1)           | 1.0E-04                      | 3.0E-05  | 3.3   | 0.38     | 0.3       |
| Upper Sand (Zone 2)           | 1.7E-4                       | 5.0E-5   | 3     | 0.38     | 0.3       |
| Upper Sand (Zone 3)           | 3.0E-5                       | 1.0E-5   | 3.4   | 0.38     | 0.3       |
| Interstratified Sand and Silt | 6.0E-05                      | 6.0E-07  | 100   | 0.39     | 0.3       |
| Middle Sand                   | 1.0E-04                      | 2.0E-05  | 5.0   | 0.38     | 0.3       |
| Clayey Silt                   | 9.5E-07                      | 5.5E-09  | 173   | 0.48     | 0.3       |
| Basal Sands                   | 1.2E-04                      | 1.0E-04  | 1.2   | 0.38     | 0.3       |
| Till                          | 9.0E-07                      | 7.0E-07  | 1.3   | 0.26     | 0.2       |
| Upper Bedrock                 | 9.0E-07                      | 9.0E-07  | 1     | 0.001    | 0.001     |
| Lower Bedrock                 | 4.0E-08                      | 4.0E-08  | 1     | 0.001    | 0.001     |

### 3.1.7 Seismicity

The CNL site is located in the Ottawa-Bonnechere Graben geologic feature and adjacent to the Western Quebec Seismic Zone. This region of the country has continued to experience minor to moderate seismic activity and within this zone, several earthquakes were documented. These include earthquakes: in 1732 near Montreal with an estimated Richter magnitude of 5.8; in 1935 in the vicinity of Temiskaming with an estimated Richter magnitude of 6.2; in 1944 located south of Cornwall with a Richter magnitude of 5.8; in

2010 near Val-des-Bois, Quebec, with a Richter magnitude of 5.0; and in 2013 near Ladysmith, Quebec with a Richter magnitude of 4.6 [3-60] and [3-59]. Most recently, an earthquake with a magnitude of 3.7 on the Richter Scale occurred on 2015 October 15, approximately 40 km from the NSDF Project site, and an earthquake with a magnitude of 3.5 occurred on 2016 May 4, approximately 10 km from the NSDF Project site, 6 km north of Petawawa, Ontario.

Canadian Nuclear Laboratories has conservatively chosen a 1 in 10 000 year earthquake as the DBE for the ECM. The 1 in 10 000 year earthquake is derived from the CSA N289.1 [3-106] standard, and this earthquake frequency is applied to the design of a nuclear power plant as the DBE. The adoption of this earthquake frequency as the DBE is considered conservative based on:

- The radioactive material inventory in the ECM is significantly less than the radioactive inventory of a nuclear power plant.
- The consequence of exceeding the DBE at the NSDF site during the 550 year design life is much less than the consequence of exceeding a DBE at an operating power reactor, if the safety and containment systems do not mitigate the event as designed.
- The DBE is commensurate with the design life time and the risk associated with the ECM.

The DBE for the ECM, is associated with the 5.4% probability of exceedance in 550 years (an event with a return period of 10 000 years), as defined by CSA Standard N289.1-08 [3-106] used for the seismic design of the ECM. The DBE for the ECM was developed in the Probabilistic Seismic Hazard Analysis (PSHA) Report [3-50], and Table 3-7 provides the results of the horizontal Uniform Hazard Response Spectrum (UHRS) on hard rock computed for the 2 500 year, 10 000 year, and 100 000 year return periods [3-50].

The ECM is designed to the DBE with a return rate of 10 000 years. The ECM and the other NSDF structures are designed to the Operating Basis Earthquake (OBE) with a return rate of 2 500 years.

**Table 3-7**  
**PSHA Results for the ECM Design [3-50]**

| <b>Annual Frequency of Exceedance (AFE)</b> | <b><math>4 \times 10^{-4}</math></b>  | <b><math>10^{-4}</math></b> | <b><math>10^{-5}</math></b> |
|---------------------------------------------|---------------------------------------|-----------------------------|-----------------------------|
| <b>Return Period (years):</b>               | <b>2 500</b>                          | <b>10 000</b>               | <b>100 000</b>              |
| <b>Period (sec)</b>                         | <b>Spectral Acceleration (SA) (g)</b> |                             |                             |
| 0.01 (PGA)                                  | 0.25                                  | 0.55                        | 1.48                        |
| 0.04                                        | 0.51                                  | 1.14                        | 3.09                        |
| 0.10                                        | 0.41                                  | 0.88                        | 2.33                        |
| 0.20                                        | 0.27                                  | 0.56                        | 1.52                        |
| 0.40                                        | 0.15                                  | 0.31                        | 0.88                        |
| 1.00                                        | 0.069                                 | 0.14                        | 0.42                        |
| 2.00                                        | 0.039                                 | 0.082                       | 0.26                        |

AFE – Annual Frequency of Exceedance; PGA – Peak Ground Acceleration; SA- Spectral Acceleration

### 3.1.8 Ecology

The CRL site is primarily forested. Forests are mixed wood and deciduous, dominated by poplar species such as aspen, red maple, with stands of eastern white pine and spruce species. Several small lakes and streams exist on the CRL site, which make up 7% of the total area. Wetlands are also common, and account for 14% of the CRL site area.

The NSDF site consists primarily of second-growth, mature, mixed forest, dominated by poplar species, red oak, eastern white pine, and spruce species (71% of the NSDF site area). There are two areas of immature coniferous forest stands comprising 12% of the NSDF site area: one is a tree research plantation containing 100% Norway spruce, and the other is a portion of a stand of spruce, balsam fir and larch species. The spruce research plantation is within the western portion of the NSDF site area, and is no longer needed for research purposes.

There are no wetlands, flooded areas, or aquatic habitat features within the NSDF site. The area surrounding the NSDF site includes a mix of forested vegetation communities and wetlands, as well as Perch Lake and Perch Creek. Wetlands surrounding the NSDF site provide habitat for bat foraging and maternity roosting (mature treed swamps), and turtle hibernation, mating, foraging, thermoregulation, staging prior to nesting and for movement.

Part of CNL's environmental impact review involves considering the potential NSDF Project impacts on a sub-set of environmental components that have been identified as sensitive and important to the public, Indigenous people and scientific communities. From these environmental components, a further sub-set of environmental values, known as VCs has been identified [3-29]. The selection of VCs represents elements of the environment that are considered to have economic, social, biological, conservation, aesthetic, and/or ethical value, and are likely to be affected by the NSDF Project [3-29].

## 3.2 Facility Design and Engineering

The NSDF is located within a Controlled Area and is designed for a 50 year operating life, and a 550 year design life. The NSDF has four main design elements, and the location of these design elements is depicted in Figure 3-17:

- ECM for the disposal of 1 000 000 m<sup>3</sup> of LLW.
- WWTP for the treatment of wastewater.
- Support facilities providing services related to the operation.
- Site infrastructure supporting the Facility operation.

Table 3-8 lists the SSCs of the four main design elements. Table 3-9 provides a summary of the NSDF support facilities and Table 3-10 provides a summary of the site infrastructure structures. For the building structures, the design basis criteria are based on NBCC 2015 [3-51] having a DBE with a rate of return of 2 475 years [3-60]. All building structures including the WWTP, VDF, and other support buildings, are expected to remain functional or seismically qualified when undergoing a seismic event with a rate of return of 2 475 years [3-60].

The safety objectives and long-term safety requirements described in Section 1.3, will be achieved by the use of multiple barriers providing defence in depth. Safety features and controls are provided in the NSDF design to prevent and eliminate hazardous conditions that would otherwise fail to protect facility personnel, on-site workers, members of the public, and the environment. Safety SSCs are relied upon to prevent accidents at the Facility or to mitigate their potential consequences, thereby, achieving one or more safety features. This is

achieved through passive engineered safety features, active engineered safety features and administrative controls.

Passive engineered safety features, such as primary containment and secondary containment that are assessed to survive accident conditions, are engineered features that use fixed physical design to maintain safe conditions without any need for external input such as actuation, mechanical movement or supply of power. The ECM passive safety features are discussed in Section 3.2.1.1.

Active engineered safety features (e.g., High Efficiency Particulate Air (HEPA)) filtered active exhaust ventilation system), that mitigate the consequences of an accident, are required to retain their functionality with sufficient redundancy during and after an accident. An active engineered feature, involves a physical mechanism that uses active electrical components, mechanical movement or supply of power to maintain safe conditions.

The main active engineered safety features include radiation monitoring, Active Ventilation Systems (AVSs), Leachate Collection System (LCS), Leak Detection System (LDS), and effluent monitoring at the WWTP. Radiation monitoring at the NSDF includes air monitoring of dust, Volatile Organic Compounds, and radioactivity on the NSDF site, as well as at fixed points along the NSDF perimeter. The NSDF active safety features are described in Section 3.2.1.1 (ECM), Section 3.2.2.1 (WWTP), and Section 3.2.3 (site infrastructure and support facilities).

Detailed information on the Facility design is available in the Design Description [3-61] and NSDF Safety Analysis Report [3-62]. Detailed information on the Facility safety features and systems important to safety, is available in the NSDF Safety Analysis Report [3-62].



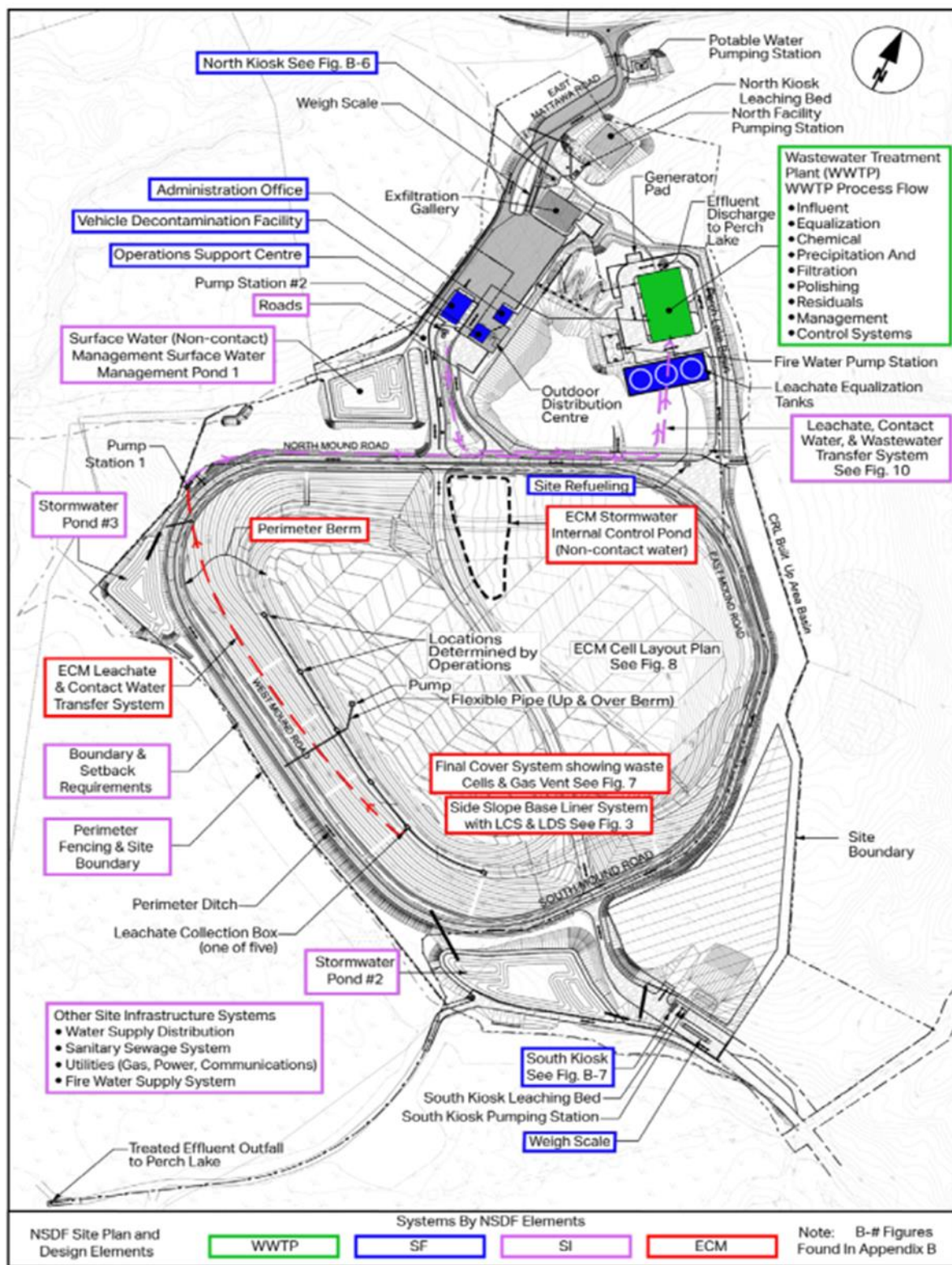


Figure 3-17 Near Surface Disposal Facility and Design Element Locations

**Table 3-8**  
**Main NSDF Design Elements and Structures, Systems and Components**

| <b>Engineered Containment Mound</b>                                                                                                                                                                                                                                                                                                                                                                    | <b>Waste Water Treatment Plant</b>                                                                                                                                                                                                                                                                                                                                         |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Disposal cells.<br>Base liner system: Primary liner and LCS, and Secondary liner and LDS.<br>Perimeter berm.<br>Temporary Storage Waste Receiving and Processing Area.<br>Leachate transfer system.<br>Contact water collection, transfer and conveyance system.<br>Non-Contact water collection, transfer and conveyance system.<br>Daily and interim cover.<br>Final cover.<br>Landfill gas venting. | Influent flow equalization (Equalization tanks).<br>Chemical precipitation.<br>Membrane filtration.<br>pH adjustment.<br>Polishing treatment system – granular activated Carbon and Ion Exchange (IX) resins.<br>Final effluent storage and sampling.<br>Residuals management.<br>Chemical storage and metering.<br>Process control systems.<br>Effluent discharge system. |
| <b>Support Facilities (SF)</b>                                                                                                                                                                                                                                                                                                                                                                         | <b>Site Infrastructures (SI)</b>                                                                                                                                                                                                                                                                                                                                           |
| Vehicle Decontamination Facility (VDF).<br>Operations Support Centre.<br>Administration Office.<br>North and South Kiosks.<br>Weigh Scales.<br>Site Vehicle Refueling Station.                                                                                                                                                                                                                         | Potable Water Pump Station.<br>Fire Water Pump Station.<br>Perimeter Fence.<br>Roads.<br>Surface Water Management Ponds.<br>Aggregate stockpile/laydown area.<br>Power distribution building.<br>Sanitary Sewage Disposal Systems.                                                                                                                                         |

**Table 3-9**  
**NSDF Support Facilities Summary**

| <b>Support Facility</b>          | <b>Description/Function</b>                                                                                                                                                                                                                                                   |
|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Vehicle Decontamination Facility | The VDF is a pre-engineered building with equipment for vehicle/equipment decontamination and vehicle maintenance activities. The VDF building area is approximately 484 m <sup>2</sup> and the building dimensions are approximately 18 m width, 28 m length and 7 m height. |
| Administration Office            | The Administration Office is a 15.36 m x 12.53 m prefabricated building that provides space for site administration staff that are responsible for the day-to-day operations of the site.                                                                                     |
| Operations Support Centre (OSC)  | The OSC building provides decontamination facilities and shower facilities for the workers. The OSC building area is approximately 200 m <sup>2</sup> , and the building dimensions are approximately 14 m width, 14 m length and 3.7 m height.                               |
| North and South Kiosks           | The NSDF site has two entrance kiosks, north and south.                                                                                                                                                                                                                       |
| Weigh Scales                     | Vehicle weigh scales are located at the NSDF site entrances, adjacent to the kiosks. The scales weigh incoming waste shipments.                                                                                                                                               |
| Site Vehicle Refuelling Station  | Located on North Mound road at the WWTP Access Road, the site vehicle refueling station stores bulk diesel in an above ground tank for use in ECM heavy equipment.                                                                                                            |

|  |                                                                                                                                                                                               |
|--|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|  | The refuelling station has an automated fueling pump capable of metering fuel and logging volume transferred. The above ground double walled fuel tank is 4 500 L and complies with ULC-S643. |
|--|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

**Table 3-10**  
**NSDF Site Infrastructure Summary**

| <b>Site Infrastructure</b>        | <b>Description/Function</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Potable Water Pump Station (PWPS) | The PWPS building area located to the north of the North Kiosk is approximately 77 m <sup>2</sup> , and the building dimensions are approximately 7.2 m width, 10.7 m length and 6.7 m height. Potable water is required within the WWTP, VDF and other support buildings for various uses, which include but are not limited to; showers, toilets, eyewash stations, faucets, floor/equipment wash down, and VDF wash water reclaim system makeup. All of the buildings and facilities are provided with potable water service; with exception to the south kiosk which will be serviced by a stand-alone potable water storage tank.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Fire water pump station (FWPS)    | <p>The FWPS building is located near the south-west corner of the WWTP. The FWPS building area is approximately 21.3 m<sup>2</sup> and the dimensions are approximately 3.7 m width, 5.8 m length and 3.2 m height. The FWPS is ventilated, heated, and located on top of the fire water storage tanks.</p> <p>The fire water storage system consists of two independent cast-in-place buried concrete tanks. The fire water storage tanks have a working volume of 403 m<sup>3</sup>, an access hatch, fill connection, combination vent/visual level gauge, and level instruments for monitoring purposes. The FWPS consists of two fire water pumps, two jockey pumps and their associated support systems.</p> <p>The fire water pump draws water from the fire water storage tank and fire water is sent to the NSDF site fire hydrant network, as needed. The pumps are sized to deliver 63.1 L/s at 896 kPa. The system includes an auto transfer switch that provides Class III back-up power in the case of Class IV power failure.</p> <p>The storage tank fill controllers (one per tank), provide level control and high/low level monitoring/alarms. Alarm signals from each controller are connected to the site wide fire alarm system, and each controller is connected to a make-water valve. When the water level drops to a predetermined level, the fill controllers open make-up water valves to add water into the storage tanks.</p> |
| Perimeter fencing                 | A 2.4 m high perimeter chain-link fence is provided, typically offset 1 m inside the NSDF boundary. A swing gate area is provided at secondary access points and automated gates are provided at primary access points. A supplemental 1 m high fabric is affixed to the exterior of the perimeter fencing in areas adjacent to existing wetlands to function as a barrier for turtle migration into the site. Tree clearing is to be conducted 4 m beyond the NSDF boundary. As such, a 5 m setback from NSDF above grade structures (i.e., buildings, trees, etc.) is achieved. The limits for site regrading account for the 30 m setback requirement from the adjacent wetland areas.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| Roads                             | <p>The NSDF site transportation network consists of primary and secondary access roads. The primary waste shipment access roadway is from the ER-3 Road/EMR intersection north- west to the NSDF site boundary. This road is comprised of a granular pavement structure. This roadway is to be utilized for waste shipments arriving to the NSDF site as well as transport vehicles leaving the NSDF site, providing that vehicle decontamination is not warranted.</p> <p>The second primary access route to the NSDF site is from Plant Road to the site boundary. This</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |



|                                       |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|---------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                       | <p>roadway is proposed to be comprised of an asphalt pavement structure from Plant Road to the site boundary, to minimize dust generation in the vicinity of Plant Road, the primary access roadway into the CRL campus. A right-turn/deceleration lane is proposed at the intersection with Plant Road to allow for slower moving vehicles to turn into the site without impeding eastbound traffic to the CRL campus. The second primary access roadway is utilized for occasional waste deliveries to the site, but is primarily dedicated for employee access to the Support Facility buildings, as well as material and equipment deliveries to the NSDF site. Secondary site access roadways generally consist of perimeter roads around the ECM as well as the WWTP. The road linking the ECM to the VDF (Decontamination Road), is an asphalt single lane granular pavement roadway and is utilized by waste shipment vehicles or equipment that require decontamination.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Surface Water Management Ponds (SWMP) | <p>The surface water management system is designed to control non-contact surface water (water that has not come into contact with waste placed in the ECM), including preventing surface water from uncontaminated areas discharging into contaminated areas.</p> <p>The SWMP design and surface waste management system: 1) mitigates erosion and intercept sediment during construction from transport into the receiving wetland area during wet weather events; 2) controls the quantity of surface water discharge from the NSDF site 3) provides quality treatment of surface water to meet the requirements of the Ontario Ministry of the Environment and Climate Change Stormwater Management Planning and Design Manual, 2003, settling suspended sediment ultimately protecting receiving watercourses/waterbodies; and 4) maximizes Total Suspended Solids removal efficiency at each SWMP location and to provide supplemental Total Suspended Solids removal as part of the open-channel (i.e., ditch and channel) non-contact water conveyance systems employed on the site to route non-contact surface water to the designated outlets.</p> <p>The surface water management system consists of four main elements, collection (i.e., site grading), conveyance (i.e., internal ditches, sewers, culverts and external flow diversion ditches), treatment (i.e., settling/detention ponds), and discharge (i.e., outlet sewers, emergency overland flow routes).</p> <p>Three SWMP are included in the ECM layout design for managing/treating non-contact water before discharging the water to adjacent wetlands. The design includes the contributing drainage ditches, culverts and related site grading which convey non-contact surface water to these facilities. The ponds are sized for an ultimate condition that includes handling non-contact run-off water draining from the ECM interim and final covers, roadways, buildings, parking lots, and clean cover/aggregate stockpile areas.</p> <p>SWMP 1 is located at the north end of the site and receives drainage from the WWTP, support facilities, parking lots and roadways; SWMP 2 is located at the south end of the site and receives drainage from stockpile areas to the east and the ECM cover to the north; and SWMP 3 is located at the west side of the site and receives drainage from the ECM cover to the east.</p> <p>Precipitation falling within the active cell that makes contact with the waste is considered contact water, and is conveyed to catchment areas within the active cell or an adjacent lined cell. Surface water collected within these catchment areas, is pumped to the leachate extraction boxes at the top of the berm and transferred to the WWTP. Precipitation falling in cells with final cover, completed with temporary sacrificial cover (interim cover), or inactive cells, is considered non-contact water, and is conveyed to the SWMPs.</p> <p>During normal operation the effluent flow from the three SWMPs is through a bottom draw, perforated pipe outlet. The outlet is connected to a dual-basin manhole structure which controls pond elevation, after which the effluent (2-year through 100-year flow) is conveyed</p> |

|                                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                  | <p>by gravity to a flow spreader (consisting of a concrete curb and rip-rap covered swale). The spreader distributes flow from the piped outlet to a natural overland flow path from the spreader to the downstream wetland.</p> <p>During periods of extreme flows (i.e., greater than the 100-year storm event with snowmelt, peak monthly rainfall and projected increases due to climate change considered), effluent discharges via a concrete weir structure, as part of the SWMP berm, and is further conveyed in a rap-rap lined channel to the site footprint limit where a natural overland flow path conveys flow to the adjacent wetland.</p>                                                                                                                                                                                                   |
| Aggregate Stockpile/Laydown Area | A stockpile area for daily cover and interim cover materials and aggregates, is located at the southeast end of the NSDF site adjacent to the South Kiosk.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| Power Distribution Building      | The Power Distribution Building is located on the east side of the OSC and houses power distribution equipment for the Facility.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Sanitary Sewage Disposal Systems | <p>The NSDF sanitary sewage system routes sewage to the primary Private Sewage Disposal System located at the north entrance, east of EMR. A second Private Sewage Disposal System is provided adjacent to the South Kiosk to support only the South Kiosk.</p> <p>The sanitary system utilizes a network of 200-mm-diameter PVC gravity sewers to convey septage from the VDF, the OSC, the Administration Office, the North Kiosk, and the WWTP to a Private Sewage Disposal System. The sanitary sewer discharges through a septic tank that discharges into a sanitary pump station, which lifts liquid effluent to the nearby septic tile field.</p> <p>Sewage discharges from the South Kiosk through a septic tank. Liquid effluent from the tank is pumped via a submersible pump within the septic tank to a septic tile field near the Kiosk.</p> |

### 3.2.1 Engineered Containment Mound

The ECM is a double-lined engineered containment, designed for the disposal of 1 million m<sup>3</sup> of LLW in 10 disposal cells that meet the NSDF WAC [3-63]. A multi-layer final cover system is installed over the placed waste upon completion of disposal operations in each cell. The volume of the airspace for the ECM is approximately 1.43 million m<sup>3</sup>. The total area of the ECM is approximately 17 hectares, including the perimeter berm. The ECM area without the perimeter berm, is approximately 12 hectares including the inner side slopes of the perimeter berm.

The ECM consists of a total of 10 individual, but contiguous disposal cells, designed to maintain structural integrity and containment of wastes over the 550 year design life. The disposal cells run parallel in rows, and are designed for a maximum height of 18 m including waste, fill material, and final cover. Waste thickness is approximately 15 m in the center of the disposal cell. The disposal cells are designed to hold the structural dead load and progressive weight of the waste and fill material, and live load from the waste placement equipment operations.

The ECM elevation ranges from approximately 163 metres above sea level (mASL) to 202 mASL, which correspond to the lowest elevation of the base liner system and highest elevation of the final cover system, respectively. Figure 3-18 shows a cross-section of the ECM and includes the elevation in mASL, and note that the figure is not to scale.



**Figure 3-18 Cross Section of the Engineered Containment Mound**

### 3.2.1.1 Engineered Containment Mound Safety Features and Systems Important to Safety

The ECM includes several SSCs listed in Table 3-8 and Table 3-11 that contribute to the safe and effective operation/performance of the ECM and protection of humans and the natural environment from the placed wastes. Passive engineered safety features associated with the ECM include the base liner system, perimeter berm, cover systems, and gas venting system. Active engineered safety features associated with the ECM base liner system that support the containment of waste and leachate during the operations period are the LCS and the LDS.

The ECM SSCs that are passive engineered safety features and systems important to safety during the operations period and long term safety in the post-closure phase are the base liner system (see Section 3.2.1.3), perimeter berm (see Section 3.2.1.4) and final cover (see Section 3.2.1.5) [3-62].

Table 3-11 summarizes the ECM active engineered safety features that are systems important to safety during the operations period [3-62].

**Table 3-11  
ECM Active Engineered Safety Features that are Systems Important to Safety**

| Active Engineered Safety Feature (SSCs)                                | Safety Function     | Basis for Selection/Justification                                                                                                                                                                                                                                                 |
|------------------------------------------------------------------------|---------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| LCS Sump High-High Level                                               | Monitor and Control | Monitoring of a passive engineered barrier (the ECM primary liner). Failure of the basic process control system could lead to undetected High-High level in a LCS sump, eventually leading to excessive liquid head on the ECM primary liner.                                     |
| LDS Sump High-High Level                                               | Monitor and Control | Monitoring of a passive engineered barrier (the ECM primary liner). Failure of the basic process control system could lead to undetected High-High level in a LDS sump, eventually leading to excessive liquid head on the ECM primary liner.                                     |
| Contact Water Pumping Station (CWPS) #1 Overflow Prevention Pumps Trip | Monitor and Control | Failure of the basic process control system could shut down all output pumps of CWPS #1 without the corresponding shutdown of all input pumps, leading to overflow of untreated wastewater to the environment.                                                                    |
| Contact Water Pumping Station #2 High-High Level Alarm                 | Monitor and control | Monitor availability of CWPS #2 to receive drainage from NSDF active drain systems. Failure of the basic process control system could shut down all output pumps of CWPS #2, along with loss of level monitoring of the CWPS #2 wet well. Without worker notification, this could |

|                                                                       |                     |                                                                                                                                                                                                                                                                                                                                                                   |
|-----------------------------------------------------------------------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                       |                     | subsequently lead to overflow of active drainage to the environment.                                                                                                                                                                                                                                                                                              |
| Secondary containment and LDS of double-walled structures and piping. | Containment         | Secondary containment provides containment in the event of a failure of the primary containment. The secondary containment provides containment to prevent a release to the environment in the event of primary containment failure (spill or leak). Alarms provide indication that liquid is collecting in the secondary containment.                            |
| Single walled Leachate Piping Transfer System                         | Containment         | Single wall, Stainless Steel (SS) piping, will only be installed where line leaks will be collected by the Equalization Tanks secondary containment or inside the WWTP.                                                                                                                                                                                           |
| Buried Leachate/Contact Water Pump/Piping Transfer System             | Containment         | All buried HDPE piping used to convey leachate/contact water are double-walled. Provides primary and secondary containment of leachate/contact water. Below grade pipes will be located below the frost line.                                                                                                                                                     |
|                                                                       | Monitor and Control | Low point leak detection ports will allow operators to conduct routine inspections of the annulus space between the two pipes. The presence of water in this space indicates a fault in the piping system.                                                                                                                                                        |
| Above Grade leachate/contact water Pump/Piping Transfer System        | Containment         | Provides primary and secondary containment of leachate/contact water. Above Grade piping used to convey leachate/contact water are HDPE double-walled and instrumented with low-point leak detection to inform operators of the presence of water in the annulus space (leak alarm).                                                                              |
| Heat Tracing on Leachate/contact water Pump/Piping Transfer System    | Monitor and Control | Heaters and insulation protect the structural integrity of the transfer lines/equipment by preventing water from freezing in the lines, potentially causing them to rupture (lines and equipment not installed below the frost line). Heat trace system monitors and control line temperatures above freezing (4°C). System alarms to notify operators of faults. |

### 3.2.1.2 Disposal Cells

Figure 3-19 shows the layout of the 10 disposal cells within the ECM. The disposal cells are filled in succession as numbered starting with disposal Cell #1 and ending with disposal Cell #10. As each cell is filled to capacity, the next cell is prepared to accept waste. The average disposal cell area is 12 000 m<sup>2</sup> and the largest active disposal cell area is 15 000 m<sup>2</sup>. There is an additional 6,000 m<sup>2</sup> adjacent to the active cells where waste is staged before disposal, and further discussed in Section 3.2.1.7.

The disposal cell development sequence provides for the progressive construction, infilling and closure of the individual cells. The initial disposal cells of Phase 1, with total waste capacity of 525 000 m<sup>3</sup>, accommodate waste now in storage in addition to other waste to be generated over the initial 20 to 25 year period. Subsequent disposal cells of Phase 2, with a total waste capacity of 475 000 m<sup>3</sup>, expand the ECM to a total waste capacity of 1 000 000 m<sup>3</sup>.

The disposal cells are oriented so that the ridges in the herringbone/shaped grading pattern can be used to contain storm water (contact or non-contact water), and convey the water to catchment areas (contact water

conveyed to sumps; non-contact water conveyed to a temporary clean stormwater catchment area, located within each cell) for removal from the ECM.



**Figure 3-19 Engineered Containment Mound Disposal Cell Layout**

### **3.2.1.3 Base Liner System**

The base liner system provides containment, isolation and retardation of the ECM waste and leachate. The base liner system includes the primary liner and the secondary liner. The secondary liner provides redundancy in the event of primary liner failure, and includes a combination of natural earthen materials and geosynthetic barrier systems.

The primary function of the base liner system is to provide containment of the waste and leachate generated during and following operation of the ECM, to minimize the potential for impacting groundwater from a release of leachate from the ECM. The primary liner system component of the base liner system is designed to contain the waste, to retain leachate generated in the ECM, and to provide a barrier system to limit leakage of leachate to the underlying components of the base liner system. The secondary liner system is designed to contain leakage that may occur through the primary liner and to minimize the potential for leachate contamination beneath the ECM. Control of contaminant migration from the ECM (retardation), is provided by the base liner system GCLs and the CCL, without any reliance on the underlying native soils and soil fill materials. The GCL's low hydraulic conductivity retards the flow of leachate that leaked passed the primary or secondary liner into the next sub-layer of the base liner system. The CCL's low hydraulic conductivity retards the flow of leachate into the geosphere.



The top elevation of the subgrade (which is the same as the starting elevation of the CCL) is set 0.25 metres above the elevation of the seasonal high water table. This separation is for constructability; to reduce the likelihood of groundwater issues during the construction of the subgrade and of the CCL. This separation is not credited for contaminant attenuation purposes.

The base liner system has a total thickness of 2.05 m and is shown in Figure 3-20. Table 3-12 lists base liner system barriers and components, from top to bottom and provides the description and function of each layer.

The base liner system materials were selected based on their compatibility with the predicted leachate characteristics in the ECM arising from the WAC, and required design service life. The “Base Liner and Leachate Compatibility Evaluation” [3-64], includes an evaluation of the compatibility of materials used in constructing the ECM liner system with the radiological and chemical characteristics of leachate predicated to be generated within the ECM.

The HDPE GMB will have a white surface and a conductive bottom surface. The white surface will help to reflect sunlight and hence, reduce heating and thermal expansion/wrinkling of the GMB during installation.

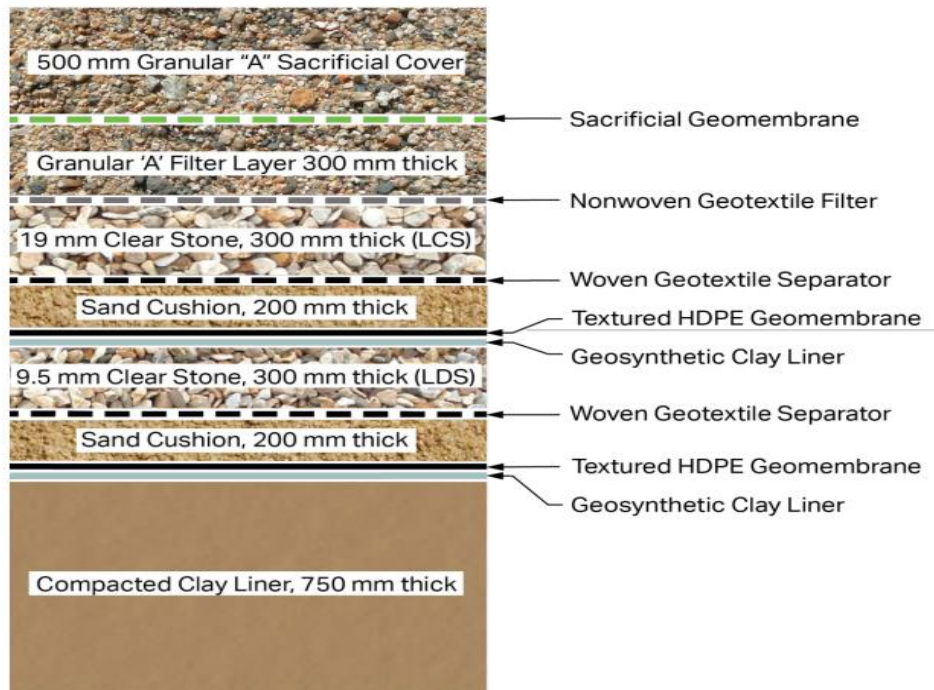


**Figure 3-20 Base Liner System**

**Table 3-12  
Base Liner System**

| Base Liner Components from Top to Bottom | Description/Function                                                                                                                                                                                                                    |
|------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 500 mm granular 'A' sacrificial cover    | The two sacrificial layers over the Phase 1 area, allow operations to divert storm water into the non-contact water collection areas and are to be removed prior to waste placement. Provides frost protection for the sacrificial GMB. |
| Sacrificial GMB -                        | 1 mm textured double sided Linear Low-Density Polyethylene                                                                                                                                                                              |

| Base Liner Components from Top to Bottom                     | Description/Function                                                                                                                                                                                                         |
|--------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                              | GMB with white surface on the top side. The two sacrificial layers over the Phase 1 area, allow operations to divert storm water into the non-contact water collection areas and are to be removed prior to waste placement. |
| 300 mm granular 'A' filter                                   | The granular 'A' sand and gravel filter layer for limiting migration of fines from the overlying waste material into an underlying granular drainage layer.                                                                  |
| Non-woven geotextile filter                                  | Provides separation for the clear stone layer and the granular 'A'.                                                                                                                                                          |
| 300 mm layer of 19 mm clear stone                            | Leachate Collection System and provides granular leachate drainage layer.                                                                                                                                                    |
| Woven geotextile separator (liner protection)                | Leachate Collection System and provides separation for the clear stone layer and the sand cushion layer.                                                                                                                     |
| 200 mm thick sand cushion (liner protection)                 | Leachate Collection System and provides protection to the primary liner HDPE GMB.                                                                                                                                            |
| 2 mm textured (both sides) HDPE GMB liner (barrier)          | Leachate Collection System. Primary liner HDPE GMB provides containment for the leachate generated from the disposed waste.                                                                                                  |
| GCL (barrier)                                                | The GCL's low hydraulic conductivity retards the flow of leachate that leaked through the primary liner GMB.                                                                                                                 |
| 300 mm layer of 9.5 mm clear stone                           | Leak Detection System and provides granular leachate drainage layer                                                                                                                                                          |
| Woven geotextile separator                                   | Leak Detection System and provides separation for the clear stone layer and the sand cushion layer.                                                                                                                          |
| 200 mm thick sand cushion                                    | Leak Detection System and provides protection to the secondary liner HDPE GMB.                                                                                                                                               |
| 2 mm (80-mil) textured (both sides) HDPE GMB liner (barrier) | Leak Detection System and provides containment for the leachate in the event of a leak in the primary liner.                                                                                                                 |
| Geosynthetic Clay Liner (GCL) (barrier)                      | The GCL's low hydraulic conductivity retards the flow of leachate that leaked through the secondary liner GMB.                                                                                                               |
| 750 mm-thick CCL (barrier)                                   | The CCL's low hydraulic conductivity retards the flow of leachate into the geosphere.                                                                                                                                        |

Leakage rates through the base liner system are estimated approximately  $\leq 2$  mm/year.

The base liners are located below the calculated maximum frost depth of 1.75 m [3-65] to prevent damage due to freeze-thaw cycles. Upper layers will provide insulation that helps limit freeze-thaw effects to within the upper portion of the final cover system - above the low permeability components of the cover (although it should be noted that the HDPE GMB and GCL have a low degree of susceptibility to freeze-thaw damage and they lie at a depth of 1.75 m in the cover system), which is equal to the calculated frost penetration depth.

Figure 3-21 shows the configuration of the base liner system at the intersection of the ECM floor and the ECM interior portion of berm. A compound longitudinal slope between 5% and 10%, defines the top of the base liner and floor surface of the ECM. A slope of 3% is provided along with the longitudinal slope, to facilitate drainage of leachate to the LCS clear stone layer with perforated collection pipe within each valley.

A geogrid is included on the sideslopes at the base as shown in Figure 3-21. The geogrid is required on the 3H:1V sideslopes to minimize the potential for downslope movement (sliding) of the non-woven geotextile cushion and granular leachate drainage layer above the primary GMB liner. The potential for this downslope movement exists during the active waste placement period prior to final buttressing of the slope with waste fill. The cause of the downslope movement is the low frictional resistance between the geotextile cushion and GMB liner. The geogrid is placed between the geotextile cushion and granular drainage layer and anchored at the crest of the slope in an anchor trench. The aperture size of the geogrid was selected to allow interlocking with the drainage layer aggregate. The geogrid design is based on the tensile force acting against the gravitational sliding forces, so as to maintain a stable configuration on the slope.

A heavyweight, non-woven geotextile cushion is included in the base liner system above the primary HDPE GMB on the 3H:1V sideslopes of the ECM. The geotextile cushion is designed to protect the primary HDPE GMB from localized strains, induced by angular particles of the overlying 19-mm clear stone drainage layer.

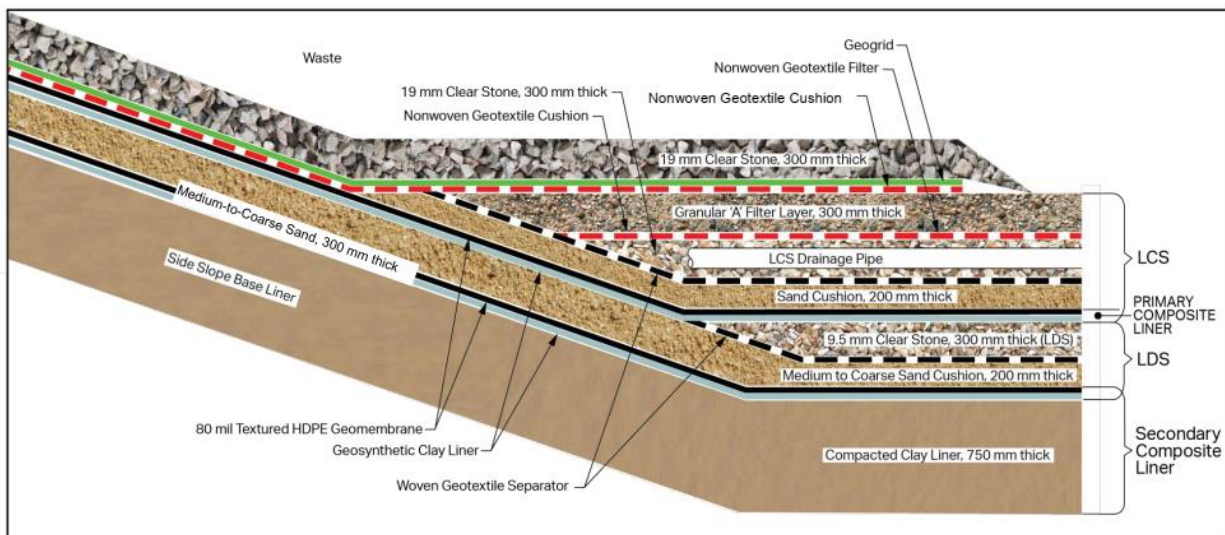


**Figure 3-21 Side-Slope Base Liner System**

#### 3.2.1.3.1 Primary Liner and Leachate Collection System

The primary function of the LCS is to collect and convey leachate generated in the ECM to the LCS component of the sump in each waste disposal cell (for subsequent removal), throughout the ECM operations period and during the post-closure phase. The LCS mitigates against the possibility of leachate build-up within the ECM during the operations phase, when water infiltration may be higher (e.g., prior to cover installation).

The LCS includes the following layers/components (from top to bottom):

- 300 mm granular 'A' filter.
- non-woven geotextile filter,
- 300 mm layer of 19 mm clear stone with a perforated leachate collection pipe.
- woven geotextile separator.
- 200 mm sand cushion layer.



- 2 mm textured (both sides) HDPE geomembrane liner (barrier).
- Geosynthetic clay liner (GCL) (barrier).

The thickness of the 19 mm clear stone layer is 300 mm throughout the ECM floor except along the full length of the valleys, where the clear stone layer thickness is increased to 0.5 m along the perforated LCS pipes. The design of the LDS does not require a perforated pipe along the valleys. The very low flows predicted for LDS can be easily conveyed by the clear stone and medium-to-coarse sand cushion layers. The piping for the LDS is restricted to the sump areas and a header pipe connection Valley 7 to Valley 6.

The LCS has access points to allow inspection and cleaning of the LCS collection pipes. Where direct access to the LCS components through the leachate extraction boxes above the sumps for cleaning purposes is not possible, separate sideslope riser pipe cleanout systems are provided to allow access to those LCS pipes. All access to the LCS pipes for cleanout is gained from the top of the perimeter berm. Monitoring of leachate levels in the sumps is to be performed using pressure transducers installed into the sumps.

An HDPE DR 17 header pipe, connects the lower end of the 200 mm diameter perforated LCS drainage pipe in Valley 7 to the sump in Valley 6. A 200 mm non-perforated header pipe, connects the 200 mm perforated LCS collection pipe in Valley 1 to the LCS sump in Valley 2. The size of the HDPE header pipe segments was selected to be the same as that of each of the LCS collection pipes. Leachate Collection System sideslope HDPE DR 17 cleanout pipes, are provided to allow access to the sumps and LCS drainage pipes and to allow periodic cleaning/jetting of the LCS header pipes.

Each cell contains a sump located at its low point to provide common collection points for leachate generated in the ECM. Additional supplemental GCL layer and supplemental GMB layers are included above the secondary liner GMB (2 mm textured HDPE) component in each sump, to reduce interface transmissivity and further minimize potential for leakage and to provide an additional level of protection of the secondary GMB.

Each Valley contains a LCS and LDS component. The LCS component contains a 50-mm clear stone backfill which interfaces with a 610 mm diameter perforated HDPE, and the distal end of the LCS drainage pipe. The perforated HDPE LCS drainage pipe connects with a sideslope cleanout riser pipe. The LDS component contains a 9.5-mm clear stone backfill layer.

The LCS drains any leachate that may accumulate on the primary liner, and is intended to limit the build-up of head to 0.3 m or less during the operational and post-closure phases of the ECM. This system is above the primary composite liner and includes (from top to bottom) a Granular "A" filter layer, a non-woven geotextile filter, and a 19 mm clear stone drainage layer with a perforated leachate collection pipe, a woven geotextile separator, and a sand cushion layer. The LCS drains to five internal collection/sumps at the southwest end of the ECM. Leachate is collected in a 200 mm diameter HDPE conveyance pipe, which drains to a header pipe at the toe of the ECM, leading to a leachate collection sump on the southeast corner of the mound. From the sump, leachate is pumped to leachate extraction boxes located on the crest of the ECM berm, and is ultimately conveyed to the WWTP for treatment. Cross sections of the LCS collection sump are shown in Figure 3-22 and Figure 3-23.

An evaluation of the LCS drainage layer capacity and the potential for long-term chemical/biological clogging is provided in the Leachate/Wastewater Collection and LDSs Evaluation and Optimization Report [3-66].

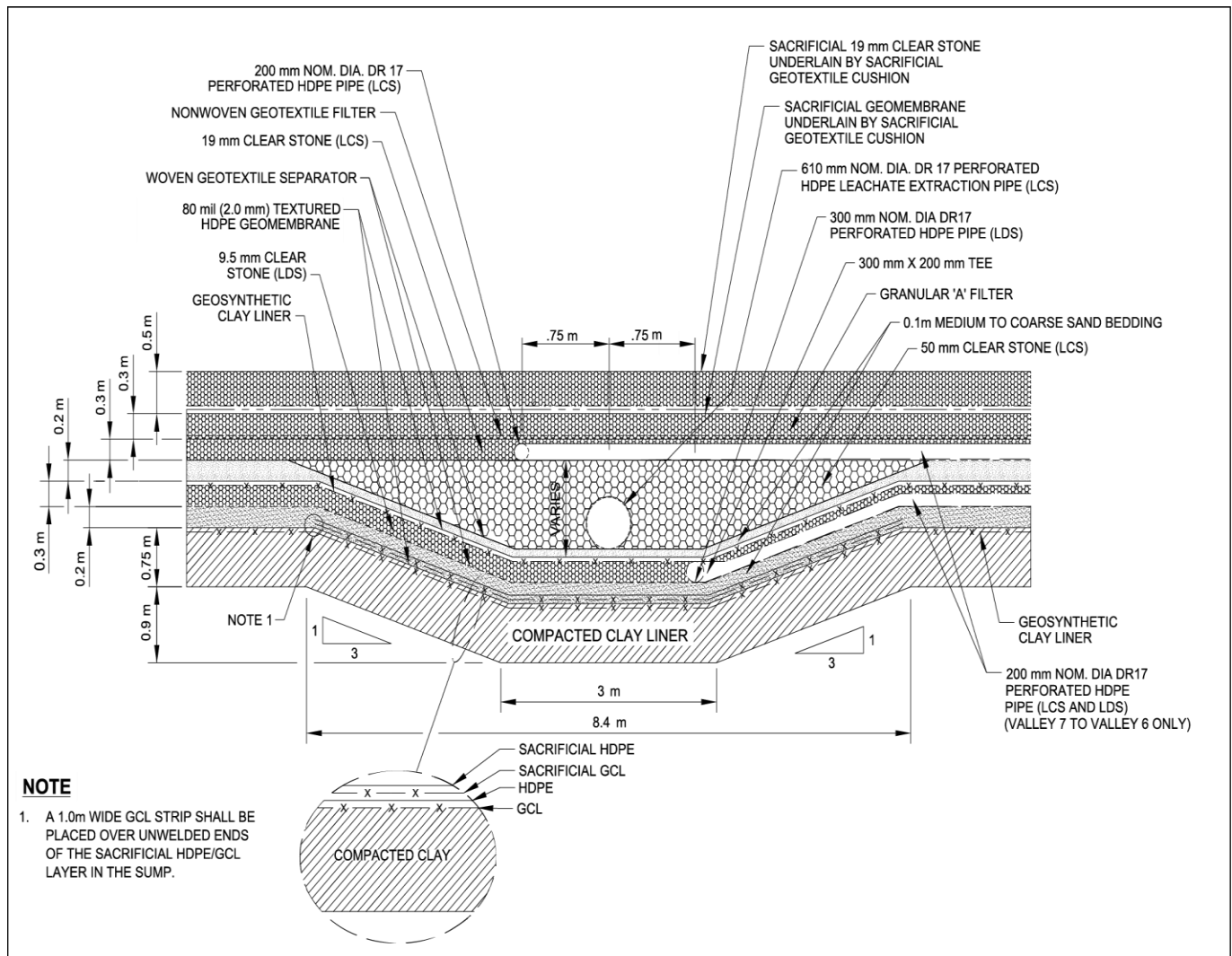


**Figure 3-22 Leachate Collection System/Leachate Drainage System Sump Cross Section**



A LDS is incorporated within the base liner system above the secondary liner. The LDS system includes a 300 mm thick granular 'A' filter layer, non-woven geotextile separator, and 9.5 mm clear stone layer, non-woven geotextile and 200 mm thick sand cushion layer.

The LDS enables monitoring of any leakage flow through the primary liner and provides secondary containment for leachate that may be released through the primary liner. The LDS allows the integrity of ECM liner engineered barriers to be monitored.

The LDS drains leachate and/or condensate to the LDS component of each sump (for each of the five sumps in the ECM). The LDS component of each sump includes a 9.5 mm clear stone layer containing a section of perforated, 300 mm diameter, DR 17 HDPE pipe with the perforations being 100 mm apart. Typical cross sections of the LDS collection sump are shown in Figure 3-22 and Figure 3-23.

#### **3.2.1.4 Perimeter Berm**

The perimeter berm shown in Figure 3-24, forms the outer boundary and sidewalls, comprising the perimeter of the ECM. The primary function of the perimeter berm, is to provide a means for maintaining the structural integrity of the ECM waste containment system during ECM operations and throughout the post-closure design period. The perimeter berm surrounding the ECM also provides containment and isolation for the ECM waste and leachate. Additionally, the perimeter berm mitigates run-on of water to the ECM from adjacent areas. The perimeter berm provides structural integrity based on the seismic analysis [3-67], that demonstrates that the perimeter berm and ECM can withstand the DBE and OBE.

The perimeter berm consists of three gradationally different fill materials, fine to coarse grained from top to bottom. The perimeter berm is lined with primary and secondary composite liner layers HDPE membrane/GCL combination and a compacted clay layer, on the side slopes to provide containment of the waste and leachate. The GCL's low hydraulic conductivity will retard the flow of leachate in the sub-layers of the base liner system. The perimeter berm constructed of rock materials forms the sidewalls of the ECM, deterring intrusion and thereby, isolating the waste from the biosphere.

The perimeter berm crest is designed to provide vehicle access required for performing operations and monitoring at the ECM. The perimeter berm provides a physical barrier to divert storm water from impinging on the ECM containment area, and is formed of earthen materials and geosynthetic materials. Exterior perimeter berm sideslopes are inclined at 3H:1V and the perimeter berm has a width of 7 m at the top (crest). The surface (face) of the exterior portion of the perimeter berm is covered with rock to provide erosion protection.

The height of the perimeter berm varies around the ECM perimeter from about 2 m minimum to about 15 m maximum. The lowest height of approximately 2 m is along the North West edge. The perimeter berm height is the height of the compacted free draining fill, and not the ECM perimeter sidewall height that contains the waste. Depending on the location around the ECM, the ECM perimeter sidewall consists of free draining fill (compacted), bedrock, or a combination of the two. This is due to the sloping terrain and distribution of bedrock. Figure 3-25 shows a typical section where the perimeter berm height is relatively small compared to the sidewall height. In Figure 3-25, the perimeter berm height is approximately 3.3 m and the overall height of the ECM sidewall is approximately 14.9 m. The ECM sidewall height is relatively consistent around the ECM.

The inside face of the perimeter berm is covered with the various liner system layers, while the outer face is covered with the intrusion barrier rockfill over an HDPE GMB liner, geotextile cushion, and geogrid. The top of the perimeter berm is covered with a layer of Granular 'A' material, an HDPE GMB, and a geotextile cushion.

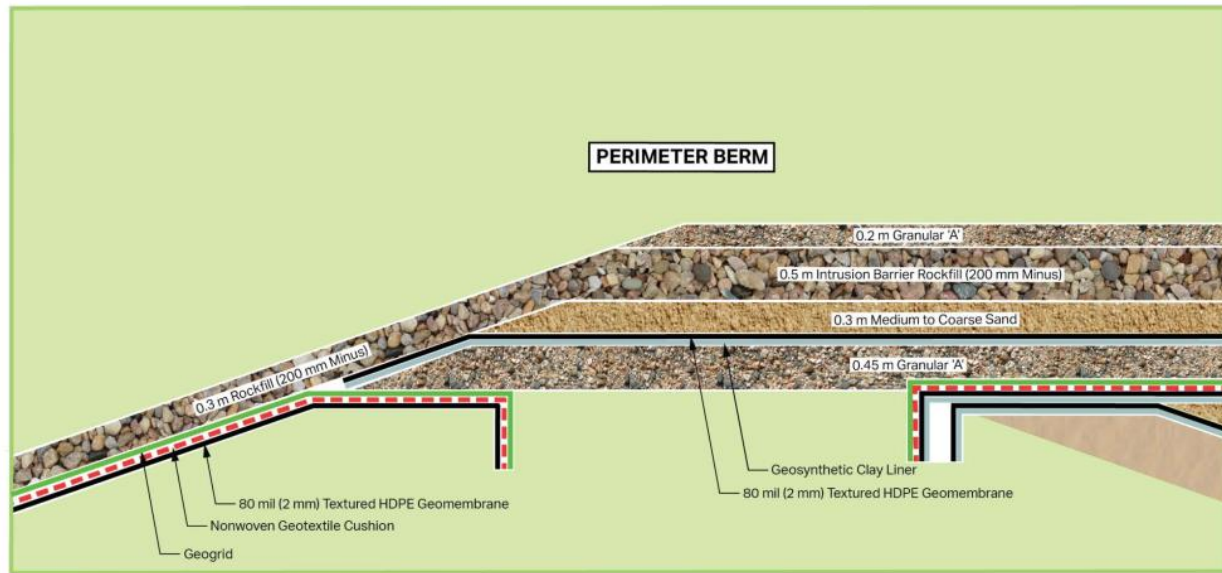


**Figure 3-24 Engineered Containment Mound Perimeter Berm**

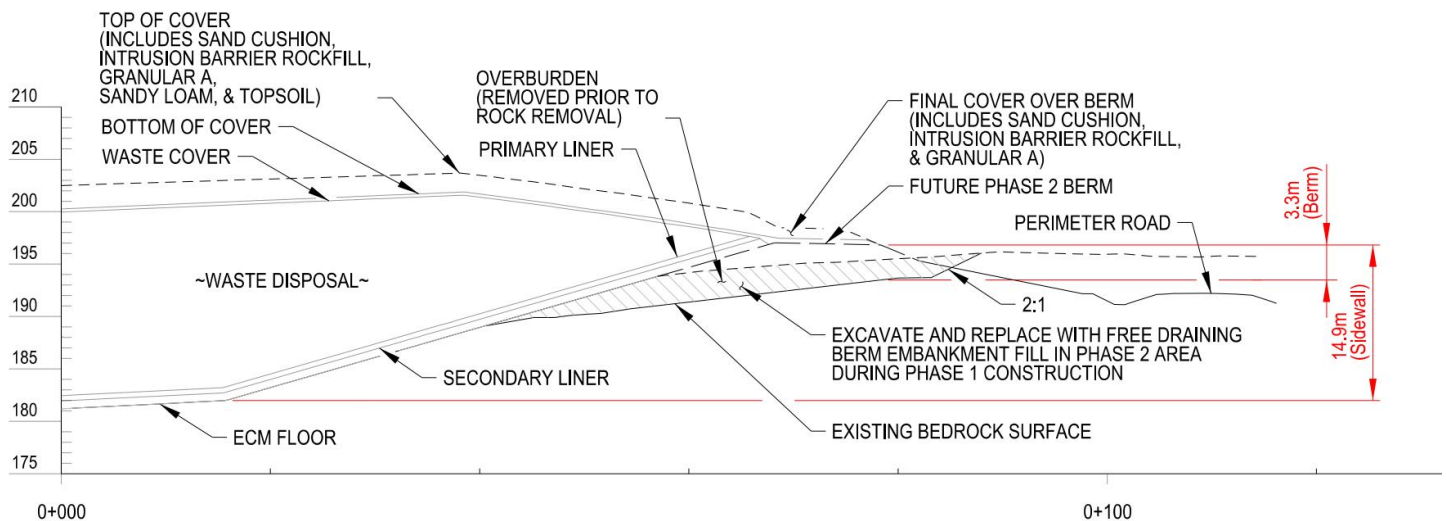


**Figure 3-25 Engineered Containment Mound Perimeter Berm Typical Section**

### 3.2.1.5 Final Cover System

The ECM final cover system is designed to protect both the human and natural environment from the waste materials and associated contamination and ensures ambient gamma radiation at the surface close to background. The final cover system provides waste containment and isolation. The final cover is a multi-component system, which includes a general fill layer to provide gamma shielding, a coarse stone layer for mitigating intrusion of biota, and HPDE and GCLs to control the ingress of water into the ECM. The final cover system mitigates leachate generation by preventing precipitation from infiltrating, thus limits exposure

to waste contaminants in the post-closure phase of the NSDF, providing containment and isolation of the waste.

The final cover system has a combined total thickness that varies but has a minimum thickness of 2.05 m; thus, providing substantial shielding from any radiation fields from the waste. The final cover system shown in Figure 3-26 and Table 3-13 provides a summary of the layers, top to bottom. Four permanent granite markers will be installed on the final cover showing the facility name, closure date, acreage and waste capacity or any other essential information about the disposal facility. The planning and details of the facility closure may evolve during the lifecycle of the facility as CNSC guidance becomes available.

The ECM final cover system and perimeter berm are integrated and are designed to resist erosion, to safely convey stormwater flows, and to maintain structural integrity during design basis scenarios. The NSDF design achieves this with robust and durable engineered materials of construction. For example in the Surface Water Modelling and Evaluation technical note [3-68], an estimated soil loss of the ECM final cover system was calculated and then conveyance channels, riprap lined downdrains, and concrete chutes were added accordingly. Frequent facility inspections are planned during the Operations, closure and post-closure (institutional control period) phases such that any erosion or subsidence from precipitation events can be quickly remediated.

Flow and velocity calculations were performed [3-68] for erosion/scour of the final cover system to show that major storm events will not cause significant damage to the surface water conveyance features of the ECM and that long-term soil loss is accounted for in the design. The Revised Universal Soil Loss Equation (RUSLE) was used to predict the estimated soil loss from the final cover over the post-closure phase. Soil loss is a long term prediction factoring in the total volume and the distribution of the annual erosive rainfall for a specific location. The annual soil loss predicted in [3-68] for the specific NSDF site characteristics and climatic conditions was used as the erosion rate inputs for the Post-closure Safety Assessment [3-39]. An additional study was performed to evaluate the effects of a Probable Maximum Precipitation (PMP) event on the perimeter berm and final cover, with a focus on erosion [3-69]. The analysis shows that for all drainage elements, allowable velocities were not exceeded by the theoretical velocities determined for the PMP and final site characteristics. As a result, the analysis shows that detrimental erosion will not occur during a PMP event for the:

- Top cover (2% vegetated slope), side cover (4:1 vegetated and 2:1 rip-rap slopes) and berm (3:1 rip-rap slope), and
- Conveyance channels – valley (5% and 10% slopes), downdrain (3:1 rip-rap slope) and chute (3:1 concrete slope).

**Table 3-13**  
**Final Cover System**

| <b>Final Cover System Layer</b>           | <b>Description/Function</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|-------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Vegetative cover                          | The final cover is vegetated to provide an aesthetically pleasing surface, enhance evapotranspiration, and reduce the potential for erosion.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| Topsoil, 150 mm thick                     | A 150 mm topsoil layer is placed on the top of the final cover system to provide a growth zone for hardy grasses.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Sandy loam, 600 mm to 1 200 mm thickness  | The primary purpose of the 600 mm to 1 200 mm thick sandy loam layer is to provide moisture retention for plant uptake and evapotranspiration. This moisture retention is important for promoting surface plant root development, which is important for transpiration and minimizing surface erosion processes. This layer also provides additional gamma radiation shielding, and additional confining stress for the final cover lining system                                                                                                                                                                                                                                                                                                                                                      |
| Granular 'A' filter layer, 200 mm thick   | The principal function of the 200 mm thick granular filter layer is to provide a natural filter layer to minimize the possibility of fines migrating downward from the sandy loam layer to the underlying intrusion barrier rock fill. This filter layer minimizes the potential for future clogging of the intrusion barrier rock fill layer, and allows for some degree of lateral flow diversion within the final cover system.                                                                                                                                                                                                                                                                                                                                                                     |
| Intrusion barrier rock fill, 500 mm thick | The 500 mm thick intrusion barrier rock fill layer deters burrowing animals and roots from potential deeper-rooted plant species reaching and possibly damaging the cover lining system, as well as penetrating into and transporting contaminants from the waste fill. This rock fill layer would also help deter inadvertent future intrusion into the buried wastes by humans. The layer provides for some lateral drainage of water that percolates through the upper layers of the final cover.                                                                                                                                                                                                                                                                                                   |
| Medium-to-coarse sand, 300 mm thick       | A 300 mm sand layer is incorporated over the HDPE GMB liner to minimize the localized strains from resultant loads by the larger grain-sized aggregate in the intrusion barrier rock fill layer above.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| Textured (both sides) 80 mil HDPE GMB     | A textured, 80-mil, HDPE GMB liner is placed directly on the GCL. The GMB serves as the upper (primary) barrier against infiltration through the final cover into the disposed wastes. This GMB is also expected to prevent or minimize the upward migration of radon and other LFGs from the waste fill into the atmosphere.                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Geosynthetic Clay Liner                   | The GCL functions as a lower (secondary) low permeability barrier that also limits the downward leakage through any potential defects that may exist in the overlying GMB liner and provides a back-up hydraulic barrier in the unexpected event that the GMB experiences deterioration over the design life of the Facility. This role of the GCL requires that its hydraulic conductivity remain at a low value over the ECM design life. The GCL has a hydraulic conductivity of approximately $5 \times 10^{-11}$ m/s [3-67]. In the event of a hole or leak in the 80 mil HDPE GMB, the clay portion of the GCL would hydrate, forming another barrier to mitigate any potential leakage flow downward into the waste profile, thereby, creating essentially a self-healing effect on the hole or |

| Final Cover System Layer    | Description/Function                                                                                                                                                                                                                                                                                                         |
|-----------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                             | leak in the HDPE liner.                                                                                                                                                                                                                                                                                                      |
| Temporary sacrificial liner | The temporary sacrificial liner is placed during operations. The temporary sacrificial liner sheds non-contact water from the disposal cell operations. The temporary sacrificial liner will be removed prior to placement of the subsequent final cover materials.                                                          |
| Sand - 300 mm               | The 300 mm sand layer provides a smooth base and contains an appropriate subgrade moisture content for installation of the GCL. This layer also helps facilitate upward movement of LFG that may be generated in the ECM below the GCL component of the final cover into the passive system for discharge to the atmosphere. |

The final cover system is designed to mitigate the ingress of surface water. The estimated steady state leakage rate through the final cover is 0.3 mm/year after final construction. Considering a total final cover area of approximately 12 hectares for the ECM, this calculated leakage rate through the final cover corresponds to an estimated post-closure (steady state) leachate generation rate of approximately 37 m<sup>3</sup>/year [3-70].

Final cover system placement occurs in stages during the ECM operations period. During ECM operations, construction of the final cover system occurs to close disposal cells that have reached their waste capacity. As a disposal cell is closed with the final cover system, the subsequent disposal cell becomes active to receive waste. Placement of the final cover begins after the select waste layer has been placed, followed by placing the first layer of the final cover. When the first layer is placed, the area is covered with a temporary sacrificial liner. When the remainder of the final cover system is ready to be constructed, the sacrificial liner is removed. The surface is then rough-graded to fill depressions, sharp edges, and graded to a relatively flat condition. The balance of the final cover system is then installed.

The final cover system is designed with a minimum 2% (cross slope) and a minimum 5% (drainage direction) to provide positive drainage off the ECM top deck surface, allow for accommodating potential long-term effects of localized differential settlement, if it were to occur during the post-closure phase, and maintain cover stability. Details pertaining to slope stability analyses performed for the ECM are documented in Base Liner and Final Cover Evaluation and Optimization [3-67], and Slope Stability Analysis.

Table 3-14 provides tolerance requirements for differential settlement of the final cover system after construction, to maintain positive drainage of surface water and to minimize localized tensile strains in the GMB liner. Minimizing local tensile strains in the GMB is important in preventing long-term stress cracking of the GMB. In this regard, a maximum allowable strain of 5% has been set for the final cover GMB liner "Recommended Maximum Allowable Strain and Design Considerations for HDPE GMB to be used in the NSDF" [3-71]. For the final cover design, differential settlement and displacement under earthquake loading are the primary potential sources of GMB tensile strains. The tolerances given in Table 3-14, limit tensile strains from differential settlement to approximately 0.1%. Settlement monitoring is performed to verify differential settlement trends in the ECM. Settlement plates are to be installed during operations to verify settlement trends prior to placement of the complete final cover system.

The final cover system is designed with a ridge and valley geometry as shown in Figure 3-27. Cross-slope inclinations of the ridge/crest configuration consisting of the sandy loam and topsoil layers are graded at 2% slopes. Ridge crests are approximately 30 m apart. The ridge and valley geometry reduces the occurrence and



magnitude of concentrated flows and maintains water run-off from the final cover system in a controlled manner.

**Table 3-14**  
**Tolerance Requirements for Cover Settlement**

| Tolerance Requirement for Cover Settlement                                                                                                                                                                |                                                       |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------|
| Distance from Point of Maximum Settlement Down Slope (in 5% Drainage Direction) to Observed Initiation of Differential Settlement (metres)                                                                | Maximum allowable elevation difference between points |
| 1                                                                                                                                                                                                         | 20 mm                                                 |
| 2                                                                                                                                                                                                         | 40 mm                                                 |
| 3                                                                                                                                                                                                         | 60 mm                                                 |
| 5                                                                                                                                                                                                         | 80 mm                                                 |
| 10                                                                                                                                                                                                        | 16 cm                                                 |
| 20                                                                                                                                                                                                        | 32 cm                                                 |
| 50                                                                                                                                                                                                        | 64 cm                                                 |
| 100                                                                                                                                                                                                       | 1.3 m                                                 |
| If the distance between points (lowest point in the depression down slope to the edge of the depression) is greater than 100 m, the acceptance criterion is a minimum uniform slope of 2% between points. |                                                       |

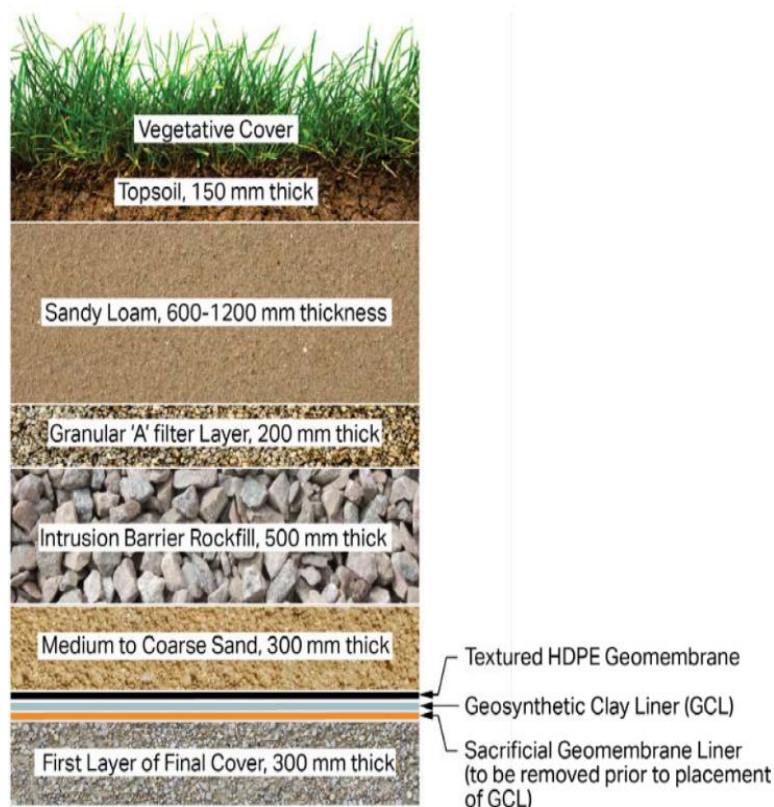


**Figure 3-26 Final Cover System**

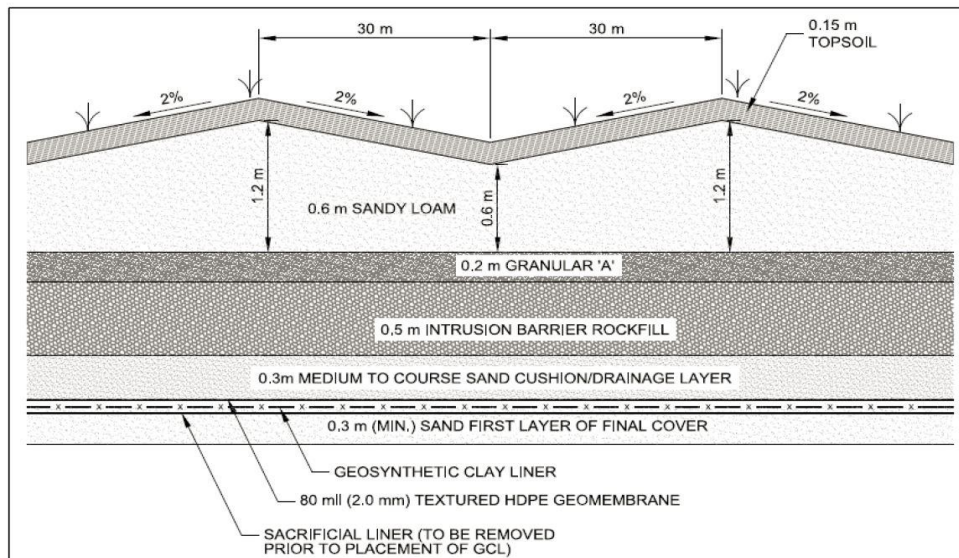


**Figure 3-27 Final Cover – Typical Contouring**

### 3.2.1.5.1 Landfill Gas Venting System

A passive gas collection and venting system is included in the ECM final cover design. The primary function of the gas venting system is to passively collect, control and safely dissipate gases that may be generated within the ECM following placement of the final cover system. The predicted LFG composition and generation rates are documented in Landfill Gas Management Plan [3-72]. Figure 3-28 shows the final cover system with waste cells and a typical LFG vent pipe.

Vertical gas vent pipes are to be placed in the final cover in specified locations in Phase 1 and specified additional locations in Phase 2, to minimize the potential for excessive build-up of pressures under the cover system and installed in a manner to preclude negatively impacting the integrity or stability of the cover system. Gases to be vented include gases that may be generated from biological decomposition, corrosion, and radioactive decay of the placed wastes. The passive venting system includes a sand bedding layer placed beneath the GCL and HDPE GMB in the cover, and a series of geovent strip drains placed atop the sand bedding layer and beneath the GCL and HDPE, connecting to the vertical vent pipes. A maximum spacing interval of approximately 186 m will be used for the LFG vents [3-72].

Landfill gas vent pipes are constructed using 316 SS (e.g., Schedule 10), that is resistant to long-term deterioration of the piping as a result of ultraviolet light and is resistant to long-term corrosion from adjacent soils. Each vent pipe extends from the “sand bedding layer” to the top of the final cover, extending to a height of approximately 3 m above the final cover surface. The base of each vertical gas vent pipe will be stabilized by including a trapezoidal mound of Granular ‘A’ stone material around the base of each vent pipe and on top of the HDPE GMB. A similar mound of Granular ‘A’ stone material will be placed and compacted if required, around the top portion of each vent pipe where it exits the final cover extending to a depth of 0.3 m below the top of the final cover system to further secure the vent pipes.

The peak generation rates of landfill gases occur at the time, 1 year after closure of the ECM (year 51), and the landfill gases and peak generation rates are:

- The total Landfill gases generation rate is 251 700 m<sup>3</sup>/y out of which:
  - Methane generation rate is 125 800 m<sup>3</sup>/y.
  - Carbon dioxide generation rate is 125 800 m<sup>3</sup>/y.

The values stated above are conservative because the rates were determined based on wastes under conditions ideal for the decomposition where all of the organic material in the waste could be completely decomposed. Conditions for the NSDF will not be ideal for waste decomposition as the design and operating practices will result in an in-place waste mass that is too dry to support optimal decomposition.

At the end of the ICP; (330 years after ECM closure), the passive LFG vent pipes are backfilled with gravel from the bottom of each vent pipe to the height of the top of the final cover system and the above-ground portion of each vent pipe removed. LandGEM modelling, shows that the expected gas generation rates will be at a maximum approximately one year after placement of the final cover and will progressively decline over time, as the inventory of organic wastes decreases. The gravel backfill placed in the below-grade portions of the passive vent pipes would allow for the continued future release of pressure resulting from remaining small amounts of LFG that might be generated beyond the end of the ICP, while also preventing intruders that could be detrimental to the performance of the final cover system.

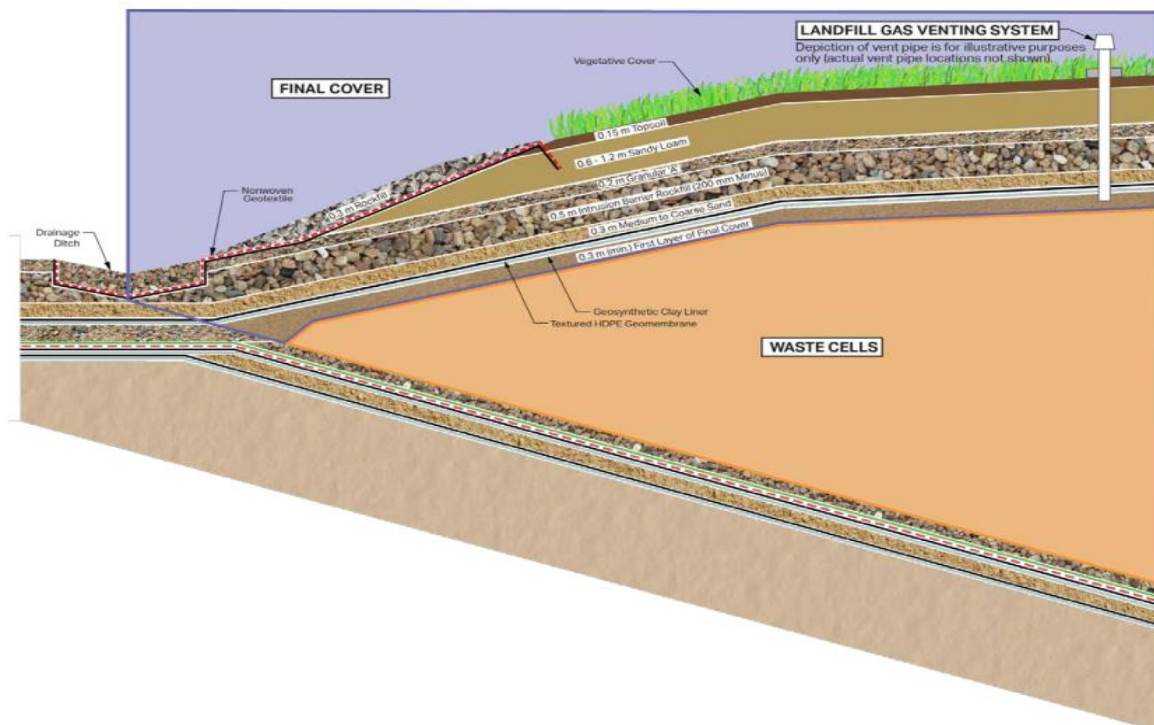


Figure 3-28 Final Cover System Showing Waste Cells and Gas Vent

### 3.2.1.6 Daily and Interim Cover

The ECM cover systems include operational covers which are the daily cover and interim cover that are used during the operational phase to provide waste containment.

#### Daily Cover

Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face, to control the release of fugitive dust from the surface of the waste. The daily cover also fulfills other functions, such as minimizing erosion of placed waste, minimizing blowing litter, reducing odour, discouraging vector and vermin activity, improving equipment access to the active disposal area, and maintaining a more aesthetically pleasing site appearance.

The daily cover consists of 0.150 m layer of clean soil or an alternative daily cover material that is pre-approved for use including tarpaulin, fixative (crusting agent), or similar temporary cover system material. The daily cover, 0.150 m layer of soil, provides fire protection for the placed waste, from wind-blown sparks or embers released from a fire. If a tarpaulin or fixative is used as an alternate daily cover material, the tarpaulin or fixative must be fire rated, and classified as "fire proof". Prior to using any fixative as an alternative daily cover material, the fixative must be verified to not adversely affect the WWTP treatment processes.

When possible, a coarser-grained soil may be used as daily cover to promote the hydraulic connection between waste layers (also known as waste lifts).

Grout, controlled low-strength material, may be used as daily cover in waste disposal areas that are using grout for void reduction, specifically for some Type 4 and Type 5 wastes. The granular "A" sacrificial cover material on the sacrificial geomembrane, protecting the base liner system in non-active cells, when removed, can be stockpiled and re-used as daily cover.

In the TSWRPA, wastes that are not stored in the disposal or transportation container are covered with the daily cover. The daily cover minimizes the release of fugitive dust from the uncovered wastes, and provides fire protection for wastes stored in the TSWRPA.

#### Interim Cover

The interim cover consists of 0.3 m layer of clean soil or clean sand that is overlain by a sacrificial liner to promote non-contact surface water run-off, and minimize precipitation infiltration into the waste material. The interim cover is applied to:

- Waste disposal areas that will remain inactive for more than 30 days and are not considered part of the active disposal area, but are scheduled to receive waste in the future.
- Waste disposal areas that have reached the design waste fill grade, and are not scheduled to receive additional waste and are awaiting installation of the final cover system.

The sacrificial liner is a 1.0 mm (40 mil) thick, double-sided, textured, white-surfaced (top side only) linear low-density polyethylene (LLDPE) geomembrane that is adequately anchored to prevent uplift by wind. In addition, the sacrificial liner is to be durable, have a suitable coefficient of expansion and be resistant to ultraviolet radiation damage.

Figure 3-29 shows the interim covers on waste disposal areas (inactive 3:1 face) that will remain inactive for more than 30 days and waste disposal areas (cell 1 and cell 2) that have reached the design waste fill grade.

The interim cover consisting of 0.3 m layer of clean soil overlain by a sacrificial liner is applied to waste disposal areas that will remain inactive for more than 30 days. The interim cover, including the clean soil layer

and sacrificial liner, are removed prior to the resumption of waste placement, to the extent practical, to promote hydraulic connection between waste lifts.

An interim cover consisting of 0.3 m layer of clean sand overlain by a sacrificial liner is also applied to waste disposal areas that have reached the design waste fill grade, and are awaiting installation of the final cover system. The interim cover is installed on the 1 m layer of select waste. The primary function of the sacrificial liner is to protect the 0.3 m layer of clean sand, first layer of the final cover system, against erosion, promote non-contact surface water run-off, and limit precipitation infiltration into the sand layer and underlying wastes prior to the installation of the remaining layers of the final cover system. The sacrificial liner is removed during the installation of the final cover system. The 0.3 m clean sand layer of the interim cover is not removed for the installation of the final cover system, and is regraded to eliminate low areas.

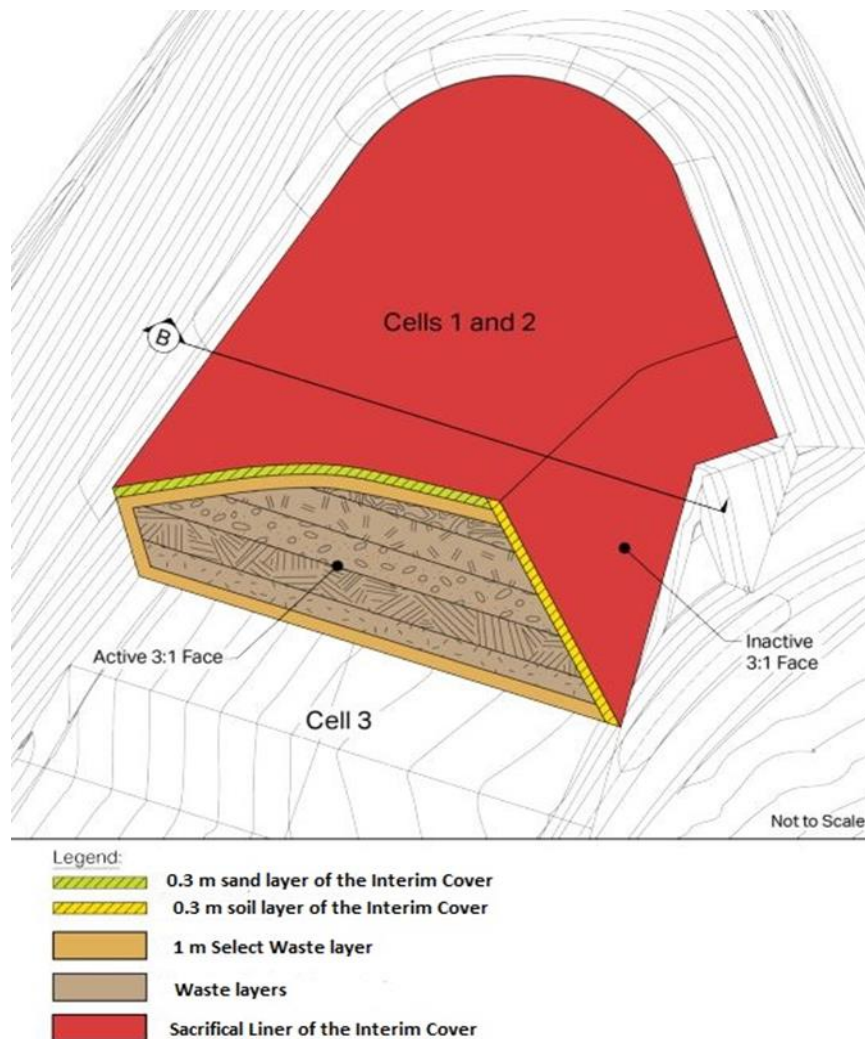


Figure 3-29 Interim Covers



### **3.2.1.7 Temporary Storage Waste Receiving and Processing Area**

The Temporary Storage Waste Receiving and Processing Area (TSWRPA), is constructed within the footprint of the active cell and includes the drum and waste unloading platform. The TSWRPA facilitates the safe unloading and transfer of bulk and package waste within the active cell. The TSWRPA is constructed at grade, consisting of aggregate material provided to minimize dust generation and facilitate contamination control. As the disposal cell is nearing closure, the TSWRPA will be removed and constructed within the new active disposal cell. The TSWRPA will normally store wastes, up to 800 m<sup>3</sup>, and stored waste shall be placed in the ECM disposal cell within one year. No uncontained waste is stored in the TSWRPA. All waste is either in its transportation container or disposal container, or covered with daily cover. The only processing that is performed is staging of waste or container preparation for grouting in the ECM.

### **3.2.1.8 Leachate Transfer System**

Leachate is removed from the ECM sumps using leachate extraction pumps and is conveyed via gravity flow conveyance piping to the leachate/contact water Pump (Lift) Station 1. The primary function of the leachate transfer system is to pump leachate and leachate/condensate from the LCS and LDS components of the sumps, to a leachate extraction box located above each cell sump on the ECM perimeter berm crest and to convey it, via a double-walled gravity flow piping system, together with contact water pumped from each disposal cell, to a sediment (knock-out) box and subsequently to the Pump (Lift) Station 1. Figure 3-30 depicts the principal components of the leachate and contact water (generated within the ECM containment area) transfer system. Figure 3-31 shows LCS and LDS system and associated piping (for ECM Phase 1).

The following components make up the Leachate Transfer System for the ECM: LCS and LDS removal pumps, LCS and LDS riser pipes, leachate extraction boxes and associated valves and hoses, and a gravity flow piping system, with an in-line sediment box, for conveying leachate and contact water to Pump (Lift) Station 1 and its associated valve chamber (described in the site infrastructure section).

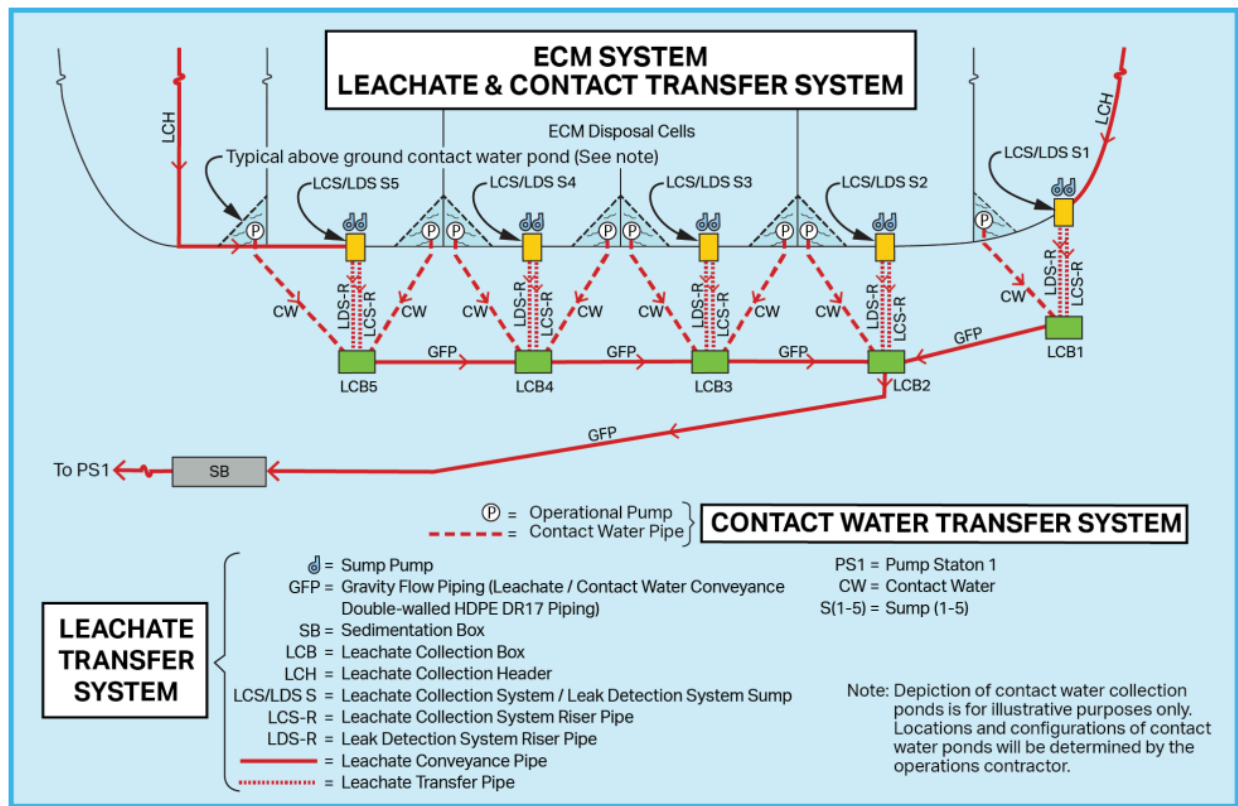


**Figure 3-30 Leachate and Contact Water Transfer System**

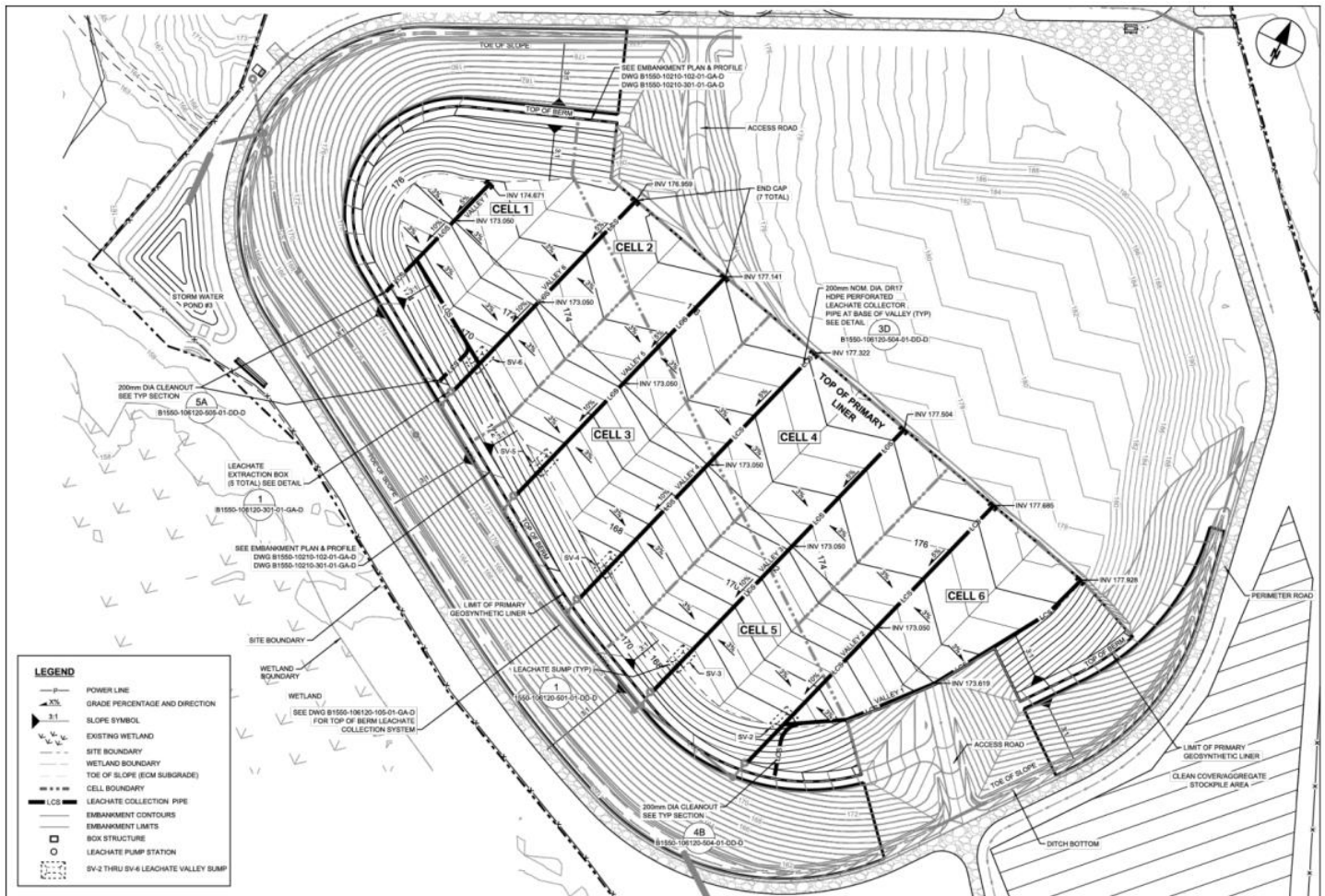


**Figure 3-31 LCS and LDS System and Associated Piping (for ECM Phase 1)**

### 3.2.1.9 Contact Water Collection and Transfer System

Contact water is managed separately from non-contact water. The primary function of the contact water collection and transfer system, is to collect and to pump contact water from the active cell to one of the leachate extraction boxes which are located on the ECM perimeter berm crest. A mobile pump is used to transfer the collected contact water to one of the leachate extraction boxes. The pumps are sized to transfer the capacity of the contact water pond (100-year storm event), in a 48 hour period. The NSDF water collection and conveyance systems are typically designed to resist erosion, safely convey flows and maintain structural integrity during peak flows generated from various design storms up to a PMP storm event.

#### 3.2.1.10 Non-Contact Water Collection and Transfer System

Precipitation that falls within the waste cells onto a waste disposal area that is covered with an interim cover, or other non-contaminated areas (e.g., inactive cell or Phase 2 area), does not come in contact with waste and is defined as non-contact water. Non-contact water from inactive areas within the ECM is prevented from entering the active disposal cell by use of temporary berms between cells.



The primary function of the non-contact water collection and transfer system is to remove (through pumping), non-contact water from the ECM containment area and convey the water to the exterior perimeter drainage channels through which the non-contact water is conveyed to the surface water management ponds.

### **3.2.1.11 Waste Placement**

Objectives for the placement and compaction of wastes in the ECM, are described in the Waste Placement and Compaction Plan [3-73]. Waste placement activities will be performed in a manner that does not damage the base/sidewall liner system, LCS, final cover system, and all ancillary NSDF features. Objectives for the waste placement and compaction plan include [3-73]:

- Waste handling, from receipt at the NSDF to final placement, is minimized to mitigate the potential for dust generation [3-74] and exposure to workers and the environment.
- When possible, wastes with higher dose rates (waste having gamma dose rates approaching or equal to 2 mSv/h near contact or 0.1 mSv/h at 1 m), are placed in the lower portions of the disposal cells and covered with waste having lower dose rates or fill materials to provide shielding from radiation. The design allows for 0.8 m of granular material on top of the primary liner to protect against radiation doses to the liner.
- Regardless of placement location, all waste exhibiting high dose rates (non-contact handleable waste), is placed and immediately covered with waste having lower dose rates or fill material to maintain doses to ECM workers ALARA.
- Waste is placed to maximize its in-place density and reduce void space to minimize the potential for future settlement of the waste and to ensure seismic stability of the ECM.
- As waste is placed into the disposal cells, the surface of the waste is maintained at a minimum 2% slope to promote run-off and minimize infiltration of surface water into the waste.
- Waste placement is conducted to minimize the time that on-site workers are required to work directly on the LLW working (disposal) face in accordance with ALARA principles.
- The waste placement sequence is conducted in a manner that provides flexibility in final side slope construction and future cell construction.
- Waste placement is designed to accommodate expected variations in the waste mix (relative percentages of the various waste types), and delivery times for waste arriving for placement.
- A key to waste placement efficiency and meeting ALARA objectives, is an effective planning and waste delivery schedule approach that is adopted by Waste Operations and the Facility Manager.

To mitigate differential settlement, waste placement will not allow individual columns to consist of only one waste type. The specified placement criteria ensures that adjacent waste columns have similar potential for long term settlement.

Waste placement will allow for placement of waste exhibiting high radiation levels only on a scheduled basis to maintain ALARA conditions associated with cell operations. Waste placement will allow for receipt and placement of waste exhibiting high radiation levels only if there is sufficient lower radiation level waste already in the vicinity to shield workers from higher radiation levels in accordance with ALARA principles [3-73]. These receipts are considered non-routine activities and are well planned to ensure safe working conditions and enhanced Conduct of Operations [3-75]. Bulk (Type 4) and packaged (Type 5) wastes are not

placed within 10 m of the sidewall slopes or 1 m of the LCS and final cover system of the cell to minimize any potential risk of damage to the LCS and liner system [3-73].

In each disposal cell, the initial waste placement will be a 1 m select waste layer, consisting of homogeneous Type-1 soil or soil-like waste or clean fill. This layer will be free of large debris and relatively free-draining, and is intended to protect the underlying LCS and base/sidewall liner. The select waste layer will be placed with equipment working from the perimeter to the centre, such that equipment is never directly on top of the LCS layer. Until this 1 m layer is in place, only low ground pressure equipment will be used for waste placement in the ECM.

The maximum pressure over the base liner system geosynthetic materials is 35 kPa, and the placement of select waste over the base liner system (geosynthetics) shall meet the 35 kPa requirement. Low-ground-pressure equipment for construction, operations, and maintenance may be used until the initial 1 m select waste lift is in place to meet the 35 kPa pressure requirement over the geosynthetic materials. The 35 kPa maximum value is based on the actual ground pressure due to industry-standard equipment used for spreading granular materials over a geomembrane liner/geosynthetic materials (e.g., Caterpillar D6M LGP Dozer). Based on industry operational experience, the NSDF design uses this 35 kPa value as a constraint until the select waste layer is placed over the base liner system, at which point higher pressure can be applied [3-67].

Subsequent waste layers will be placed in approximately 3 m layers called operational lifts. Each operational lift will consist of individually compacted layers with thicknesses of approximately 0.3 m. Placement will initially be performed by unloading waste on an offloading ramp across a clean contamination barrier. The waste is graded out and across the cell into position using bulldozers or other heavy equipment. The surface of each waste lift will be graded at 2%, to provide surface run-off and minimize surface water infiltration into the waste. Type 1 waste is compacted to a minimum of 92% Standard Proctor Density (SPD) or equivalent, using method based compaction. Type 1 waste is mixed with Type 2, 3 and 4 waste to achieve compaction targets. The waste compaction methods as waste is placed in the ECM, and the methods for testing to meet the compaction specifications, are defined in [3-73].

To confirm that the waste can meet the required as-placed dry density and moisture content, the following steps will be conducted:

1. Prior to waste placement, SPD testing will be completed on samples of Type 1 waste following ASTM 698 [3-111]. This testing will determine the relationship between dry density and moisture content (or water content) of the waste, the target 92% of SPD optimum dry density, and -1% to +3% of the optimum moisture.
2. Considering that the waste moisture content can affect compacted dry density, during the compaction, the moisture content of the Type 1 waste will be controlled within 1% below and 3% above the optimal moisture content to attain the required level of compaction. Waste with moisture content higher than the target may be spread and allowed to dry before compaction. Alternatively, waste that has a moisture content too high for compaction may be amended with drying agents (e.g., hydrated lime) to allow compaction. Any waste amendment material additions should be conducted in a controlled area. Treatability and Bench testing may be required to optimize amendment mixtures.
3. After waste compaction, the as-placed density and moisture content will be measured according to ASTM D6938 [3-112]. These as-placed properties will be used to confirm if the waste compaction has met the criteria defined in the 1<sup>st</sup> step.

4. The as-placed waste density should be compared to properties used for the detailed design analyses to ensure that the latter are still valid or sufficiently conservative. For example, assumed waste unit weight for slope stability analyses was assumed as  $18 \text{ kN/m}^3$ , corresponding to approximately  $1\,800 \text{ kg/m}^3$ .

Waste packages placed in the ECM will have a maximum of 10% void space within the package to prevent collapse. The maximum void space of 10% was selected based on benchmarking of similar near surface disposal facilities. The 10% maximum void space requirement for Type 5 Packaged Waste [3-63] is consistent with WAC of other LLW facilities, such as Hanford Site 200 Area [3-108], and the Port Hope Area Initiative (PHAI) [3-109], and with the container void space requirement for hazardous waste landfills in the United States [3-110]. The 10% internal void space of waste packages was selected to minimize the differential subsidence of the final cover system due to degrading waste packages.

Waste will either be transported directly from the location of generation to off-loading or waste placement location within the open disposal cell, or transported from location of generation to the TSWRPA for storage and subsequent disposal using dedicated waste placement equipment. No uncontained waste is stored in the TSWRPA. All waste is either in its transportation container or disposal container, or covered with daily cover. The only processing that is performed at the TSWRPA is staging of waste or container preparation for grouting in the ECM.

Debris, large bulky items, and packaged waste, will not be placed within 10 m of cell sidewalls, or 1 m of the LCS and final cover system. Soil or soil-like debris will be compacted around bulky debris. Debris waste may alternatively be placed in trenches that are cut into underlying waste layers.

Conditions to prevent and minimize contact water and leachate (for both placed waste and waste in temporary storage) include, but are not limited to:

- Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face, to control the release of fugitive dust from the surface of the waste. The daily cover performs several functions, including minimizing erosion and dust generation.
- Interim cover is applied to: 1) waste disposal areas that will remain inactive for more than 30 days; and 2) waste disposal areas that have reached the design waste fill grade. The interim cover is used to promote non-contact surface water run-off.
- The surface of each waste lift is graded at a minimum 2% slope to promote run-off and minimize infiltration of surface water into the waste.

The location of wastes placed in the disposal cell and characteristic information about the waste shall be recorded. A Waste Placement Mapping Plan will be developed to accurately record the placement locations of each waste stream in each cell. The plan will specify a three-dimensional waste location recording system for waste placed within the ECM. As waste is placed in the ECM, the locations/elevations are documented on the placed waste map/plan, and updated on a regular basis during NSDF operation.

As recommended in IAEA SSG-31, Monitoring and Surveillance of Radioactive Waste Disposal Facilities [3-76] waste retrieval, may be performed to reverse the action of waste placement. For the NSDF, waste may only be retrieved from a cell before the final cover is installed. Waste retrieval is not intended, nor is required, thus is not assessed. In the unlikely event that a waste retrieval becomes necessary, a safety assessment for waste retrieval will be required prior to the retrieval activities. The assessment will be unique to the type of waste being retrieved, the volume of waste excavated, and the types of wastes surrounding the retrieval target.

### 3.2.2 Waste Water Treatment Plant

The WWTP building houses the wastewater treatment process equipment, support equipment, and areas for administration and services. The WWTP building area is approximately 2 489 m<sup>2</sup>, and the building dimensions are approximately 39 m width, 64 m length and 13.5 m height with a lower height of 10 m. The WWTP structure has an approximate design life of 55 years.

The WWTP treats NSDF wastewater from the following wastewater sources: ECM leachate, ECM contact water, VDF decontamination water, WWTP Laboratory wastewater, and wastewater generated during WWTP operations including recycle flow.

The WWTP includes a dual-train system for treating NSDF-generated wastewater, and the treatment process was designed based on the results of the Leachate and Wastewater Treatability Assessment [3-76]. The WWTP treatment trains each have a treatment capacity of 3.155 L/s in a continuous final effluent discharge scenario. The process also can be operated in a batched final effluent discharge scenario. Three pumps (two duty, one standby), within the WWTP building, transfer wastewater from the Equalization Tanks to the treatment system. Each pump has a wastewater transfer capacity of up to 11.36 m<sup>3</sup>/hour, allowing a full equalization system to be emptied in 21 days of continuous operation using a single treatment train, or 10.4 days with both treatment trains online. The WWTP treated effluent conveyance system peak discharge is 12.5 L/s (45 m<sup>3</sup>/h) based on batch discharge. Based on a six hour production cycle, the WWTP can process 540 m<sup>3</sup>/day.

The WWTP process tanks and the Equalization Tanks are equipped with level instruments for monitoring purposes and are vented to atmosphere.

A simplified WWTP process flow diagram is provided in Figure 3-32, and the WWTP consists of the following systems:

- Equalization Tanks (influent flow equalization).
- Wastewater transfer system (from Equalization Tanks to WWTP).
- Chemical Precipitation Membrane Filtration.
- pH adjustment.
- Polishing treatment system.
  - Granular Activated Carbon (GAC) polishing.
  - IX resin polishing (Zeolite & strong acid cation).
- Final effluent storage and sampling.
- Residuals management- storage and filter press.
  - Spent IX resin, spent GAC media
- Chemical storage and metering.
- Process control systems.
  - Supervisory Control and Data Acquisition (SCADA) System
  - Building Automation System (BAS)
- Hardwired trips, interlocks, or alarms that are important to safety.

- Effluent conveyance and discharge.
- Compressed air system.

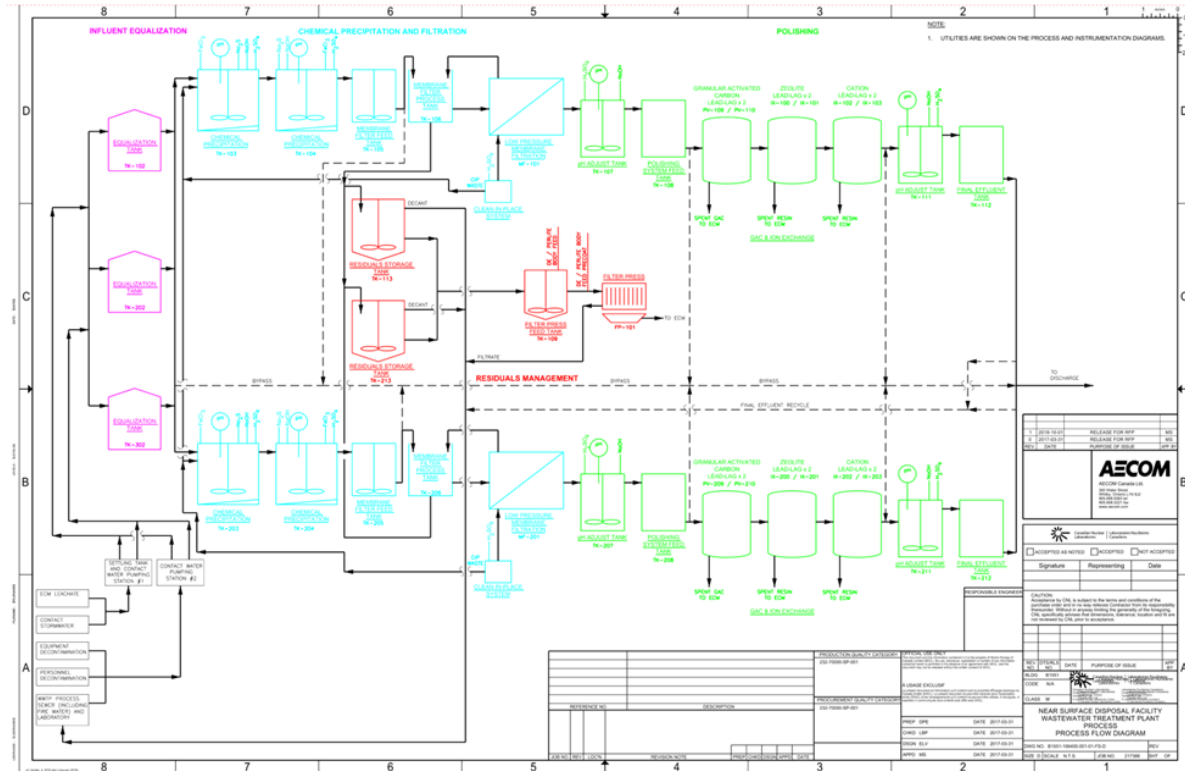


**Figure 3-32 Waste Water Treatment Plant Process Flow Diagram**

### 3.2.2.1 Waste Water Treatment Plant Safety Features and Systems Important to Safety

The design of the WWTP incorporates passive safety features to mitigate hazards to workers and the environment that may occur as a result of abnormal events. These features include Equalization Tanks secondary containment and tank overflow lines connected to active drain.

The main active engineered safety features at the WWTP include the AVS, and effluent monitoring. The WWTP AVS, removes and filters air from potentially contaminated spaces, and is provided for radiological safety Zone 3 areas within the WWTP. The NSDF includes several monitoring features to verify that radiological and non-radiological releases are within the NSDF Effluent Discharge Targets [3-78]. These ensure the safety of NSDF workers and off-site members of the public.

Table 3-15 summarizes the WWTP engineered safety features that are systems important to safety during the operations period and closure period (few years only) [3-62]. Table 3-16 summarizes the WWTP engineered safety features that are systems important to non-nuclear or conventional safety during the operations period and closure period (few years only) [3-62].

**Table 3-15**  
**Waste Water Treatment Plant Systems Important to Safety**

| Structure, System and Component                              | Safety Function                                                        | Basis for Selection/Justification                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|--------------------------------------------------------------|------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Equalization Tanks<br>Secondary<br>Containment               | Containment                                                            | Provides secondary containment from a leak or failure of Equalization Tanks or single-walled transfer piping installed within the containment boundary. Containment structure is designed to contain the maximum operational capacity of a single tank plus the accumulation of precipitation inside the secondary containment area from a 100-year storm event. The secondary containment structure is designed to withstand a 1:2 500 year seismic event (OBE). |
|                                                              | Monitor and Control                                                    | Equalization Tank concrete curb secondary containment sump is equipped with a leak detection sensor, which activates an alarm in the WWTP Control Room to inform workers of the fault condition. Monitoring of a passive engineered barrier, the Equalization Tanks secondary containment.                                                                                                                                                                        |
| Equalization Tanks Heaters                                   | Monitor and Control                                                    | Heaters and insulation protect the structural integrity of the tanks by preventing water from freezing, potentially causing them to rupture. Heat trace system monitors and control tank temperatures above freezing (4°C). System alarms notify operators of faults.                                                                                                                                                                                             |
| Equalization Tank Heating - Low Wastewater Temperature Alarm | Monitor and Control                                                    | Warn of Low-Low wastewater temperature in any Equalization Tank. Failure of the basic process control system could lead to undetected low temperature of stored wastewater, eventually leading to freezing of wastewater.                                                                                                                                                                                                                                         |
| Equalization Tank Level Control and Overflow                 | Monitor and Control                                                    | Each tank is equipped with multiple level transmitters to indicate the level inside each tank and to provide early warning (alarms). Each tank is equipped with multiple level switches that warn of high and low levels. Upon activation of the High-High Level Alarm, power is automatically removed to stop all influent LCS, LDS and contact water pumps to avoid reaching a tank overflow situation.                                                         |
| Active Drain System                                          | Containment                                                            | Floor drains in the WWTP process areas are connected to the active drainage system. The process tanks have overflow piping connected to the active drain system. The active drain provide containment of leaks and overflow of the WWTP process tanks.                                                                                                                                                                                                            |
| Active Ventilation Exhaust                                   | Provides ventilation exhaust for the removal of airborne contamination | Failure of the ventilation system exhaust has the potential to have an impact on radiological safety of the Facility personnel and could result in unacceptable levels of airborne contamination. The room air in the filter press area is continuously HEPA filtered and exhausted.                                                                                                                                                                              |

| Structure, System and Component                       | Safety Function                  | Basis for Selection/Justification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|-------------------------------------------------------|----------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Fire Protection System                                | Monitor and Control              | Building Fire Detection system provides early warning for building occupants to evacuate the building and simultaneously transmits the alarm to the CRL Fire Department to activate their emergency response protocols. Building fire separations are rated to provide the required level of protection for compartments within the building. Building is equipped with emergency and exit lighting. The communication HUB room is protected by a dry agent fire suppression system. Duct-mounted smoke detectors are installed on all air handling equipment with flow rates above 944 L/s, and on two Zone 3 HEPA filter exhaust units. Failure of the fire detection system could result in fire related exposures, injuries or damage to the building. |
| Lightning Protection System                           | Instrument/ Equipment Protection | Protects the Equalization Tanks, the monitoring and control systems, process equipment and instruments from potential high voltage/current surges as a result of a lightning strike.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
| Radiation Monitoring System in Filter Press Enclosure | Monitor and Control              | Portable, real-time alpha/beta particulate monitors (iCams). Fixed area dose-rate monitors                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

**Table 3-16**  
**Waste Water Treatment Plant Systems Important to Non-Nuclear or Conventional Safety**

| Structure, System and Component             | Safety Function     | Basis for Selection/Justification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|---------------------------------------------|---------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Chemical Feed Tanks                         | Containment         | Tanks are dual-walled. The secondary containment provides containment to prevent a release in the event of primary containment failure.                                                                                                                                                                                                                                                                                                                                                                                                                |
|                                             | Monitor and Control | The interstitial space is equipped with leak detection and alarms provide notification that liquid is collecting in the secondary containment.                                                                                                                                                                                                                                                                                                                                                                                                         |
| Chemical precipitation system interlocks    | Control             | <p>The interlocks prevent the mixing of incompatible chemicals within the WWTP process tanks.</p> <p>Chemical precipitation system interlocks:</p> <ul style="list-style-type: none"> <li>• Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running.</li> <li>• pH Low or pH High Alarm, plant held state is triggered.</li> <li>• pH Instrument fails for the tank that has pH control enabled.</li> <li>• Sodium sulphide and sulphuric acid or ferric chloride dosing pumps running together is not allowed.</li> </ul> |
| Polishing system interlocks                 | Control             | <p>The interlocks prevent the mixing of incompatible chemicals within the WWTP process tanks.</p> <p>Polishing system interlocks:</p> <ul style="list-style-type: none"> <li>• Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running.</li> <li>• pH Low or pH High Alarm, plant held state is triggered.</li> <li>• pH Instrument fails for the tank that has pH control enabled.</li> </ul>                                                                                                                             |
| Final pH adjustment interlocks              | Control             | <p>The interlocks prevent the mixing of incompatible chemicals within the WWTP process tanks.</p> <p>Final pH adjustment interlocks:</p> <ul style="list-style-type: none"> <li>• Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running.</li> <li>• pH Low or pH High Alarm, plant held state is triggered.</li> <li>• Final pH adjustment tank pH Instrument failure.</li> </ul>                                                                                                                                        |
| Hydrogen sulphide monitors in WWTP          | Monitor and Control | Hydrogen sulphide gas monitor for gas formation resulting from mixing incompatible chemicals. Alarms provide notification that hydrogen sulphide gas levels are unsafe.                                                                                                                                                                                                                                                                                                                                                                                |
| Chemical Storage Room Secondary Containment | Containment         | The secondary containment provides containment to prevent a release in the event of primary containment failure. Two storage rooms are available to store incompatible chemicals separately, and the secondary containments are not interconnected.                                                                                                                                                                                                                                                                                                    |



### 3.2.2.2 Wastewater Characterizations

Leachate quantities and characteristics were estimated based on a water balance calculation conducted with the HELP model [3-79] and [3-80]. The HELP model estimates the amount of infiltrating water from precipitation in the open active disposal cell with an area of 15 000 m<sup>2</sup> and with no cover over the waste [3-79] and [3-80]. The model uses the leachable inventory in the disposal cell that includes all of the placed bulk waste and 5% of the placed packaged waste [3-79]. Ten percent (10%) of total radionuclide activity in Table 3-17 for bulk and packaged waste is assumed placed in each disposal cell [3-79]. Waste compaction is assumed to result in the immediate failure of 5% of the waste packages [3-79]. As time progresses, waste containers are assumed to fail at a rate of 1% per year due to corrosion [3-79]. The average annual volume of wastewater expected to require treatment is about 11 000 m<sup>3</sup>.

Table 3-17 shows the radionuclide partitioning coefficients,  $K_d$  values, and the radionuclide activity concentrations in wastewater [3-79] and [3-80]. Table 3-17 shows the radionuclide partitioning coefficients,  $K_d$  values, and the non-radiological constituent concentrations in wastewater, respectively [3-79]. Table 3-18 show the non-target constituent concentrations in wastewater, [3-79] and [3-80]. Non-target constituents are not considered as COPCs, however are commonly found in leachate, industrial wastewater and in CRL groundwater [3-79]. Table 3-19 shows total volume of wastewater generated during the NSDF operations [3-79] and [3-80].

**Table 3-17**  
**Radionuclide Activity Concentrations in Wastewater [3-79] and [3-80]**

| Radionuclide | $K_d$ (ml/g) | Activity Concentration (Bq/L) |
|--------------|--------------|-------------------------------|
| Ag-108m      | 1600         | 1.8E-04                       |
| Am-241       | 953          | 2.8E-03                       |
| Am-243       | 953          | 1.7E-06                       |
| C-14         | 16.7         | 3.1E+00                       |
| Cl-36        | 2.13         | 5.9E-02                       |
| Co-60        | 113          | 1.3E+03                       |
| Cs-135       | 175          | 4.1E-05                       |
| Cs-137       | 175          | 9.3E-01                       |
| H-3          | 0            | 1.4E+05                       |
| I-129        | 3.69         | 9.1E-02                       |
| Mo-93        | 10.5         | 4.1E-07                       |
| Nb-94        | 429          | 1.5E-02                       |
| Ni-59        | 205          | 1.7E-04                       |
| Ni-63        | 205          | 4.4E-02                       |
| Np-237       | 851          | 6.3E-07                       |
| Pu-239       | 596          | 4.4E-03                       |
| Pu-241       | 596          | 7.9E-02                       |
| Pu-242       | 596          | 3.3E-06                       |
| Ra-226       | 673          | 6.4E-04                       |
| Se-79        | 119          | 2.4E-05                       |
| Sn-126       | 534          | 7.2E-06                       |
| Sr-90        | 18.2         | 9.6E+00                       |
| Tc-99        | 0.403        | 5.7E+00                       |
| Th-230       | 841          | 2.2E-04                       |

|        |     |         |
|--------|-----|---------|
| Th-232 | 841 | 9.6E-04 |
| U-233  | 290 | 2.9E-05 |
| U-234  | 290 | 7.8E-03 |
| U-235  | 290 | 3.3E-04 |
| U-238  | 290 | 7.6E-03 |
| Zr-93  | 822 | 4.4E-02 |

**Table 3-18**  
**Non-radiological Constituents Concentrations in Wastewater [3-79]**

| Constituent                      | K <sub>d</sub> (ml/g) | Concentration (mg/L) |
|----------------------------------|-----------------------|----------------------|
| 1,1,2,2-Tetrachloroethane        | 4.27                  | 1.4E-03              |
| 1,1,2-Trichloroethane            | 2.71                  | 2.2E-03              |
| 1,4-Dichlorobenzene              | 17.4                  | 3.5E-04              |
| Acetone                          | 0.0792                | 6.9E-01              |
| Anthracene                       | 816                   | 4.3E-06              |
| Antimony                         | 3600                  | 3.3E-07              |
| Arsenic                          | 16.3                  | 3.1E-04              |
| Barium                           | 146                   | 7.1E-04              |
| Benzene                          | 6.62                  | 1.5E-03              |
| Benzo(a)pyrene                   | 31500                 | 1.1E-07              |
| Beryllium                        | 643                   | 1.9E-06              |
| Bis(2-ethylhexyl) phthalate      | 6600                  | 4.4E-06              |
| Boron                            | 4.20                  | 1.2E-01              |
| Cadmium                          | 179                   | 2.9E-06              |
| Carbon tetrachloride             | 1.95                  | 2.9E-03              |
| Chromium (total)                 | 20.5                  | 2.5E-04              |
| Chlorobenzene                    | 10.7                  | 7.6E-04              |
| Chloroform                       | 1.40                  | 6.6E-03              |
| Chrysene                         | 9440                  | 3.7E-07              |
| Cobalt                           | 113                   | 2.7E-03              |
| Copper                           | 386                   | 8.0E-04              |
| Dioxin                           | 5840                  | 2.7E-13              |
| Ethylene dibromide               | 1.75                  | 8.1E-03              |
| Fluoranthene                     | 2840                  | 1.2E-06              |
| Fluorene                         | 452                   | 7.8E-06              |
| Fluoride (aq)                    | 0                     | 1.2E-01              |
| Furan                            | 5840                  | 2.7E-13              |
| Lead                             | 218                   | 2.4E-05              |
| Mercury (aq)                     | 44.1                  | 2.3E-06              |
| Methylene chloride               | 0.95                  | 2.8E-02              |
| Molybdenum                       | 10.5                  | 3.9E-03              |
| Nitrate                          | 0                     | 6.6E+00              |
| Nitrite                          | 0                     | 2.65E-01             |
| Nickel                           | 205                   | 5.5E-05              |
| Phenol                           | 10.70                 | 5.7E-04              |
| Phenolic compounds - no chlorine | 14.6                  | 7.0E-04              |

| Constituent         | K <sub>d</sub> (ml/g) | Concentration (mg/L) |
|---------------------|-----------------------|----------------------|
| PCB                 | 12400                 | 2.5E-08              |
| Selenium            | 119                   | 4.8E-05              |
| Silver              | 1600                  | 3.2E-06              |
| Tetrachloroethylene | 4.27                  | 1.4E-03              |
| Thallium            | 54.3                  | 3.8E-06              |
| Tin                 | 534                   | 5.8E-04              |
| Vanadium            | 314                   | 4.3E-04              |
| Zinc                | 239                   | 1.6E-03              |

**Table 3-19**  
**Average Wastewater Volumes Generated during the NSDF Operation [3-79] and [3-80]**

|                            | Time (yr)    |              |              |              |              |              |              |              |              |              |           |
|----------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|-----------|
|                            | 0-5          | 5-10         | 10-15        | 15-20        | 20-25        | 25-30        | 30-35        | 35-40        | 40-45        | 45-50        | 50+       |
| Cell 1                     | Active 10995 | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 4.5 |
| Cell 2                     | ---          | Active 10995 | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 4.5 |
| Cell 3                     | ---          | ---          | Active 10995 | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 4.5 |
| Cell 4                     | ---          | ---          | ---          | Active 10995 | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 4.5 |
| Cell 5                     | ---          | ---          | ---          | ---          | Active 10995 | Final 15     | Final 15     | Final 15     | Final 15     | Final 15     | Final 4.5 |
| Cell 6                     | ---          | ---          | ---          | ---          | ---          | Active 10995 | Final 15     | Final 15     | Final 15     | Final 15     | Final 4.5 |
| Cell 7                     | ---          | ---          | ---          | ---          | ---          | ---          | Active 10995 | Final 15     | Final 15     | Final 15     | Final 4.5 |
| Cell 8                     | ---          | ---          | ---          | ---          | ---          | ---          | ---          | Active 10995 | Final 15     | Final 15     | Final 4.5 |
| Cell 9                     | ---          | ---          | ---          | ---          | ---          | ---          | ---          | ---          | Active 10995 | Final 15     | Final 4.5 |
| Cell 10                    | ---          | ---          | ---          | ---          | ---          | ---          | ---          | ---          | ---          | Active 10995 | Final 4.5 |
| Decon water                | 100          | 100          | 100          | 100          | 100          | 100          | 100          | 100          | 100          | 100          | 0         |
| Total (m <sup>3</sup> /yr) | 11095        | 11110        | 11125        | 11140        | 11155        | 11170        | 11185        | 11200        | 11215        | 11230        | 45        |

### 3.2.2.3 Equalization Tanks (Influent Flow Equalization)

The influent equalization system is designed to contain 4 710 m<sup>3</sup> of contact water that would be produced from the largest cell of the ECM during back-to-back 100 year, 24-hour storm events. Three above-grade, covered tanks, constructed of SS, each with a capacity of 1 900 m<sup>3</sup> (and a combined capacity of 5 700 m<sup>3</sup>), will provide the required equalization volume. The equalization volume was selected to contain the worst-case contact water flow, as well as provide adequate buffer capacity for ongoing WWTP operations.

#### **3.2.2.4 Chemical Precipitation**

The chemical precipitation is designed for removal of metals and radionuclides that can be chemically precipitated from the wastewater. Each treatment train includes two chemical precipitation tanks operated in series for the addition of ferric chloride, sodium sulphide, sodium hydroxide, and sulphuric acid. The chemical precipitation tanks are:

- Constructed of 316 L stainless steel, with closed tops, access hatches and sloped bottoms.
- Sized to provide a minimum of 20 minutes of hydraulic detention time at the design flow rate of 11.36 m<sup>3</sup>/hour.
- Equipped with a variable speed mixer, a pH probe to automatically control chemical feed pumps to maintain a set-point pH, and a sampling port.

#### **3.2.2.5 Membrane Filtration**

The membrane filtration system is designed for removal of heavy metals and radionuclides that can be filtered from the wastewater. Membrane filtration provides nearly complete removal of suspended solids from the chemically-pretreated wastewater, and effectively eliminates the presence of suspended solids in the filtered effluent. The membrane filtration system is specified to achieve an effluent suspended solids concentration less than 5 mg/L. Each membrane filtration treatment train includes a membrane filter feed tank, membrane filter process tank, membrane filtration skid, and Clean-in-Place (CIP) system. The membrane filter feed tanks are sized to provide eight hours of hydraulic retention time at a flow rate of 11.36 m<sup>3</sup>/hour. The membrane filter feed tanks and process tanks are closed top, flat bottom vertical cylindrical tanks constructed of 316 SS.

#### **3.2.2.6 pH Adjustment Tanks**

The pH adjustment tanks are:

- Closed top, flat bottom, vertical cylindrical tanks constructed of 316 SS.
- Sized to provide 20 minutes of hydraulic detention time at the design flow rate of 11.36 m<sup>3</sup>/hour.
- Equipped with a mixer, pH probe and controller, and level instrument. The pH controller is used to automatically control chemical feed pumps to maintain a selected set-point pH within the required effluent discharge pH range.

#### **3.2.2.7 Granular Activated Carbon Polishing**

Granular activated carbon adsorption is used for removal of organic COPC, which may be present in the NSDF wastewater. The GAC vessels, constructed of 316 SS, contain approximately 860 kg or a minimum of 1.93 m<sup>3</sup> of GAC and provide 1.3 m of GAC depth with an empty bed contact time of more than 10 minutes.

#### **3.2.2.8 Ion Exchange Resin Polishing**

The IX process provides polishing treatment for removal of low concentrations of metals and radionuclides that remain after chemical precipitation and membrane filtration. The results of the pilot scale test, illustrate that Strong Acid Cation (SAC) exchange resin can remove heavy metals and radionuclide surrogates such as strontium to very low concentrations, in many cases below detection limit. Zeolite was demonstrated to be effective for removal of cesium.

Resin capacity was demonstrated during the pilot scale test to be 712 bed volumes to breakthrough of strontium from SAC resin, and 792 bed volumes to breakthrough for cesium removal on zeolite resin. It should be noted that, concentrations of strontium and cesium in the pilot scale test wastewater simulant are several orders of magnitude higher than that expected in the WWTP wastewater.

The IX vessels constructed of 316 SS, contain 1.93 m<sup>3</sup> of zeolite (cesium removal) per vessel, 2.55 m<sup>3</sup> of SAC resin (heavy metals and cationic radionuclides removal) per vessel, provide 1.3 m of resin depth and an empty bed contact time of more than 10 minutes.

The design has the capability and the flexibility to accommodate future changes in wastewater chemistry and the IX resins can be changed to mitigate unforeseen influent wastewater characteristics. In addition, a future third set of IX vessels can be added if required for future process optimization. Once operational data is available, IX resin selection can be optimized for efficiency and reduced secondary waste. Although anionic radionuclides are not projected to be present in the NSDF wastewater at concentrations that exceed discharge requirements, anion resin vessels can also be operated in the IX treatment trains, if required to reduce the concentrations of anionic radionuclides during the operating period of the ECM.

Samples of the effluent from each GAC and IX vessel are taken on a periodic basis, depending on the frequency and duration of WWTP operation, to confirm treatment effectiveness and determine when breakthrough of the target contaminants from the lead vessel occurs. Breakthrough in the lead vessel will signify a need to replace the resin.

#### **3.2.2.9 Final Effluent Storage and Sampling**

Treated effluent from the final pH adjustment tanks, is conveyed by gravity to the final effluent storage tanks, each sized for eight hours of hydraulic detention time at the design flow rate of 11.36 m<sup>3</sup>/hour. The final effluent storage tanks provide storage of final effluent for sampling, prior to discharge. The tanks constructed of SS are closed top, flat bottom, vertical cylindrical tanks. Effluent samplers are provided for automatic collection of composite effluent samples. Flow meters measure and totalize the final effluent that is discharged from the WWTP. Final effluent is discharged to the exfiltration gallery or to Perch Lake.

#### **3.2.2.10 Residuals Management – Storage and Filter Press**

The residuals management system is designed for handling and de-watering of residuals generated as a by-product of wastewater treatment process.

The residuals storage tanks constructed of 316 SS are closed top, vertical cylindrical tanks with cone bottom and a capacity of approximately 80 m<sup>3</sup>. The tanks are equipped with a mixer, level instruments, and decant ports. The filter press feed tank constructed of 316 SS is closed top, vertical cylindrical tank with cone bottom, and a capacity of 9.5 m<sup>3</sup>.

The WWTP generated residuals are dewatered residuals from the chemical precipitation process, and spent media from the GAC and IX polishing processes. Based upon the projected wastewater quantity and characteristics, and results of laboratory and pilot scale tests, the annual quantity of dewatered residuals is expected to be approximately 42 m<sup>3</sup>/year, and the annual quantity of spent GAC and IX resin is expected to be approximately 17 m<sup>3</sup>/year and 30 m<sup>3</sup>/year, respectively. De-watered residuals and dewatered spent GAC and IX resins are transported to the ECM for disposal. After de-watering, any remaining void space in the spent resin container would be grouted prior to disposal in the ECM.

Based on the projected wastewater quantity and characteristics, and results of pilot scale tests, an average of approximately 1 to 2 m<sup>3</sup>/day of liquid residuals is estimated to be generated from the chemical precipitation and membrane filtration process, with a solids concentration ranging from 15 000 to 50 000 mg/L. The estimated dry mass of residuals is 35 kg/day, prior to addition of body feed and pre-coat chemicals.

#### **3.2.2.10.1 Filter Press**

Results of the pilot scale test, indicate that a body feed dosage of 25% of the dry solids in the residuals was effective in enhancing de-waterability characteristics, including higher cake solids concentration and more effective release of the dewatered cake from the filter cloths.

The filter press is located on the first floor in the residuals management area of the WWTP building. The recessed chamber filter press is a packaged system that includes a manufacturer-supplied programmable logic controller to automatically control the functions of the filter press. The filter press de-watering operation is a batch process, consisting of filling the press with residuals for de-watering, building pressure to complete the de-watering process, and opening the press to allow de-watered residuals to be removed. The filter press is equipped with a pre-coat system to apply a thin layer of diatomaceous earth or Perlite to the filter press cloths prior to filling the press with residuals. The estimated pre-coat requirement is 43 kg/m<sup>3</sup> of filter press volume. After applying the pre-coat that enhances residuals de-waterability, the filter press is filled with residuals from the filter press feed tank, gradually building the pressure in the filter press to approximately 690 kPa.

The filter press plates are opened to allow dewatered residuals that have formed between the filter press plates and cloths, to drop into a transport container located below the filter press. Optional styles of transport containers are compatible with the filter press operation, including a B25 box, or a soft-sided container. The soft-sided container is positioned in a collapsible frame located beneath the filter press during de-watering and discharge of de-watered filter cake.

Based on the results of the pilot scale test, it is expected that the dewatered residuals will have a solids content in excess of 30%, with a density of 1 390 kg/m<sup>3</sup>. The filter press is specified to achieve minimum dewatered cake solids of 30%.

#### **3.2.2.11 Chemical Storage and Metering**

The chemical storage and metering systems support the WWTP processes. Acid chemicals are stored in Chemical Storage Room #1 and caustic chemicals in Chemical Storage Room #2, to avoid the mixing of incompatible chemicals in the event of a spill. Chemical spills in the Chemical Rooms are not directed to floor drain, but contained in trenches and dry sumps around the chemical feed tanks. Liquid chemicals are transferred from totes or drums to chemical feed tanks for metering to each chemical dosing location.

Two chemical feed tanks, each with a volume of 600 L, are provided for the chemicals:

- Sodium sulphide, 15% solution as Na<sub>2</sub>S.
- Sulphuric acid, 93% solution as H<sub>2</sub>SO<sub>4</sub>.

Two chemical feed tanks, each with a volume of 1 000 L, are provided for the chemicals:

- Ferric chloride, 38% solution as FeCl<sub>3</sub>.
- Sodium hydroxide, 50% solution as NaOH.

The metering pumps are variable speed, and pumping rates will be controlled to achieve the selected set-point pH or chemical dose that is based on the flow of metered wastewater. An isolation valve and ball check valve are provided at each chemical dosing point of application. The ball check valve provides positive shutoff when the pump stops and prevents the chemical line from draining and adding unwanted chemical into the process. Pressure relief valves in the chemical feed systems relieve system pressure in the event the chemical feed pump operates against a closed valve either at the chemical precipitation tank or elsewhere in the pump discharge.

### **3.2.2.12 Process Control Systems**

The process control system provides the process information and alarms required to make operational decisions in a timely manner. The complete process control system consists of field instruments, Local Control Panels, Chemical Unloading Panels, PLC Control Panels, PLCs, SCADA system, vendor package PLCs, and Operator Interface Terminals. The process control system is designed for 24/7 availability and utilizes components with a level of reliability suitable to the operating requirements. Field equipment and instruments feedback information to the PLCs, which control the WWTP process and the contact water pump stations. The SCADA system enables remote operation and monitoring of the processes.

#### **3.2.2.12.1 Supervisory Control and Data Acquisition System**

The SCADA system, located in the Control Room, provides monitoring and supervisory control of the WWTP processes, the Contact Water pump stations, and the Leachate Transfer System (LCS and LDS), to allow the workers to monitor and control the process equipment. The requirements design of the SCADA system is described in the SCADA Program and Design Report [3-81].

The SCADA system logs all the alarms, historical data from field instruments and equipment status, and events (events are worker-initiated events such as set-point changes). Data logged by the SCADA system are available for diagnostic and troubleshooting purposes, to provide the workers with incident management capability. The SCADA system alerts the WWTP staff, via alarms, when critical process parameters are outside of acceptable limits, and when worker attention is required to investigate and address these alarm conditions. Where bypass options are provided in the process design, provisions are made to monitor bypass status in SCADA.

### **3.2.2.13 Compressed Air System**

The air compressor room is located on the second floor of the WWTP and includes dual air compressors and filters to ensure continuity of compressed air supply. The compressed air system feeds air operated process equipment (membrane filter, filter press, de-watering system) and the breathing air system. Two breathing air stations are provided for the filter press enclosure (lower and upper levels). The breathing air system includes six stages of air filtration in accordance with CSA Z180.1 for air quality. The compressed air system is provided with Class III power in the event of a Class IV power outage.

### **3.2.2.14 Effluent Discharge System**

Treated effluent is discharged to the Perch Lake watershed either through the exfiltration gallery and/or by pumping to Perch Lake. The treated effluent conveyance system has been designed to transfer the peak flow generated by the WWTP. The two discharge paths for the treated effluent are:

- Gravity piping to the exfiltration gallery.

- Forcemain and gravity piping system to Perch Lake.

#### **3.2.2.14.1 Exfiltration Gallery**

The exfiltration gallery discharge is located adjacent to the WWTP within the Perch Lake Watershed, and is sized to accommodate the peak discharge rate of 6.3 L/s based on native soil hydraulic conductivity parameters. The location and footprint of the exfiltration gallery is maximized to approximately 1 000 m<sup>2</sup>. The exfiltration gallery makes use of underground storage chambers surrounded with crushed stone at a total storage depth of approximately 1 m. The discharge flow rate to the exfiltration gallery will be limited, depending on the elevation of the groundwater table. Three monitoring wells are provided for monitoring the groundwater elevations.

For discharge to the exfiltration gallery, the effluent flow path is via groundwater to East Swamp Stream, the nearest surface water body providing aquatic habitat. A dilution factor of approximately seven is estimated for this discharge pathway, based on the ratio of the estimated annual effluent discharge rate of 11 230 m<sup>3</sup>/year to the receiving water body, East Swamp Stream, average flow rate of approximately 73 000 m<sup>3</sup>/year.

#### **3.2.2.14.2 Perch Lake Discharge**

Groundwater monitoring in proximity to the exfiltration gallery has indicated that groundwater elevation under spring conditions is near ground level. Groundwater flow modelling has also indicated that under high seasonal groundwater conditions discharge to the exfiltration gallery will result in flooding at the exfiltration gallery. It is therefore anticipated that under spring conditions all effluent will be discharged to Perch Lake to ensure that the water table remains below grade at the exfiltration gallery and there is no flooding. Under summer conditions when the water table is lower and the volume of wastewater generated is lower, effluent will be routed to the exfiltration gallery.

Real time groundwater monitoring wells will be installed in proximity to the exfiltration gallery and provide water table elevation. The water table elevation data will be used to determine when the treated effluent can be discharged to the exfiltration gallery.

Centrifugal pumps (three pump system), located within the WWTP, will be used to convey effluent through dual containment HDPE piping with leak detection, routed along WWTP Access Road, East Mound Road, South Mound Road, and ultimately along the Access Road to Perch Lake. The pipeline is installed at a depth below the anticipated maximum frost penetration depth. Leak detection stations are provided at 100 m spacing to allow for inspection of the pipeline at various locations. A submerged diffuser in Perch Lake will be used to disperse the effluent.

### **3.2.3 NSDF Site Infrastructure and Support Facilities Systems Important to Safety**

Table 3-20, summarizes the NSDF site infrastructure and support facilities engineered safety features that are systems important to safety during the operations period and closure period (few years only) [3-62].



**Table 3-20****Near Surface Disposal Facility Site Infrastructure and Support Facilities Systems Important to Safety**

| Structure Systems and Components          | Safety Function                                                              | Basis for Selection/Justification                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
|-------------------------------------------|------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Class III Power                           | Provide emergency back-up power to safety SSCs during Class IV power outages | Class III Generator operates on an unlimited supply of natural gas. Generator will provide power to the individual components of the “active” SSCs, which require electricity to perform their safety functions during normal Class IV power Outages.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Class II Power                            | Battery Back-Up Power                                                        | Uninterruptable battery power supplies will provide power to the SCADA system and critical input instruments to continue to log critical parameters for 30 minutes after loss of Class III power and unavailability of Class IV. Class II power is commonly used in buildings at CRL for emergency lighting, exit lighting, security, and fire monitoring systems.                                                                                                                                                                                                                                                                                                                                                                                               |
| Fire Water System                         | Fire Protection                                                              | A network of fire hydrants will be provided to service the NSDF support facilities. A ventilated and heated fire pump house is located on top of the fire water storage tanks. The FWPS houses the fire pump control panels, an automated transfer switch to redirect power from Class IV to Class III if needed, the fire pumps and supply lines.<br>Failure of the fire water system could diminish response capability and result in greater fire-related injuries and/or exposures in the event of a fire.                                                                                                                                                                                                                                                   |
| VDF Fire and Radiation Protection Systems | Fire Protection                                                              | Failure of the fire detection system could result in fire related exposures, injuries or damage to the building.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|                                           | Radiation Protection Monitor and Control                                     | Portable, real-time alpha/beta particulate monitors (iCams) and fixed area dose-rate monitors. Failure of the Continuous Air Monitor (CAM) systems, could result in a loss of indication of elevated airborne contamination levels in the buildings and has the potential to have an impact on radiological safety of the Facility personnel. Provides audible and visual alarms for excessive alpha/beta/gamma-in-air particulate activity levels in accordance with RP requirements. Provides personnel with early indication of a potential release of airborne contaminants, due to waste management activities. If the airborne concentration exceeds the set point (as determined by RP), an audible alarm annunciates and a red visual alarm illuminates. |
| Carbon monoxide monitor in VDF*           | Monitor and Control                                                          | Carbon monoxide gas monitoring. Alarms provide notification that carbon monoxide gas levels are unsafe.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| Operations Support Center - Fire          | Fire Protection                                                              | Failure of the fire detection system could result in fire related exposures, injuries or damage to the building.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |

| Structure Systems and Components                | Safety Function | Basis for Selection/Justification                                                                                |
|-------------------------------------------------|-----------------|------------------------------------------------------------------------------------------------------------------|
| protection Systems                              |                 |                                                                                                                  |
| Administration Office Fire Protection System    | Fire Protection | Failure of the fire detection system could result in fire related exposures, injuries or damage to the building. |
| Kiosks (North and South) Fire Protection System | Fire Protection | Failure of the fire detection system could result in fire related exposures, injuries or damage to the building. |

**Note:** \* Non-nuclear or Conventional Safety

### 3.2.4 Containment

The NSDF design and operation will provide containment during the operations phase through preventing and controlling the release of nuclear and/or hazardous substances.

The NSDF Project has considered measures to contain and isolate waste during placement, specifically to minimize/prevent contact water and radionuclide migration. The principles of isolation and containment [3-1], are satisfied in the inventory management, design features and planned operational practices. Further, the NSDF Project is assessing additional measures to minimize contact water that are considered an optimization to the current proposed NSDF design and safety basis.

#### Inventory Management

The inventory proposed for the NSDF is solid LLW, which will be controlled through the NSDF WAC [3-63]. The WAC [3-63] applies a graded approach to control leachate radionuclide concentrations during placement of waste. There will be a small portion of waste, which will be required to utilize robust packaging to isolate the waste from precipitation and prevent the spread of contamination. Specifically, leachate controlled waste packages are intended to provide short-term barriers for wastes with higher radionuclides concentrations during the time the disposal cell is not covered with the final cover system (approximately 5-10 years). Thus, more mobile radionuclides, such as tritium, are kept isolated from the environment to minimize liquid effluent releases during the operations phase.

#### Design Features and Planned Operational Practices

Containment of the disposed LLW in the NSDF is controlled through engineered barriers including the ECM base liner system, ECM perimeter berm and the final cover system that are designed to perform multiple safety functions for at least 550 years.

The NSDF includes a number of design features to minimize the generation of wastewater (including contact water) including:

- Limiting the active cell area to 21 000 m<sup>2</sup>.
- The separate management of contact water, and non-contact water within the ECM.
- The use of interim covers over waste areas that will be inactive for greater than 30 days.

These design features are discussed in Sections 3.2.1.2, Section 3.2.1.6, Section 3.2.1.9, and Section 3.2.1.10.

During waste placement operations, all efforts are made to minimize the contact of precipitation with the contaminated waste thus, minimizing contact water and leachate generation. The operation of the NSDF is limited to one open cell at a time to limit the surface area of waste that is exposed to the environment (i.e., precipitation) at any given time. As a cell is constructed, interim covers are placed over the waste to limit

infiltration of precipitation and promote non-contact surface water run-off. As each disposal cell is completed, the final cover system is installed over the filled disposal cell. Other operational practices to limit contact with precipitation include grading (i.e., minimum 2% slope) and compaction of the waste fill to promote surface water run-off.

During the operations phase, sacrificial liners are used on top of the waste (as part of the interim cover) and the base liner systems to divert storm water into the non-contact water collection areas (ponds). A sacrificial liner for Phase 1 is provided to cover the entire floor. An interim cover is applied to 3:1 side-slope areas to prevent storm water from entering the LCS system at non active cells. The temporary sacrificial liners on the ECM floor and as part of the interim cover will be removed, cell by cell, prior to placement of the waste and final cover materials. The waste is also covered with an interim cover composed of a 0.3 m layer of soil or sand overlain with a sacrificial liner that minimizes precipitation infiltration into the waste matrix.

Non-contact water in the ECM is managed and contained using the non-contact water ponds. Non-contact water that is analyzed to be free of contamination is pumped out of the ECM and released through the surface water management ponds.

Containment of contact water in the ECM is managed and contained using contact water ponds and sacrificial liners. Contact water is transferred to the Equalization Tanks and then to the WWTP for processing.

Furthermore, containment of any contact water generated is managed using the ECM LCS, ECM LDS, Equalization Tanks and the WWTP. Any water run-off that makes contact with (or is suspected to have contacted) the contaminated waste, will be diverted to a contact water pond and conveyed to the WWTP for treatment to remove contaminants prior to controlled release into the environment. Treated effluent discharge targets [3-107], are established to be protective of human and non-human biota health.

#### **Additional Measures:**

Additional measures that could be taken to keep the waste dry during waste handling, placement and storage (operation), and minimize precipitation infiltration into the active disposal cell are being considered including assessing the feasibility of using a conceptual weather cover structure over the open disposal cell to minimize contact water and precipitation infiltration [3-113]. Minimizing precipitation infiltration into the active disposal cell will reduce the volume of leachate and contact water generated in the ECM. However, this concept will increase the volume of water that is managed as non-contact water within the surface water management system [3-113].

The weather cover structure is considered to be an optimization of the current design and the ECM can be operated effectively without the weather cover structure [3-113].

### **3.3 Waste Inventory**

The projected waste volumes and inventory of significant radionuclides (activities) in bulk and packaged waste were developed by CNL and are documented in the NSDF Reference Inventory Report [3-82]. The NSDF Reference Inventory [3-82] has been used to inform the design and safety analyses. The Licensed Inventory is a modified reference inventory, and represents a maximum radiological inventory limit for the NSDF.

The NSDF radiological waste inventory was developed by using the main steps [3-82]:

1. Assemble characterization data obtained or derived from waste package records, facility decommissioning and environmental remediation projects.
2. Assess the data against the WAC and report total radioactivity and radionuclide concentrations.

3. Evaluating the reference inventory against the long-term safety criteria to confirm the radiological inventory provides acceptable results in the PostSA.
4. Produce the Licensed Inventory [3-62] representing a maximum radiological inventory limit for the NSDF.

Figure 3-33 provides a graphic representation of the iterative process that led to the development of the NSDF Reference Inventory and the Licensed Inventory. Table 3-21 provides the projected volume by waste type for the NSDF and Figure 3-34 provides a graphic representation of the projected volume by waste type for the NSDF [3-82]. The NSDF Reference Inventory [3-82] and the NSDF Licensed Inventory [3-62] are in Table 3-22 that provides:

- The NSDF reference inventory [3-82], the proposed total activity of significant radionuclides at placement and at closure, including the radionuclide activity of bulk and packaged wastes, used as an input to the design and safety analyses; and
- The NSDF Licensed Inventory [3-62] defines the maximum radioactivity of significant radionuclides at placement and at closure.

Wastes being disposed in the NSDF, are organized into six physical waste types defined by material type, and are [3-63]:

**Type 1 Waste** – Soil and soil-like wastes that includes contaminated soils and other waste materials with characteristics similar to soil, that can be placed within the mound with little to no handling requirements beyond what would be required for the disposal of soil.

**Type 2 Waste** – Co-mingled radioactive waste, debris, refuse, soil, and soil-like waste that includes wastes that are anticipated to be at least 50% soil or soil-like in nature. Type 2 waste also contains varying amounts of radioactive wastes that require additional handling procedures beyond those for Type 1 wastes.

**Type 3 Waste** – Non-soil-like waste that includes materials that can be excavated and handled as bulk materials, but do not have the physical characteristics of soil and soil-like materials. Type 3 waste includes process wastes, highly organic wastes, highly compressible wastes, flowing wastes, and similar waste types.

**Type 4 Waste** – This refers to decommissioning and demolition waste that includes typical materials used in construction, such as: concrete, asphalt, brick, lumber, structural steel, process equipment, piping, wood and other building materials produced by decommissioning and demolition activities.

**Type 5 Waste** – Packaged Waste, refers to wastes contained in rigid packages. There are two types of rigid waste packages: Non-Leachate Controlled Waste Packages and Leachate Controlled Waste Packages. Liners and soft-sided packages are not considered Type 5 waste.

Non-Leachate Controlled Waste Packages are waste packages that must be able to contain the waste until placement in the NSDF including intermodal containers (e.g., 6.1 m ISO container), steel waste boxes (e.g., B-25 boxes) and drums (e.g., 205 L drum).

Leachate Controlled Waste Packages are waste packages that provide waste containment during the time that the disposal cell is not covered with the final cover (approximately 5-10 years). Containment of the waste can be provided by the final waste form itself, or by using approved overpacks or waste processing methods.

**Type 6 Waste** – Oversize debris, includes waste that does not fall within the definition of waste Types 1 through 5, primarily by its size and shape. The Infrequently Performed Operations process [3-83], is used to approve the placement and disposal of Type 6 wastes.

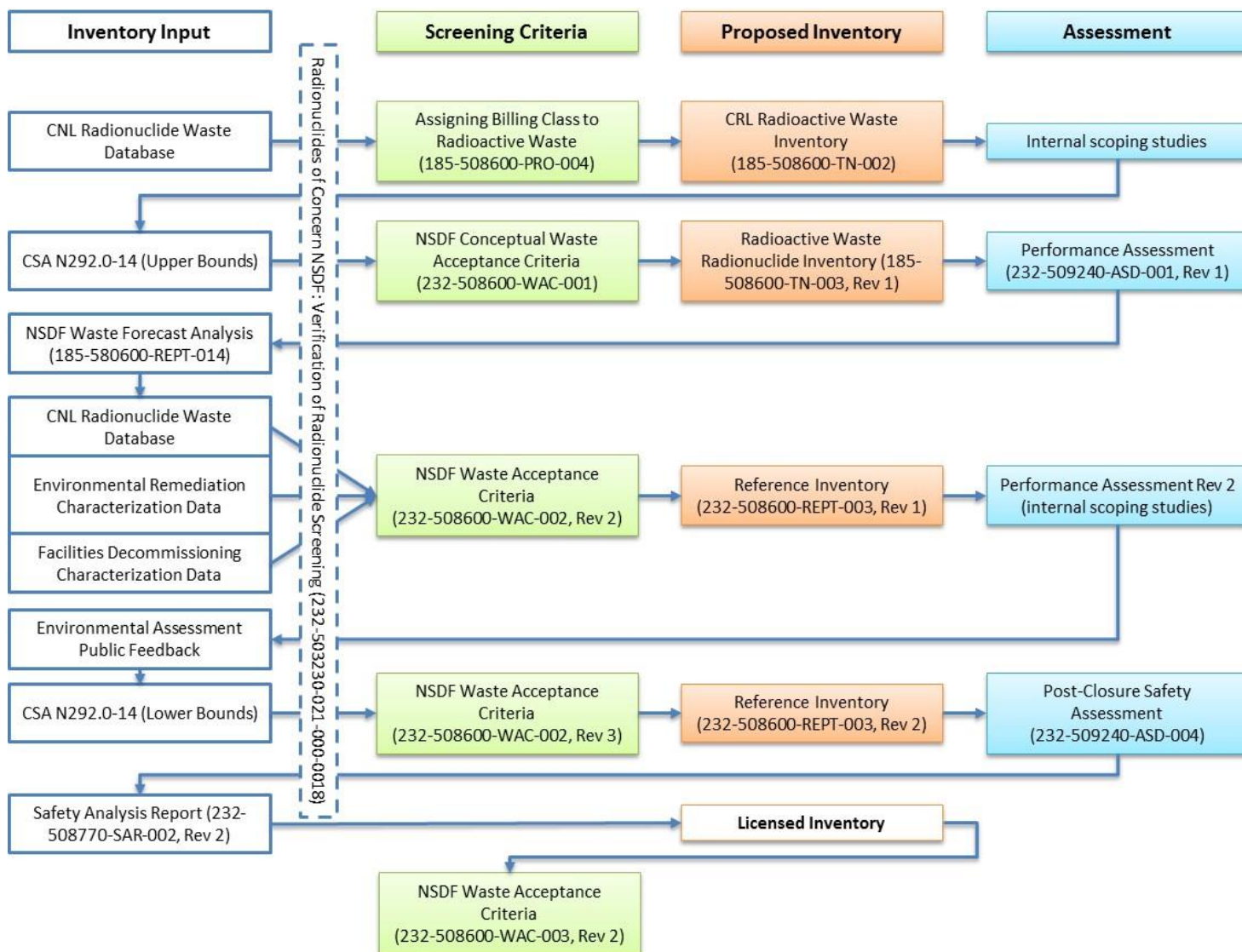


**Figure 3-33 NSDF Reference and Licensed Inventory Development Iterative Process**

**Table 3-21**  
**Projected NSDF Waste Volumes, by Waste Type [3-82]**

| Waste Type                           | Initial Volume Distribution Estimate (m <sup>3</sup> ) | Additional Waste Added (m <sup>3</sup> ) | Volume Distribution Used for the Reference Inventory (m <sup>3</sup> ) | Volume after Linear Extrapolation to 1 000 000 m <sup>3</sup> (m <sup>3</sup> ) |
|--------------------------------------|--------------------------------------------------------|------------------------------------------|------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| Type 1: Soil and Soil-Like           | 363 451                                                | 60 500 <sup>(a)</sup>                    | 423 951                                                                | 472 432                                                                         |
| Type 2: Co-mingled refuse            | 60 967                                                 |                                          | 60 967                                                                 | 67 939                                                                          |
| Type 3: Non-Soil-Like                | 170                                                    |                                          | 170                                                                    | 189                                                                             |
| Type 4: Decommissioning & Demolition | 282 791                                                |                                          | 282 791                                                                | 315 130                                                                         |
| Type 5: Packaged Waste               | 119 753                                                | 260 <sup>(b)</sup>                       | 120 013                                                                | 133 737                                                                         |
| Type 6: Oversized Debris             | 9 488                                                  |                                          | 9 488                                                                  | 10 573                                                                          |
| Total                                | 83 620                                                 | 60 760                                   | 897 380                                                                | 1 000 000                                                                       |

Note <sup>a</sup>: This volume represents the compacted waste volume from soil stored in WMA F.

Note <sup>b</sup>: This volume represents solidified stored liquid waste, which was being explored for disposal in NSDF when the reference inventory was being developed.

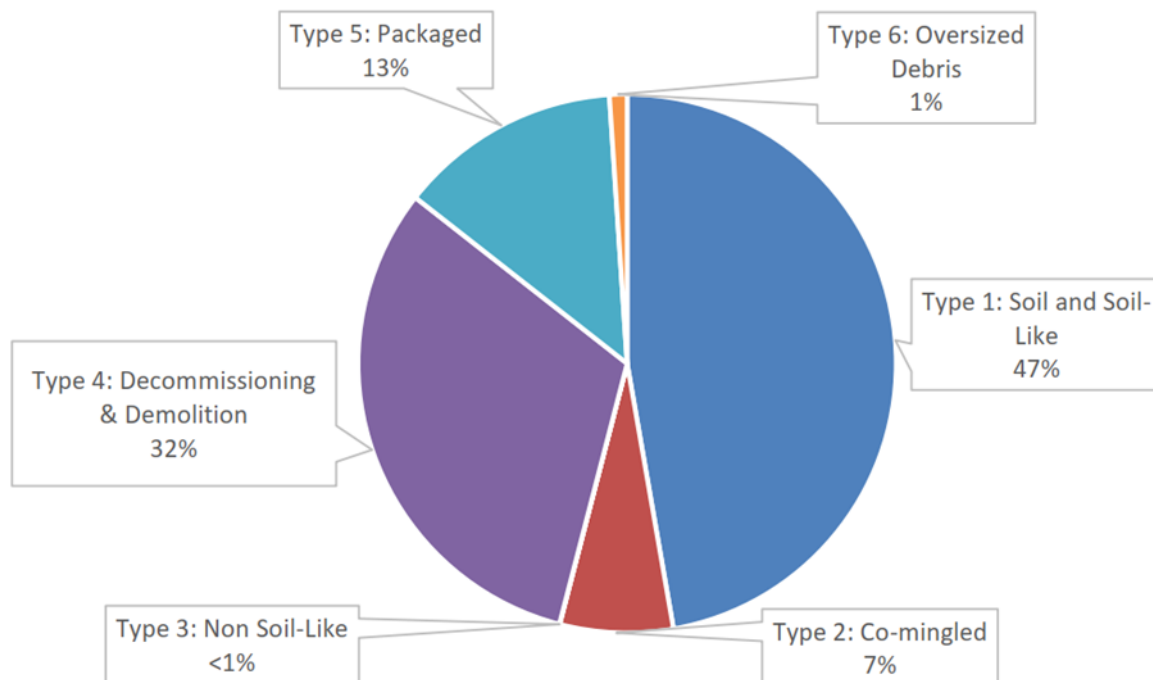


**Figure 3-34 Projected Volume Distribution for the NSDF by Waste Type [3-82]**

**Table 3-22**  
**NSDF Reference Inventory and Licensed Inventory**

| Radionuclide | Reference Inventory [3-82]       |                                | Licensed Inventory [3-62]          |                                  |
|--------------|----------------------------------|--------------------------------|------------------------------------|----------------------------------|
|              | Total Activity (Bq) at Placement | Total Activity (Bq) at Closure | Maximum Activity (Bq) at Placement | Maximum Activity (Bq) at Closure |
| Ag-108m      | 2.73E+10                         | 2.62E+10                       | 2.73E+10                           | 2.62E+10                         |
| Am-241       | 6.04E+10                         | 9.74E+10                       | 6.04E+10                           | 9.74E+10                         |
| Am-243       | 5.26E+07                         | 5.24E+07                       | 5.26E+07                           | 5.24E+07                         |
| C-14         | 1.71E+12                         | 1.70E+12                       | 1.71E+12                           | 1.70E+12                         |
| Cl-36        | 3.97E+09                         | 3.97E+09                       | 3.97E+09                           | 3.97E+09                         |
| Co-60        | 9.06E+16                         | 1.47E+16                       | 9.06E+16                           | 1.47E+16                         |
| Cs-135       | 5.19E+08                         | 5.19E+08                       | 5.19E+08                           | 5.19E+08                         |
| Cs-137       | 5.59E+12                         | 3.17E+12                       | 5.59E+12                           | 3.17E+12                         |
| H-3          | 8.91E+14                         | 2.79E+14                       | 8.91E+14                           | 2.79E+14                         |
| I-129        | 3.03E+10                         | 3.03E+10                       | 1.75E+10                           | 1.75E+10                         |
| Mo-93        | 1.47E+05                         | 1.47E+05                       | 1.47E+05                           | 1.47E+05                         |
| Nb-94        | 2.34E+10                         | 2.34E+10                       | 2.34E+10                           | 2.34E+10                         |
| Ni-59        | 1.21E+09                         | 1.21E+09                       | 1.21E+09                           | 1.21E+09                         |
| Ni-63        | 3.11E+11                         | 2.59E+11                       | 3.11E+11                           | 2.59E+11                         |
| Np-237       | 1.74E+07                         | 1.74E+07                       | 1.74E+07                           | 1.74E+07                         |
| Pu-239/240   | 8.77E+10                         | 8.76E+10                       | 5.07E+10                           | 5.06E+10                         |
| Pu-241       | 1.67E+12                         | 5.84E+11                       | 1.67E+12                           | 5.84E+11                         |
| Pu-242       | 6.32E+07                         | 6.32E+07                       | 6.32E+07                           | 6.32E+07                         |
| Ra-226       | 3.65E+10                         | 3.61E+10                       | 3.65E+10                           | 3.61E+10                         |
| Se-79        | 9.26E+07                         | 9.26E+07                       | 9.26E+07                           | 9.26E+07                         |
| Sn-126       | 1.24E+08                         | 1.24E+08                       | 1.24E+08                           | 1.24E+08                         |
| Sr-90        | 6.05E+12                         | 3.35E+12                       | 6.05E+12                           | 3.35E+12                         |
| Tc-99        | 3.16E+11                         | 3.16E+11                       | 3.16E+11                           | 3.16E+11                         |
| Th-230       | 5.30E+09                         | 5.30E+09                       | 5.30E+09                           | 5.30E+09                         |
| Th-232       | 2.70E+10                         | 2.70E+10                       | 2.70E+10                           | 2.70E+10                         |
| U-233        | 2.74E+08                         | 2.74E+08                       | 2.74E+08                           | 2.74E+08                         |
| U-234        | 6.88E+10                         | 6.88E+10                       | 6.88E+10                           | 6.88E+10                         |
| U-235        | 2.96E+09                         | 2.96E+09                       | 2.96E+09                           | 2.96E+09                         |
| U-238        | 7.57E+10                         | 7.57E+10                       | 7.57E+10                           | 7.57E+10                         |
| Zr-93        | 4.92E+11                         | 4.92E+11                       | 4.92E+11                           | 4.92E+11                         |

### 3.3.1 Non-Radiological Waste Inventory

The NSDF WAC [3-63] requires non-radiological COPCs present in waste to meet Ontario Regulation 347 Land Disposal Treatment Requirements prior to disposal. Table 3-23 provides the list of key non-radiological COPC, and the lower and maximum estimated leachable quantities [3-84]. Table 3-24 provides the estimated quantity of metals disposed of in the NSDF at closure [3-84]. Table 3-25 provides the estimated quantity of

organic materials disposed of in the NSDF at closure [3-84]. Dry active waste is assumed to be 10% organic materials including mop heads, cotton based clothing, paper, and wipes [3-84].

**Table 3-23**  
**Key Non-Radiological Constituents of Potential Concern [3-84]**

| Chemical Name              | Chemical Abstract System Number | Estimated Leachable Quantity (kg) |         |
|----------------------------|---------------------------------|-----------------------------------|---------|
|                            |                                 | Lower                             | Maximum |
| 1,1,2,2-Tetrachloroethane  | 79-34-5                         | 3.1E+01                           | 1.2E+02 |
| 1,1,2-Trichloroethane      | 79-00-5                         | 3.1E+01                           | 1.2E+02 |
| 1,4-Dichlorobenzene        | 106-46-7                        | 3.1E+01                           | 1.2E+02 |
| Acetone                    | 67-64-1                         | 8.2E+02                           | 3.2E+03 |
| Anthracene                 | 120-12-7                        | 1.7E+01                           | 6.8E+01 |
| Antimony                   | 7440-36-0                       | 5.9E+00                           | 2.3E+01 |
| Arsenic                    | 7440-38-2                       | 2.6E+01                           | 1.0E+02 |
| Barium                     | 7440-39-3                       | 5.1E+02                           | 2.0E+03 |
| Benzene                    | 71-43-2                         | 5.1E+01                           | 2.0E+02 |
| Benzo[a]pyrene             | 50-32-8                         | 1.7E+01                           | 6.8E+01 |
| Beryllium                  | 7440-41-7                       | 6.2E+00                           | 2.4E+01 |
| Bis(2-ethylhexyl)phthalate | 117-81-7                        | 1.4E+02                           | 5.6E+02 |
| Boron                      | 7440-42-8                       | 2.6E+03                           | 1.0E+04 |
| Cadmium                    | 7440-43-9                       | 2.6E+00                           | 1.0E+01 |
| Carbon tetrachloride       | 56-23-5                         | 3.1E+01                           | 1.2E+02 |
| Chromium (Total)           | 7440-47-3                       | 2.6E+01                           | 1.0E+02 |
| Chromium VI                | 18540-29-9                      | 2.6E+01                           | 1.0E+02 |
| Chlorobenzene              | 108-90-7                        | 4.1E+01                           | 1.6E+02 |
| Chloroform                 | 67-66-3                         | 5.1E+01                           | 2.0E+02 |
| Chrysene                   | 218-01-9                        | 1.7E+01                           | 6.8E+01 |
| Cobalt                     | 7440-48-4                       | 1.5E+03                           | 6.0E+03 |
| Copper                     | 7440-50-8                       | 1.5E+03                           | 6.0E+03 |
| Dioxin (TEQ)               | 9014-42-0                       | 7.7E-06                           | 3.0E-05 |
| Ethylene dibromide         | 106-93-4                        | 7.7E+01                           | 3.0E+02 |
| Fluoranthene               | 206-44-0                        | 1.7E+01                           | 6.8E+01 |
| Fluorene                   | 86-73-7                         | 1.7E+01                           | 6.8E+01 |
| Fluoride (aqueous)         | 16984-48-8                      | NA                                | 3.6E+02 |
| Furan (TEQ)                | 110-00-9                        | 7.7E-06                           | 3.0E-05 |



| Chemical Name                       | Chemical Abstract System Number | Estimated Leachable Quantity (kg) |         |
|-------------------------------------|---------------------------------|-----------------------------------|---------|
|                                     |                                 | Lower                             | Maximum |
| Lead                                | 7439-92-1                       | 2.6E+01                           | 1.0E+02 |
| Mercury                             | 7439-97-6                       | 5.1E-01                           | 2.0E+00 |
| Methylene Chloride                  | 75-09-2                         | 1.5E+02                           | 6.0E+02 |
| Molybdenum                          | 7439-98-7                       | 2.0E+02                           | 8.0E+02 |
| Nitrate                             | 14797-55-8                      | 5.1E+03                           | 2.0E+04 |
| Nitrite                             | 14797-65-00                     | NA                                | 8.0E+02 |
| Nickel                              | 7440-02-0                       | 5.6E+01                           | 2.2E+02 |
| Phenol                              | 108-95-2                        | 3.2E+01                           | 1.2E+02 |
| Phenolic compounds, non-chlorinated | NA                              | 5.1E+01                           | 2.0E+02 |
| Polychlorinated Biphenyls (PCB)     | 1336-36-3                       | 1.5E+00                           | 6.0E+00 |
| Selenium                            | 7782-49-2                       | 2.9E+01                           | 1.1E+02 |
| Silver                              | 7440-22-4                       | 2.6E+01                           | 1.0E+02 |
| Tetrachloroethylene                 | 127-18-4                        | 3.1E+01                           | 1.2E+02 |
| Thallium                            | 7440-28-0                       | 1.0E-00                           | 4.0E+00 |
| Tin                                 | 7440-31-5                       | 1.5E+03                           | 6.0E+03 |
| Vanadium                            | 7440-62-2                       | 6.6E+0                            | 2.6E+03 |
| Zinc                                | 7440-66-6                       | 1.8E+03                           | 7.2E+03 |

**Table 3-24**  
**Estimated Quantity of Metals in NSDF at Closure [3-84]**

| Metal    | Estimated quantities of metal in NSDF (kg) |               |
|----------|--------------------------------------------|---------------|
|          | Waste Metal                                | Package Metal |
| Aluminum | 32 966                                     | 0             |
| Copper   | 3 519 725                                  | 0             |
| Iron     | 1 790 389                                  | 8 651 507     |
| Lead     | 177 988                                    | 0             |

**Table 3-25**  
**Estimated Quantity of Organic Materials in NSDF at Closure [3-84]**

| Organic Material | Estimated Volume (m <sup>3</sup> ) | Density (kg/m <sup>3</sup> ) | Total Estimated Mass (kg) |
|------------------|------------------------------------|------------------------------|---------------------------|
| Wood             | 83 256                             | 753                          | 62 691 798                |
| Dry Active Waste | 36 688                             | 481                          | 17 647 136                |
| Total            | 119 944                            | -                            | 80 338 934                |

### 3.3.2 Uncertainties Associated with the Waste Inventory

Uncertainties associated with the NSDF waste inventory are managed by using values that are conservative and defensible. These uncertainties are discussed in detail in Section 6.2.

The uncertainty with the non-radiological source term is managed through the CNL waste characterization process and adherence to the NSDF WAC [3-63]. The following aspects contribute to the uncertainties associated with the NSDF waste inventory:

- The quality and accuracy of information recorded in the CNL waste database.
- Waste characterization process used.
- The CNL waste database for package radioactivity represents a package's radioactivity at the time of generation and decay is not applied to package radioactivity records [3-82] which ultimately leads to conservatism.
- The CNL waste database records only represent packages generated from 1995 to 2015 [3-82].
- The use of "hot-spot" measurements to represent the average radioactivity of an entire package which leads to conservatism.
- Gross alpha and beta measurements were used to estimate concentrations of alpha and low energy beta emitting radionuclides.

### 3.4 Regulatory Requirements and International Guidance Addressed by the Facility Design

Section 1.6 of this document, describes the regulatory framework for the NSDF Project and the applicable regulatory requirements and international guidance. The safety case in Appendix B, Concordance Tables, addresses the requirements of REGDOC-2.11.1, Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management [3-85] and REGDOC-2.9.1 - Environmental Protection: Environmental Principles, Assessments and Protection Measures [3-86]. In addition, Appendix B contains concordance tables for Disposal of Radioactive Waste [3-1], Near Surface Disposal Facilities for Radioactive Waste [3-2], and The Safety Case and Safety Assessment for the Disposal of Radioactive Waste [3-87].

Structures, Systems and Components in the NSDF design, that are considered important to safety, have been classified following the intent and principles of REGDOC-2.5.2, Design of Reactor Facilities: Nuclear Power Plants [3-88]. The key sections from REGDOC-2.5.2 [3-88] applicable to safety classifications are:

- Section 5.7 requires the SSCs be classified [3-88], and
- Section 7.1 further requires that the design authority shall classify SSCs using a consistent and clearly defined classification method, and in addition that SSCs be identified as “important to safety” or “not important to safety” [3-88].

### **3.5 Radiological, Thermal, Hydraulic, Mechanical, Chemical and Biological Processes That May Affect the Facility**

This section following the guidance in SSG-23 [3-87], provides a description of radiological, thermal, hydraulic, mechanical, chemical and biological processes that may affect the disposal system. Table 3-26 summarizes how these processes interact with the elements of the disposal system.

**Table 3-26**  
**Processes Affecting the Waste Management System**

| <b>Processes</b> | <b>Waste Management System Component</b>                                                                                       |                                                                                                                                                                                                                                                                                                    |                                                                                                                     |                                                                                                                                                                                                                                                                                                          |
|------------------|--------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                  | <b><i>Waste Inventory</i></b>                                                                                                  | <b><i>Waste Form / Packaging</i></b>                                                                                                                                                                                                                                                               | <b><i>Engineered Barriers</i></b>                                                                                   | <b><i>Natural Barriers/Host Environment</i></b>                                                                                                                                                                                                                                                          |
| Radiological     | Limits on radiation and contamination (Section 5.6 of the Safety Case) influence the type and amount of radionuclides present. | Waste packages are not credited for limiting the migration of contaminants in the long term (Section 4.1.10.1 of the Safety Case). Leachate controlled packages are assumed to limit the release of contaminants to the leachate during the operations phase (Section 3.2.2.2 of the Safety Case). | No effect, radiation fields too low to affect the geosynthetics (Sections 5.3.4.5 and 6.6.3.5.1 of the Safety Case) | The release rate of contaminants exiting the facility lead to acceptable environmental concentrations and radiological dose consequence to both the public receptors and non-human biota due to the natural attenuation of the geosphere and surrounding environment (Section 8.1.5 of the Safety Case). |
| Thermal          | Not Applicable*                                                                                                                | Not Applicable*                                                                                                                                                                                                                                                                                    | Not Applicable*                                                                                                     | Not Applicable*                                                                                                                                                                                                                                                                                          |
| Hydraulic        | No effect                                                                                                                      | The majority of the wastes are compacted soil and building debris.                                                                                                                                                                                                                                 | Engineered drainage system leads to no effect until after the                                                       | There are two potential water pathways for radionuclides leaving                                                                                                                                                                                                                                         |

|            |                                                |                                                                                                                                                                                                                                                   |                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                                                                                             |
|------------|------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            |                                                | The compaction of the wastes limits the waste porosity, thus limiting the infiltration of water, which limits contaminant mobility (Section 8.1.6 of the Safety Case).                                                                            | Institutional Control Period (ICP) (Table 3-8 and Section 8.1.6 of the Safety Case). Effects of erosion following the ICP have been assessed (Section 4.1.9.3 of the Safety Case).              | the ECM: groundwater flow paths from beneath the ECM to Perch Creek and while bath-tubbing occurs, water may overtop the perimeter berm and move down slope towards Perch Creek. (Section 4.1.5 of the Safety Case.) This information has been incorporated throughout Section 4.1 of the Safety Case.                                      |
| Mechanical | No effect                                      | The slope stability analysis assumes proper compaction during seismic events (Section 5.3.2.4 of the Safety Case). Subsidence is limited by proper compaction so that the engineered barriers aren't affected (Section 8.1.6 of the Safety Case). | Barriers designed for the expected forces (Sections 5.3.2 and 5.3.3 of the Safety Case).                                                                                                        | The CRL site is considered to be in the Canadian Shield, a stable rock formation and the proposed ECM is to be constructed on or near the bedrock. Structures founded on bedrock are in general seismically resistant because the motion is not amplified as much as the ones founded on overburden (See section 8.1.5 of the Safety Case). |
| Chemical   | Placed waste affects the chemistry of the ECM. | The use of grout to fill void space in packages and concrete from building debris may affect the chemistry in the ECM and subsequently the rate of leaching.                                                                                      | Predicted chemistry has no detrimental effect on the geosynthetics (Sections 4.3.4, 5.3.4.2 and 6.6.3.5.1 of the Safety Case). Chemical dust control agents must be approved to ensure they are | The NSDF site is in the Perch Lake basin, an extremely well understood and characterized area; thus, there is good understanding of chemical processes in the natural environment. This information has been incorporated throughout Section                                                                                                |

|            |                                                                                                                                                                                                                 |                                                                                                                                                                                                                 |                                                                                                                             |                                                                                                                                                                                                                                                                        |
|------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|            |                                                                                                                                                                                                                 |                                                                                                                                                                                                                 | compatible with the geosynthetics. (Section 7.2.6 of the Safety Case)                                                       | 4.1 of the Safety Case.                                                                                                                                                                                                                                                |
| Biological | Organics in the waste stream are subject to biological processes. Type and quantity of organics will determine the type and magnitude of the effects. (Section 3.3.1 of the Safety Case for expected inventory) | Organics in the waste stream are subject to biological processes. Type and quantity of organics will determine the type and magnitude of the effects. (Section 3.3.1 of the Safety Case for expected inventory) | Discussed in Section 6.6.3.5.1 of the Safety Case. Effects are accounted for in the design of the Engineered Barrier system | The NSDF site is in the Perch Lake basin, an extremely well understood and characterized area; thus, there is good understanding of biological processes in the natural environment. This information has been incorporated throughout Section 4.1 of the Safety Case. |

\* Note that the NSDF waste inventory is LLW thus, is not heat generating; therefore there are no thermal effects.

### Radiological

The NSDF only accepts LLW; thus, limiting the inventory of radioactive species in the ECM. Section 5.6 of the Safety Case discusses this in more detail. Waste packages and waste forms are not credited for limiting the migration of contaminants in the long term (Section 4.1.10.1 of the Safety Case). Leachate controlled packages are assumed to limit the release of contaminants to the leachate during a portion of the operations phase (Section 3.2.2.2 of the Safety Case). Note that radioactive decay and ingrowth will affect any radionuclides released from the waste packages into the repository. There is no effect on the engineered barriers from radiation fields as the radiation fields are too low to affect the geosynthetic clay liners and geomembranes (Sections 5.3.4.5 and 6.6.3.5.1 of the Safety Case), and would have no effect on the other materials in the engineered barriers (e.g., sand, gravel etc.). The natural barriers of the geosphere and surrounding environment attenuate any contaminant that may leave the facility and lead to acceptable environmental concentrations and radiological consequence to both the public receptors and non-human biota (Section 8.1.5 of the Safety Case).

### Thermal

Note that the NSDF waste inventory is LLW and is not heat generating; therefore, there are no thermal effects on the waste inventory, waste forms/packages, engineered barriers or the natural barriers. Similarly, heat production resulting from chemical or biological processes occurring in the ECM is expected to be low [3-39] and have no effect on the waste inventory, waste forms/packages, engineered barriers or the natural barriers.

### Hydraulic

Hydraulic effects are limited to interactions between the NSDF and precipitation, groundwater and surface water. Hydrogeological modelling was completed to estimate the groundwater flow pathways from the ECM, and the rates of groundwater flow from the NSDF Project site under operations and post-closure conditions [3-19]. Within the ECM footprint, groundwater flow is from the northeast, flowing towards the south-western

perimeter berm of the ECM. Subsequently in the post-closure phase, water flows south out of the ECM discharging into Perch Creek. Given the groundwater flow patterns, and the location of the ECM relative to Perch Lake and Perch Creek, there is no potential for release to Perch Lake. Based on hydrogeological models, the travel time in the post-closure phase, from the ECM to Perch Creek is approximately 7 years [3-19], for the majority of particles. Once radionuclides reach the surface water, they are assumed to be quickly transported to the Ottawa River [3-19].

Hydraulic and hydrogeological processes that may affect the NSDF include: infiltration, precipitation, saturation/desaturation, and movement of groundwater [3-39]. These processes may impact the mobility of contaminant migration from the ECM and may alter exposure pathways and, therefore, are included in the PostSA [3-39].

The waste inventory has no impact on the hydraulic process; however the waste forms and packages do. The majority of the wastes are in the form of compacted soil and building debris. The compaction of the wastes limits the waste porosity, thus limiting the infiltration of water and subsequently, contaminant mobility (Section 8.1.6 of the Safety Case). The engineered drainage system incorporated in the final cover ensures there is no effect from hydraulic processes (e.g., extreme precipitation events leading to erosion) until after the ICP (Table 3-10 and Section 8.1.6 of the Safety Case) as the final cover will be remediated if damage is noticed during routine inspections. The effects of erosion on the final cover system and perimeter berm following the ICP have been assessed (Section 4.1.9.3 of the Safety Case) and incorporated throughout Section 4.1 of the Safety Case. With respect to natural barriers, there are two potential water pathways for radionuclides leaving the ECM: groundwater flow paths from beneath the ECM to Perch Creek and while bath-tubbing occurs, water may overtop the perimeter berm and move down slope towards Perch Creek, (Section 4.1.5 of the Safety Case). This information has been incorporated throughout Section 4.1 of the Safety Case.

### Mechanical

Mechanical processes, including differential settlement and the impact of the ECM load on underlying material, is assessed in the Bearing Capacity, Settlement, and Earth Pressure Analysis [3-89].

The waste inventory will have no effect on the mechanical aspects of the ECM. The waste form/package will have an effect on the mechanical performance of the ECM. The slope stability analysis for seismic events assumes waste compaction meeting specifications has been performed (Section 5.3.2.4 of the Safety Case). Also, subsidence is limited by waste compaction meeting the specifications so that the engineered barriers are not affected (Section 8.1.6 of the Safety Case). The engineered barriers of the ECM have been designed for the expected forces they would experience (Sections 5.3.2 and 5.3.3 of the Safety Case). Differential settlement of the base liner system is not expected to significantly affect leachate drainage, and is not expected to cause tensile cracking of the CCL within the base liner system [3-89]. The ECM is located on or close to the bedrock, therefore, it will not likely be affected by mechanical processes and conditions in the geosphere, particularly those occurring at great depth [3-39]. This natural barrier (bedrock) mitigates the effects of a seismic event, because the motion is not amplified as much as in overburden (See Section 8.1.5 of the Safety Case).

### Chemical

Chemical processes may influence the degradation of materials within the NSDF and impact contaminant mobility [3-39]. Some of these chemical processes will arise from biological processes; thus, there is a strong link between these two processes in the ECM. Chemical processes and conditions are accounted for in the assessment of all post-closure scenarios [3-39].

The waste placed in the ECM will affect the chemistry of the leachate during the Operations phase and what radiological and non-radiological contaminants are released from the ECM and the rate at which they are released during the Post-closure phase. Canadian Nuclear Laboratories has incorporated the predicted inventory of radiological and non-radiological contaminants throughout the analysis presented in Section 4.1 of the Safety Case.

The waste form and waste packages are subject to chemical processes. The use of grout to fill void space in and around packages and concrete from building debris affects the chemistry in the ECM and subsequently the rate of leaching. As the grouted waste form degrades its hydraulic conductivity increases, and flow of water through the waste form increases [3-39]. Degradation of organic material can yield acetic acid under non-reducing conditions. However, oxygen within the facility is expected to be rapidly consumed and reducing conditions are expected to be attained fairly rapidly. Under reducing conditions, it is expected that organic degradation rates would decrease, and organic acids, including acetic acid, present in the ECM would be consumed and converted to methane [3-90] and [3-91]. Moreover, the initial production of acetic acid is not likely to lead to low pH conditions (i.e.,  $\text{pH} \approx 5$ ) because of the neutralizing capacity of the soils, concrete and other concrete-like materials placed in the Facility. Degradation of concrete materials produces bases such as calcium hydroxide, which would neutralize any acid generated by organic degradation. Even if the pH was lower, the results of the PostSA [3-39] and summarized in Section 4.1 of the Safety Case would not be affected, because although a lower pH would increase metal corrosion rates and hence shorten the lifetimes of metal packages, it is assumed that packages provide no containment after ECM closure.

The predicted chemistry in the ECM has no detrimental effect on the geosynthetic clay liners or geomembranes (Sections 4.3.4, 5.3.4.2 and 6.6.3.5.1 of the Safety Case) which form part of the engineered barriers. During the Construction and Operations phases, chemical dust control agents must be approved to ensure that they are compatible with the geosynthetic clay liners or geomembranes, (Section 7.2.5 of the Safety Case). With regard to natural barriers, the NSDF site is in the Perch Lake Basin, an extremely well understood and characterized area; thus, there is good understanding of chemical processes in the natural environment. This information has been incorporated throughout Section 4.1 of the Safety Case.

### Biological

Organics in the waste stream are subject to biological processes. The type and quantity of organics will determine the type and magnitude of the effects (See section 3.3.1 of the Safety Case for the expected organic inventory). Waste stream projections for organics are estimated at about 10% of the total ECM waste volume. The vast majority of the waste will be soils and the majority of organics is wood waste from facilities decommissioning. The volume of highly decomposable organic waste is anticipated to be small at less than 1% compared to the total waste volume of the ECM [3-90].

Biological/biochemical processes may affect the behaviour and mobility of contaminants in the NSDF and surrounding area. Biological activity may affect conditions relevant to corrosion, contaminant mobility, radionuclide release, and gas generation [3-39]. Organic materials such as wood, may be degraded by microbial activity leading to formation of organic complexing agents [3-39].

The potential for degradation of organic material (largely wood), has been accounted for in the design of the engineered barrier system and discussed in Section 5.3.3 of the Safety Case. The degradation of wood has been assessed and the resultant subsidence is not expected to lead to undue strains on the geomembranes (See Section 5.3.3.1 of the Safety Case). With regard to natural barriers, the NSDF site is in the Perch Lake Basin, an extremely well understood and characterized area; thus, there is good understanding of biological processes in the natural environment. This information has been incorporated throughout Section 4.1 of the Safety Case.

### **3.6 Possible Environmental Changes and Impacts on the NSDF**

Environmental changes and impacts on the Facility have been analyzed in the EIS, [3-29] and the PostSA, [3-39], as part of the normal evolution and disruptive events scenarios. The normal evolution of the waste disposal system in the post-closure period, addresses normal conditions where changes in the contaminants and waste, facility, geosphere and biosphere are considered over thousands of years. Environmental changes are part of the FEPs screening, and scenarios and models are developed by examining the FEPs that could affect the long-term performance and safety of the Facility.

#### **3.6.1 Climate Change**

Climate change is a FEP that was used to develop scenario assessed in the PostSA [3-39]. Climate change in the post-closure period is anticipated to lead to warmer and wetter conditions at the NSDF ECM. The increased rainfall and higher temperatures will lead to increased evapotranspiration and may lead to accelerated erosion of the engineered cover. In this case, the increase in evapotranspiration is greater than the increase in rainfall, leading to a reduction in Hydrologically Effective Rainfall [3-39]. The reduction in Hydrologically Effective Rainfall leads to lower infiltration through the final cover into the ECM, lower groundwater flow rates, and reduced creek and river flows. The frequency of extreme events such as extreme rain, is predicted to increase, although, the magnitude of bounding events is unlikely to be impacted.

#### **3.6.2 Earthquake**

Within the 10 000 year assessment timeframe, a DBE is not expected to affect the safety function of the final cover, base liner system and perimeter berm [3-49]. The Seismic Analysis [3-49] results indicated that global failure with loss of containment is very unlikely for the ECM during a DBE. The ECM is designed for the DBE with a rate of return of 10 000 years.

The effects of more severe earthquakes (beyond design basis) on the ECM are considered as Disruptive Event Scenarios and are assessed in the PostSA [3-39]. Any potential damage resulting from a beyond design basis event occurring during the period of IC would be remediated. Any damage occurring beyond IC would result in the reduction of resistivity provided by the resistive layers.

The buildings in use during the pre-closure period are not expected to be affected by seismic activity and are designed for the OBE with a return period of 2 500 years.



### 3.6.3 Flooding

The Facility would not be directly affected by a flooding event since the surface elevations at the NSDF site range from a low of 156 mASL near the north side of Perch Lake, to a high of 197 mASL at the crest of the ridge that separates Perch Lake and Ottawa River drainage basins. The ECM elevations range from approximately 163 mASL to 202 mASL, which correspond to the lowest elevation of the base liner system and highest elevation of the final cover system, respectively. This is further evidenced by the fact that the low point of the NSDF has an elevation of approximately 156 mASL, which is higher than the 100 year flood elevation of 115 mASL and the CRL design basis flood level of 122 mASL, for this portion of the Ottawa River [3-7].

Flooding of the ECM in the post-closure period has been considered in the PostSA in the form of bathtubting assessments. These assessments consider the effect of the final cover failing while the base liner remains intact, thereby resulting in water gathering within the ECM and spilling out over the side.

### 3.7 Interactions between System Components

The interactions between systems components, both active and passive, are required for the NSDF operation. Following closure of the ECM, interactions between ECM components will be minimal as the ECM components are all passive. Leachate will drain from the passive LCS, however will cease, due to the final cover.

### 3.8 Time Dependent Changes in Properties and Behavior of System Components and Their Interfaces

Time dependent changes in the NSDF ECM are analyzed in the PostSA [3-39]. A fundamental objective of the waste disposal strategy is to contain and isolate the disposed LLW in the NSDF ECM for a sufficiently long time, to ensure that post-closure doses to the critical receptors and environmental concentrations are not of concern. This was determined by analysis of the degradation of the ECM engineered barriers, including the final cover degradation resulting in bath-tubbing and the subsequent potential mobilization of contaminants from the Facility into the geosphere and eventually the biosphere. Three flows through the ECM represent transport of contaminants through the near-field and into the geosphere [3-39]:

- Flow with intact final cover and base liner system.
- Flow with degraded final cover, but base liner system remains intact.
- Flow with degraded final cover and base liner system.

The time dependent changes associated with the final cover and base liner system degradation are [3-39]:

- The performance of the final cover has degraded by 37%<sup>1</sup> at the end of the 550 year design life of the ECM. Even if the GMB has significantly degraded, the GCL will significantly limit infiltration into the ECM.
- The final cover degrades quickly beyond the design life. The final cover is assumed to fully degrade at 650 years after the closure period in the post-closure period. Infiltration through the degraded final cover is similar to that through natural soils.

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<sup>1</sup> This value is determined by the assumption that the final cover has fully degraded at 650 year, and the assumed logarithmic increase in the infiltration rate as the final cover degrades.

- The infiltration rate of precipitation through the final cover increases as the final cover degrades. This will increase the height of leachate/water on the base liner and will increase leakage through the base liner, such that leakage balances infiltration.
- Bathtubbing would most likely occur between 450 years and 4 100 years after the closure period in the post-closure period, when the final cover degrades and the base liner is intact. The maximum flow over the perimeter berm occurs at 650 years after the closure period in the post-closure period. Note that this is based on the conservative modelling assumption that the water mounding in the waste occurs shortly after the 300 year ICP, which is earlier than the final cover system's end of design life.
- Post-650 years after the closure period, flow over the perimeter berm progressively decreases, and flow out the base liner progressively increases, as the base liner degrades.
- At 3 250 years after the closure period, the geosphere adjacent to the perimeter berm has reached its drainage capacity.
- The ECM base liner CCL will perform for at least several thousand years, and possibly longer.
- For the NES, the base liner CCL starts to degrade at 650 years after construction of the base liner and has fully degraded 5 000 years post-closure.
- As the base liner degrades, drainage/leakage through the base liner of the ECM will increase.
- As the base liner continues to degrade, the leachate/water level in the ECM will continue to fall and eventually there will be predominantly vertical flow through the ECM, with the recharge through the base liner equal to the infiltration through the final cover.
- Between 3 250 years to 4 100 years after the closure period, the base liner is continuing to degrade, but the geosphere adjacent to the perimeter berm has reached its drainage capacity. Therefore, flow over the perimeter berm does not continue to decrease from 3 250 years to 4 100 years, and flow out of the base liner adjacent to the perimeter berm does not continue to increase.
- At 4 100 years after the closure period, the base liner has fully degraded. The base liner no longer directs water towards the perimeter berm, and leachate/water drains through the base liner across the whole ECM footprint.

The total radioactivity in the ECM decreases by over three orders of magnitude in the first 100 years after ECM closure, as short-lived radionuclides decay. Thereafter the total radioactivity in the ECM decreases slowly as only long-lived radionuclides remain.

### **3.9 Radionuclide Migration Pathways (Normal Evolution and Disruptive Events)**

Detailed information of the radionuclide pathways identified for normal and disruptive events is given in the PostSA [3-39]. These pathways also apply to the non-radiological contaminants that remain in the Facility.

The radionuclide migration pathways during the operations period include:

- Precipitation infiltrates the ECM and flows through the waste layers to the base liner system (leachate).
- Leachate migrates to the ECM LCS.
- Any leachate that leaks through the primary liner migrates to the ECM LDS.
- Leachate is transferred from the ECM into the Equalization Tanks and ultimately into the WWTP for treatment.

- Leachate migrates through the ECM base liner system and leaks into the soil below the ECM, and migrates through the soil into the groundwater and discharges to Perch Creek.
- Discharge of treated WWTP effluent to the Exfiltration Gallery. The contaminants migrate into the groundwater water and discharges to Perch Lake basin wetlands.
- Discharge of treated WWTP effluent to Perch Lake. Perch Lake drains into Perch Creek and ultimately the Ottawa River (surface water pathway).
- Airborne emissions are both gaseous and particulate matter, from waste disposed in the ECM, and releases from the Equalization tanks and the WWTP process tanks.

The radionuclide contaminant migration pathways in the near field and geosphere during the post-closure period normal evolution and disruptive events include:

- Precipitation infiltrates the ECM and flows into the waste layers to the base liner system.
- Transport of contaminants within the waste is by advection and diffusion.
- Leachate migrates through the ECM base liner system into the soil below the ECM, and migrates through the soil into the groundwater.
- Groundwater discharges to Perch Creek.

The radionuclide contaminant migration pathways in the biosphere during the post-closure period normal evolution and disruptive events include:

- Discharge of potentially contaminated groundwater to Perch Creek.
- Overland flow/interflow of potentially contaminated leachate and sediment transport over the berm (erosion).
- Exchange between Perch Creek bed sediments and Perch Creek water.
- Mixing and dilution of Perch Creek water with Ottawa River water.
- Exchange between Ottawa River water and river shore sediments.
- Root uptake from soil to plant and decay from plant to soil.
- Incidental ingestion of soil by animals and fertilization of soil by animals.
- Ingestion of Perch Creek water by animals.
- Ingestion of plants by animals.
- Uptake by plants from the atmosphere (C-14), losses from plants to the atmosphere (e.g., respiration).
- Inhalation, exhalation and eructation.
- Uptake from Ottawa River water into fish.
- Discharges from Perch Creek/Ottawa River water to the atmosphere.
- Loss to outside the region of interest due to air flow.
- Discharge of potentially contaminated gas.
- Uptake from water by aquatic plants and invertebrates.
- Gas volatilization from soils.
- Loss to outside the region of interest due to water flow.
- Consumption of aquatic plants and invertebrates, and incidental ingestion of sediment, by game animals.

- Collection of pollen/nectar from flowering plants by bees and transfer into honey.

The radionuclide migration pathways are the same in the normal evolution and disruptive events, however, the exposure pathways and the time of peak dose are different based on the scenario.

The key exposure pathways during the post-closure period normal evolution include:

- External irradiation from soil.
- Ingestion of beef.
- Ingestion of garden foodstuffs.
- Ingestion of game.
- Ingestion of fish.

The key exposure pathways during the post-closure period disruptive events include:

- External irradiation from soil.
- Inhalation.
- Incidental ingestion of soil.
- Ingestion of drinking water (well water).
- Ingestion of beef.
- Ingestion of garden foodstuffs.
- Ingestion of game.
- Ingestion of fish.

### **3.10 Data Sources Supporting Safety Assessments**

The data to support the NSDF safety assessments has been developed from the CRL site characteristics, NSDF site characterization, detailed design documentation, waste inventory, CNL Safety Analysis Program documentation and published literature (i.e., dose coefficient factors). Site specific data is used, however, if unavailable, data has been selected from the most recently published and relevant information sources.

The primary data sources include:

- CRL Site Characteristics [3-7].
- NSDF Reference Inventory Report [3-82].
- NSDF Non-Radiological Inventory of Constituents of Potential Concern (COPC) [3-84].
- Geotechnical Report [3-12].
- Design Description [3-60] and detailed design documentation suite.
- Compendium of Dose Coefficients based on ICRP 60 (ICRP 119) [3-92].

#### **3.10.1 Safety Related Data Quality**

Canadian Nuclear Laboratories' Management System [3-93], has processes in place to ensure the quality of safety related data. A systematic process was used to ensure that the set of data used for developing the assessment model is accurate and representative.

The Safety Analysis Program Description Document [3-94], has processes for ensuring the quality of all safety analysis and compliance with all policies, procedures, regulations and site licensing requirements. Safety analysis verification activities are carried out in accordance with the Design and Development Review and Design Verification procedure [3-95] and include [3-94]:

- Independent review of technical work, analysis methods and calculations.
- Review of both technical and process documentation for safety-related activities.

The safety analyses and assessment have undergone peer and management review to ensure that the assessment is comprehensive, that all contributions to the radiological risks or conventional risks have been taken into account. The review also determined whether the models and data used are accurate representations of the design and operation of the Facility or the planning and conduct of the activity, and have been appropriately considered.

The technical calculations in the safety analyses have been verified following the Design and Development Review and Design Verification procedure [3-95]. The verification activities include verification of the data, inputs, outputs (results), methodology, calculations, and assumptions. The use of appropriate conservatism, engineering judgement and justified assumptions in the quantitative analyses ensures that the estimates of radiological consequences (dose) are conservative.

The Quality Assurance of Analytical, Scientific and Design Computer Programs [3-96], defines the software QA processes in place to ensure the quality of analytical, scientific and design computer programs. The software QA processes are applicable to computer programs developed or procured, maintained, modified, and used by CNL, that are within or not within the scope of the CSA Standard, Quality Assurance of Analytical, Scientific, and Design Computer Programs for Nuclear Power Plants, CSA N286.7-99 [3-96].

### **3.11 Construction**

The NSDF construction will be undertaken in two construction phases:

- Phase 1: Site preparation and construction of the ECM with six disposal cells with a 525 000 m<sup>3</sup> capacity, WWTP, NSDF support facilities and site infrastructure.
- Phase 2: Construction of the additional four disposal cells to expand the ECM capacity by 475 000 m<sup>3</sup>, for a combined maximum inventory of 1 000 000 m<sup>3</sup>.

The Construction Quality Assurance (CQA) Plan [3-97], documents the QA procedures and monitoring requirements for the construction of the NSDF. The NSDF construction will be completed in accordance with the Construction Drawings and Specifications in accordance with ISO 9001:2015 requirements. The construction work will be inspected and tested in accordance with the Construction Specifications to ensure that the work/materials meets specification acceptance criteria [3-97]. The ECM construction and construction quality control are important to ensure that the ECM performance meets the long-term safety criteria. Comprehensive construction specifications and CQA have been developed and are followed to minimize uncertainties associated with the ECM construction and materials.

The CNL Construction Process provides the framework for external contractors performing construction and installation activities at CNL sites, to ensure they are being adequately controlled and documented within approved safety margins and regulatory/statutory requirements [3-98]. The Construction Process [3-98] work conducted at CNL, is controlled by various procedures, which provide the necessary guidelines to ensure that construction work is compliant with Management System Requirements for Nuclear Power Plants [3-99].

### **3.11.1 Phase 1 Construction**

Phase 1 construction is expected to take 2-3 years and will be performed by contractors and managed by CNL. The NSDF Project site preparation and Phase 1 construction involves:

- Tree and vegetation removal.
- Excavation of the overburden native soils.
- Replacement of the overburden native soils in the southwestern region of the ECM footprint with coarse granular fill material.
- Slope depressurization accompanied with rock blasting to drain groundwater within the rock mass in the ECM footprint. Prior to rock blasting, horizontal drains will be drilled in the rock mass to lower the water table. An enhanced permeability zone in the bedrock beneath the ECM footprint, will be established through blasting to promote drainage and lower groundwater elevations beneath the ECM footprint.
- Blasting, excavation and regrading of the bedrock within the ECM footprint. The blast depths range from 1 m to 8 m.
- After the blasted rock is removed from the rock floor, a sacrificial liner will be placed to seal the area and prevent ground water from recharging the area.
- Blasting is required to construct the surface water management ponds and the trenches that will house and distribute the site utilities.
- Prior to construction of the CCL, three Clay Liner trial pads, 15 m x 25 m, will be constructed at the clay source location for field and laboratory testing. The test results will be used to specify the compaction water content and dry density criteria for the construction of the CCL, with the objective of achieving a hydraulic conductivity of less than or equal to  $1 \times 10^{-9}$  m/s.
- Delivery, storage, stockpiling, and handling of construction materials.
- Construction of the ECM with six disposal cells including the perimeter berm and the base liner system.
- Construction of the WWTP, Support Facilities and Site Infrastructure.

Due to limitations of the site boundary, bedrock elevation and maximum design elevation of the ECM bedrock removal, is necessary to construct the ECM to reach design volume requirements [3-12]. Blasting is the most efficient method of removing the bedrock in terms of both time and materials [3-12]. Rock blasting is a method of rock excavation that involves drilling a number of boreholes into the rock to be removed and detonating explosives to fracture the rock [3-12]. The fractured rock may then be repurposed and processed for on-site aggregate, engineered fill, rip-rap, etc., as long as the materials excavated meet the site prequalification requirements [3-12].

### **3.11.2 Phase 2 Construction**

Phase 2 construction is planned to start approximately 25 years after the start of operations. Preparation activities for Phase 2 construction, start with removal of the frost protection fill and sacrificial liner that was installed at the interface between Phase 1 and Phase 2. The LCS/LDS sumps and piping will be installed and tied-in with the existing LCS and LDS infrastructure. Other construction activities such as minor modifications to roads, waste unloading ramps and temporary storage areas are likely.

Construction work will be performed in parallel with routine waste placement operations in Phase 1 disposal cells. Temporary operating and construction procedures will be developed to manage day-to-day and

emergency communications, interfaces, routine and non-routine work control, resource inter-dependencies and so-on.

Construction activities will be performed in accordance with the approved licensing basis conditions and restrictions. Canadian Nuclear Laboratories work control processes will govern, authorize and control the work during this period.

Construction specifications and procedures, including those for CQA used for Phase 1 Construction of the base liner system, will be reviewed and updated as needed prior to Phase 2 construction. The long-term performance test on the HDPE GMB that was completed for the Phase 1 construction, may need to be repeated for Phase 2 construction, since the GMB product used may no longer be available at the time of Phase 2 construction.

### **3.12 Facility Operations**

The NSDF operation is governed by the following documentation:

- CRL Site Licence [3-100].
- CRL Licence Conditions Handbook (LCH) [3-101].
- Near Surface Disposal Facility Authorization [3-102].
- Quality Assurance Manual [3-103].
- Management System [3-93].
- Management System Governing Documentation Index [3-104].
- Conduct of Operations Program [3-75].

Operation of the Facility is conducted according to Integrated Work Control [3-105]:

- Operating procedures for normal operation and for responding to abnormal situations.
- Emergency procedures for response to emergency conditions.
- Commissioning procedures when new equipment is being tested.
- Return to service of equipment or systems after any maintenance, repair, calibration, inspection, or tests shall be carried out as per the documents listed in the NSDF Main Governing Documentation Index (to be developed).
- Temporary procedures as required for non-standard operation of a system because of equipment failure, maintenance or modification.
- Non-routine and infrequently-performed high-hazard activities shall be subject to the same standard of review, approval and authorization.

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#### **4. SAFETY ASSESSMENT**

The Safety Assessment section provides an evaluation of the aspects that are relevant for the safety of the development, operation, closure and post-closure of the NSDF. The evaluation will present a summary of the available information, with detailed information contained within the referenced supporting material.

The aspects that are relevant for the safety of the NSDF include:

- Post-closure radiological impact.
- Operational safety.
- Non-radiological environmental impact.
- Site and engineering.
- Management system.
- Scientific and Engineering Principles.
- Quality of Site Characterization.

An assessment/summary of the NSDF radiological and non-radiological safety analyses/assessments is provided. Details of the assessment methodology and results are given in the various safety assessment reports and their supporting references. Safety is assessed using qualitative and quantitative analyses by considering a range of potential initiating events or scenarios.

##### **4.1 Post-Closure Radiological Impact**

The safety assessment of the NSDF Project post-closure phase is performed in the PostSA [4-1].

The purpose of the PostSA is to assess the impact of the NSDF on the environment in a variety of scenarios extending hundreds and thousands of years into the future. The PostSA results include radiological dose and dose rates to both human and non-human biota, as well as environmental concentrations of contaminants, for both the expected normal evolution of the Facility as well as a variety of disruptive and alternative scenarios.

The PostSA [4-1] uses up-to-date Project documentation and current understanding of the surrounding environment to develop models and scenarios which describe the Facility's anticipated evolution through time.

The following sections describe and summarize the work performed in the PostSA [4-1]. For detailed information regarding specific parameter inputs, the reader is directed to the PostSA report [4-1].

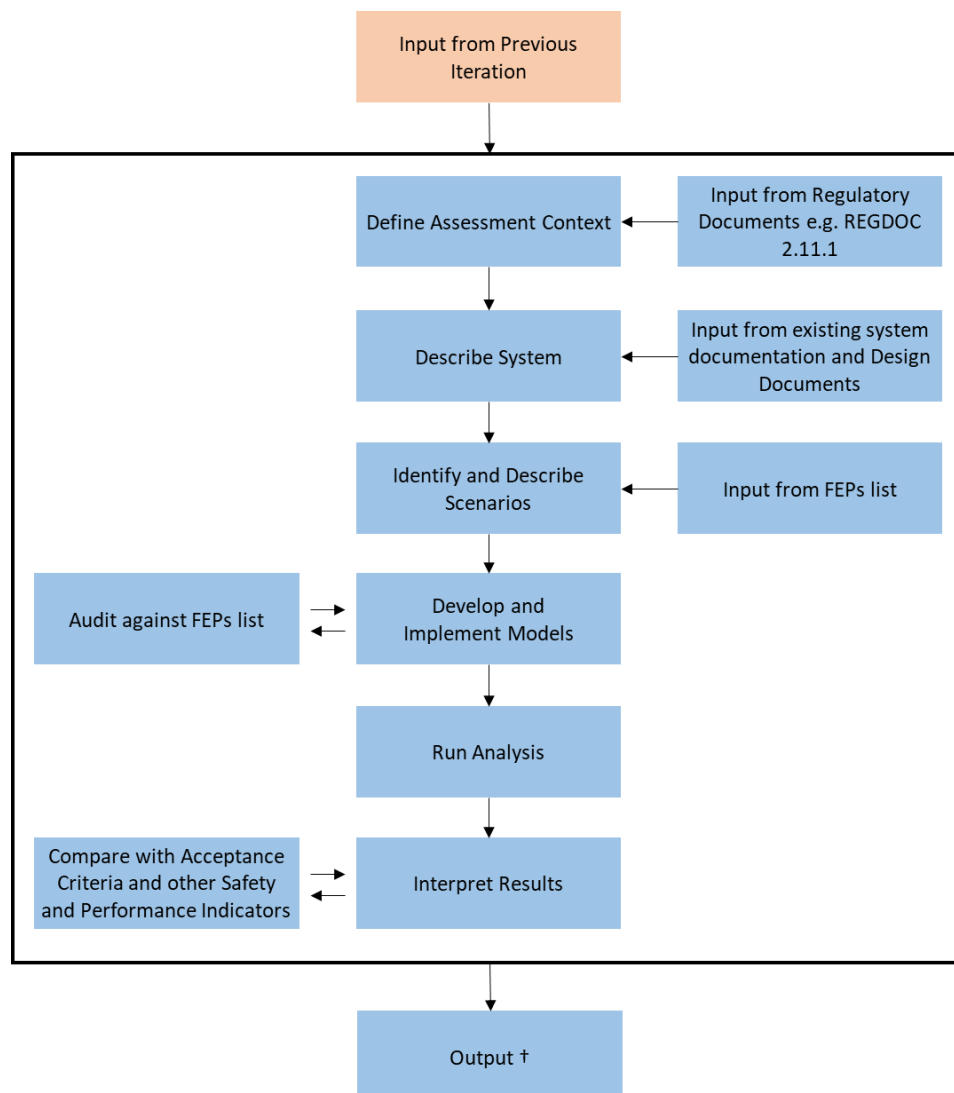
##### **4.1.1 Methodology for the Post-Closure Safety Assessment**

The PostSA [4-1] has been developed using the IAEA's Improvement of Safety Assessment Methodologies (ISAM) guidance [4-2]. This is a systematic, stepwise approach, illustrated in Figure 4-1.

The approach comprises:

- The context of the assessment is defined, documenting the high-level assumptions, the constraints (reflecting the regulatory requirements), and the assessment's purpose, end points, treatment of uncertainties, and timeframes.
- The current information on the waste, repository, geological setting and surface environment relevant to post-closure safety is reported.

- A range of potential future evolutions of the system (scenarios), is systematically identified using FEPs, together with a suite of calculation cases that examine the performance of the disposal system under other conditions of interest and explore its sensitivity to key uncertainties.
- Conceptual and mathematical models and data are developed for the scenarios and a range of calculation cases, which explore key areas of uncertainty, are identified and implemented using appropriate software.
- The results are analysed, interpreted and discussed to inform on the performance of the system, its overall robustness, and the nature and role of key uncertainties. Particular emphasis is given to the comparison of the results for the identified safety and performance indicators against the relevant reference levels, which have been derived from Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management [4-3].



† Includes output to Environmental Impact Statement (EIS), Ecological Risk Assessment, safety case, and next iteration (if necessary).

**Figure 4-1 General Approach Used in the Post-Closure Safety Assessment**

#### 4.1.2 Features, Events, and Processes Analysis

The FEPs are reasonable and feasible items that a PostSA needs to consider to be comprehensive. The FEPs are developed by the Nuclear Energy Agency (NEA) Integration Group for the Safety Case (IGSC), and its predecessor, the Performance Assessment Advisory Group (PAAG). The working groups of SMEs, have carried out activities related to the compilation and use of lists and databases of FEPs in safety and performance assessment studies since the early 1990s. The FEPs are a starting point used internationally for the development of the safety assessment and safety case for radioactive waste disposal facilities. In practice, this means that a proponent of a radioactive waste disposal facility is not starting from scratch when developing what needs to be considered for the long-term safety assessment.

- Features include the physical characteristics or properties of the system, such as lithology, porosity, permeability, faults, wells, and nearby communities.
- Events include discrete occurrences that may occur in the future affecting one or more components of the system, such as earthquakes, subsidence, flooding, and human intrusion.
- Processes include physico-chemical processes, often marked by gradual or continuous changes, that influence the evolution of the system; chemical reactions, precipitation of minerals, ground water flow, sorption and, geomechanical stress changes.

The scenarios and models in the PostSA [4-1], are developed by examining the FEPs that could affect the long-term performance and safety of the Facility, including FEPs directly or indirectly influencing the release and transport of contaminants (radiological and non-radiological) from the Facility, or subsequent radiation exposures to humans, as well as factors such as regulatory requirements or modelling issues that constrain or focus the analysis [4-2].

The FEPs list used in the PostSA follows the latest readily available NEA International FEP list [4-4]. Features, Events and Processes are identified based on the following categories:

- **Category 1 – External Factors:** the FEPs with causes or origins outside the assessed disposal system (repository, the surrounding geosphere and overlying biosphere).
- **Category 2 – Waste Package Factors:** the factors related to waste packages (i.e., waste forms and any associated packaging), and the associated release and migration of contaminants.
- **Category 3 – Repository Factors:** the factors related to the repository (i.e., including the excavation damaged and disturbed zones, and site investigation/monitoring boreholes, but excluding the waste packages) and the associated migration of contaminants.
- **Category 4 – Geosphere Factors:** the factors related to the geosphere mechanically undisturbed by the construction of the repository and the associated migration of contaminants.
- **Category 5 – Biosphere Factors:** the factors related to the biosphere (the surface environment, humans and non-human biota) and the associated migration of contaminants.

The five categories are subdivided to many sub-levels, resulting in over 300 individual FEPs to be considered. The entire FEPs list, and the associated screening analysis are included as an Appendix to the PostSA [4-1].

The FEPs are screened with the primary goal of guiding the development of the NES of the PostSA. A FEP is either screened “in” or “out” based on its applicability to the facility design, site characteristics, waste inventory, or other characteristic about the Project as a whole.



Some FEPs may be screened in, as they represent events or considerations that are plausible, but very low--probability for the timeframe being considered for the PostSA (i.e., 10 000 years, see Section 2.3 for more information on Assessment Timeframe). These FEPs help guide the development of Disruptive Events, which are similar to what an operational safety assessment would refer to as “Accidents” or “Malfunctions”.

Features, Events, and Processes are screened out for a variety of reasons, the main being that they are either out of scope (e.g., refer to deep geologic facilities), of insignificant consequence (e.g., airborne investigation of the facility), or the FEP is of insignificant probability (e.g., volcanic activity in Ontario). Screened out FEPs aren't necessarily forgotten about or discarded. Some of the plausible FEPs become the basis for Sensitivity Analyses, and “What-If?” Scenarios. Sensitivity Analyses test the effect of varying a particular important parameter of the Facility, which is how the PostSA [4-1], examines some uncertainties in input parameters. “What-If?” scenarios are deliberately chosen as bounding, very low probability events, with the purpose of testing the bounds of the Facility under near unrealistic conditions.

The screening process results in one of three outcomes for each FEP:

1. Applicable to base assumptions, incorporated into NES.
2. Applicable as input into Sensitivity Analyses, Disruptive Events, or “What-If?” scenarios.
3. Not applicable, screened out entirely.

The PostSA [4-1] also evaluates scenarios not derived from the FEPs screening: Defence-in-depth, and Dose Optimization. Defence-in-Depth scenarios assess the importance of specific barriers by evaluating the consequences of simply not having that barrier present. Dose Optimization scenarios assess some alternative strategies that the Project has considered to reduce the dose risk from the NSDF.

#### **4.1.3 Scenarios and Receptors**

Scenarios are descriptions of possible evolutions of the disposal system and its surroundings. They are developed by consideration of the FEPs that could affect the disposal facility and its evolution.

The PostSA [4-1] considers the NES and various Disruptive Event scenarios. The NES is based on a reasonable extrapolation of site and Facility FEPs. For example, the NES accounts for the expected degradation of the engineered barriers. Disruptive Event Scenarios postulate the occurrence of unlikely events leading to possible penetration or abnormal degradation of barriers. Note that the Disruptive Events group is used to encompass a range of plausible developments and to evaluate the NSDF's performance under a diverse set of challenging conditions. These latter scenarios provide a method by which future uncertainties can be taken into account in a PostSA. Other types of uncertainties (e.g., uncertainties in the properties of the geosphere through which contaminated groundwater may flow), are addressed in different ways, e.g., by using a range of values for a parameter in an assessment, or even by using a different model to represent the process. The scenarios selected for assessment need to reflect the Assessment Context and the specific environment and disposal facility under assessment.

The scenarios provide a narrative description of a specific set of future conditions for the NSDF system. Following the scenario identification stage conceptual models are developed using the assumed evolution of the system in the Normal Evolution and Disruptive Event Scenarios.

Table 4-1 shows the scenarios have been developed in conjunction with the FEPs assessment. These scenarios are described in detail in the following sections.

**Table 4-1**  
**Post-Closure Scenarios**

|                                                   |
|---------------------------------------------------|
| <b>Normal Evolution Scenario</b>                  |
| Sensitivity Analysis (S.A.) Cases                 |
| S.A. – Inventory Sensitivity                      |
| S.A. – Institutional Control Sensitivity          |
| S.A. – Sorption Coefficient Sensitivity           |
| S.A. – Geosphere – Rapid Transit to Perch Creek   |
| S.A. – Enhanced Degradation of Cover and Liner    |
| S.A. – Climate Change - Reduced HER               |
| S.A. – Receptors of Public Interest               |
| S.A. – Self-Sufficient Indigenous Receptor        |
| S.A. – Degredation of Berm                        |
| <b>Disruptive Events</b>                          |
| Human Intrusion (H.I.) Borehole (Acute)           |
| H.I. House with Basement – Resident (Chronic)     |
| Enhanced Erosion Case                             |
| Localized Cover Failure                           |
| Localized Liner Failure                           |
| Damage to Berm                                    |
| <b>Dose Optimization</b>                          |
| Waste Packages – Wastes Grouted into Steel Liners |
| Establishment of a Long-Term Buffer Zone          |
| Radon Optimization Through Waste Placement        |
| <b>Defence-in-Depth</b>                           |
| Role of Geosphere                                 |
| Role of Cover                                     |
| Role of Base Liner                                |
| Series of Landslides                              |
| <b>What-If?</b>                                   |
| H.I. Well Case (shallow contaminated well)        |
| H.I. Mass Excavation and Farming                  |
| Permanent Bathtub                                 |

#### **4.1.3.1 Receptors**

Beyond the ICP, people may live in the vicinity of or on top of the ECM, or may use the area for grazing cattle or for recreational purposes such as hunting and fishing. Indigenous people may use the land to pursue a self-sufficient lifestyle. Three potentially exposed groups are selected for the majority of the scenarios:

- **On-site Resident/Farmer:** A small household (comprising two adults, a child and an infant) above the ECM footprint. While the land quality around the mound is not expected to be conducive to farming, this receptor is conservatively assumed to live on the mound and farm the surrounding area. A portion of fruits, vegetables, and potatoes are assumed to be grown in the garden beside the house, on top of the

mound. The on-site resident/farmer receptor is assumed to raise cattle, which are allowed to graze in the Perch Lake Swamp area. While the area comprises poor quality grazing land, and may not be suitable for cattle, it has been assumed that the farmer raises cattle. The on-site resident/farmer raises chickens, which are fed with feed grown in the garden. Approximately 10 chickens are kept at any time. 100% of the receptors' occupancy time occurs within the contaminated area and that they use a deep well (that draws uncontaminated water) for drinking (humans and animals), domestic use and irrigation.

- **Hunting/Recreational:** This group is represented by a small number of adults and children making hunting and/or recreational use of the area surrounding the ECM, including Perch Creek and the Ottawa River. This group occasionally drinks water from the creek, and eats deer hunted from the site.
- **Self-Sufficient Indigenous Group<sup>2</sup>:** This group represents a group of Indigenous people, including adults and children, using area surrounding the ECM, including Perch Creek and the Ottawa River, for hunting, and gathering. Individuals in this group are assumed to obtain their food through hunting and gathering in the vicinity of the ECM. This group is assumed to have increased consumption of local fish and wild game compared to the resident/farmer receptor. Furthermore, separate consideration of berry and mushroom intake is considered.

#### 4.1.3.1.1 Exposure Pathways for the Onsite Resident/Farmer

The exposure pathways for the on-site resident/farmer are:

- Consumption of vegetables grown in the garden, which are contaminated with C-14 gas.
- Inhalation of radon during time spent indoors.
- Groundshine, inhalation of dust, and inadvertent consumption of soil from occupancy of the area between the ECM and Perch Creek.
- Immersion in contaminated creek water, and external irradiation from creek bed sediments, for children paddling/playing in the creek. (The creek bank is also assumed to be contaminated, with radionuclide concentrations in the bank assumed to be the same as in the bed sediments).
- Consumption of beef from cattle that are grazed on the swamp between the ECM and Perch Creek and drink some water from the creek.
- Consumption of poultry raised in the garden, with all the poultry's feed being sourced from the garden.
- Plants in the swamp may uptake contaminants from the swamp soil porewater through their roots, and uptake volatilised C-14 through their foliage.

The on-site resident/farmer is modeled to maximise their occupancy on the ECM final cover and in the area between the ECM and Perch Creek.

#### 4.1.3.1.2 Exposure Pathways for the Hunting/Recreational Group

The exposure pathways for the hunting/recreational group are:

- Drinking a small volume of water from Perch Creek.
- Ingestion of fish caught from the Ottawa River.

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<sup>2</sup> The self-sufficient Indigenous group is studied as a sensitivity analysis.

- Groundshine, inhalation of dust and inadvertent consumption of soil from occasional use of the area between the ECM and Perch Creek, and while fishing from the river shore.
- Hunting of game that uses the river and creek for drinking water and grazes the area between the ECM and Perch Creek.
- Foraging of wild honey.

#### 4.1.3.1.3 Exposure Pathways for the Self-sufficient Indigenous Group

The exposure pathways for the self-sufficient Indigenous group are:

- Drinking water from Perch Creek.
- Ingestion of fish caught from the Ottawa River.
- Groundshine, inhalation of dust and inadvertent consumption of soil from occasional use of the area between the ECM and Perch Creek, and while fishing from the river shore.
- Hunting of game that uses the Ottawa River and Perch Creek for drinking water and grazes the area between the ECM and Perch Creek.
- Foraging of wild honey, berries, and mushrooms.

The locations of the site resident house, garden/horticultural area and grazing/foraging area, are illustrated in Figure 4-2.



**Figure 4-2 Illustrative Location of the Site Resident House, Garden/Horticultural Area and Grazing/Forage Area. (Dwelling and Garden are not to scale).**

#### 4.1.3.1.4 Additional Receptors

While the Resident Farmer and Hunter/Recreational receptors are studied for the majority of scenarios, there are several additional receptors included for specific scenarios.

Receptors of Public Interest: This category includes two representative residents located downstream from the NSDF; one in Sheenboro Quebec (approximately 8 km downstream of CRL), the other in the Ottawa/Gatineau region (approximately 200 km downstream from CRL). These receptors were added specifically to address concerns from Stakeholders that were particularly concerned about downstream effects from the NSDF. The only exposure pathway to these receptors is through drinking from, and bathing in the Ottawa River.

Off-site Resident - Perch Creek Outfall: This receptor represents the case where the land-use restrictions placed on the NSDF site are enforced and adhered to. This is contrary to the NES which assumes that IC fails 300 years after the closure of the Facility, which allows for a receptor to build a residence on the facility. The Perch Creek Outfall resident respects IC and resides just outside the buffer zone, at the point where Perch Creek flows into the Ottawa River. This location was chosen to be conservative, as Perch Creek is a primary contaminant pathway. This receptor uses the Ottawa River for drinking water and household uses, as well as to irrigate a small vegetable garden. A portion of the receptor's diet is fish caught from the Ottawa River.

#### 4.1.3.2 Normal Evolution Scenario

The NES is a reference description of the expected evolution of the ECM, its surroundings, and its resulting releases, consistent with CNSC REGDOC 2.11.1 [4-3], which states that:

*"A normal evolution scenario should be based on reasonable extrapolation of present day site features and receptor lifestyles. It should include expected evolution of the site and degradation of the waste disposal system (gradual or total loss of barrier function) as it ages. Evolution scenarios are not expected to include biological evolution of individual receptor species, which can be assumed to be static for the purposes of the safety assessment."*

The scenario description is a narrative summary of the evolution of the site, the sources of radionuclides, transport pathways and receptors and should be regarded in these qualitative terms. It is not an exhaustive description of all the components of the system model, these are presented in the Models and Data section of the PostSA [4-1]. The assessment considers timescales from closure (the year 2100) to 10 000 years post-closure.

##### 4.1.3.2.1 External Factors

###### Institutional Control (IC)

A period of IC will take effect following closure of the site, for as long as necessary. For planning purposes, CNL uses an ICP of at least 100 years after closure, and up to 300 years after closure.

Note that as part of this NES, no human intrusion occurs within the ICP. The potential exposures that could result from human intrusion or other disruptive events are examined in other scenarios. An alternative strategy case (Dose Optimization: Establishment of a Long-Term Buffer Zone) examines the influence of conceivable land-use restrictions and observance of an imposed buffer zone.

### Seismicity

The safety analysis accounts for seismicity, with information from CRL site-specific seismic surveys conducted in 2016 [4-5] and the CRL Probabilistic Seismic Hazard Analysis [4-6]. The seismic design criteria and seismic analysis results are documented in the NSDF Seismic Analysis Report [4-7]. The seismic design basis for the ECM is based on a DBE having a recurrence interval of 1 in 10 000 years. Within the 10 000 year assessment timeframe, a DBE is not expected to affect the safety function of the final cover, base liner system and perimeter berm [4-8].

The effects of more severe earthquakes (beyond design basis) on the Facility are considered as Disruptive Event Scenarios [4-1]. The effects of the beyond design basis seismic event was evaluated in [4-9], and it was found that the Series of Landslides scenario is bounding for the consequences. Liquefaction is not a credible event based on the ECM design, as detailed in [4-10]. In the event of a beyond design basis earthquake occurring during the ICP, damage would be assessed and remediated as required.

### Climate Change

The climate is assumed to evolve according to the current interpretation of anthropogenically-forced climate change. This is anticipated to include global warming of several degrees Celsius for a period of up to 100 000 years from the present. This is sufficient to defer the next scheduled ice age to beyond 100 000 years from now. See Section 2.3 for further discussion of timeframes.

Climate change may alter the regional and local meteorology, in particular the temperature, annual rainfall, snowfall, and duration of snow cover. The NSDF EIS [4-11], contains a climate change assessment for the NSDF site. Based on the information in Golder [4-11] and Intergovernmental Panel on Climate Change [4-12], in the NES the temperature is assumed to increase by 3.9°C, and precipitation is assumed to increase by 3% per-degree of increase (to 952 mm) [4-1]. Such changes could impact rainfall, groundwater recharge, creek and river flows, vegetation and land use. However, for the NES, the assumed changes are relatively small such that the present-day biosphere is adequately representative of future conditions. The effects of *increased* rainfall (*beyond* that included as part of this NES), are also explored in a separate sensitivity case.

### Surface Erosion

The ground surface may be subject to erosion by various mechanisms such as by precipitation, biotic weathering, and wind-induced erosion. In this NES, there is a balance of processes (involving erosion, some deposition, and also stabilization of soils – for example, by vegetation), resulting in minimal net erosion. Note that more severe erosion of the surface is addressed as a Disruptive Event Scenario.

#### **4.1.4 Waste**

The ECM radioactive waste inventory is described in Section 3.3, i.e., LLW associated with bulk unpackaged wastes, packaged wastes in mild steel drums and wastes cement grouted into steel liners. Radioactive decay and ingrowth are accounted for during the assessment time frame.

The ECM non-radioactive waste inventory is comprised of primarily wood, metals (including iron, copper, lead, aluminum), and bulk solid wastes. The metals inventory is expressed as both “total” estimated quantities, and, “leachable” quantities based on Toxicity Characteristics Leaching Procedure (TCLP) testing [4-13].

Radioactive (and non-radioactive) contaminants in bulk wastes and mild steel drums are assumed to be immediately available for release upon contact with water, while radionuclide contaminants grouted into steel liners will only become available once there has been sufficient corrosion to breach the liner, and once

breached, the grout will continue to provide a barrier to their release. Note that these corrosion-dependent delays are not credited in the NES (a conservative assumption). A Dose Optimization Case examines the influence of corrosion-dependent release from steel-lined packages.

While the final cover acts as a barrier to infiltration, the wastes will remain mostly unsaturated, i.e., mostly dry. During this period, there will be some dissolution of radioactive and non-radioactive contaminants into pore water but no significant flow out of the ECM. Steel liners will begin to corrode, although this process could be limited to some extent by the availability of water. Anaerobic corrosion will generate hydrogen gas. Gases will also be generated through degradation of organic matter (methane and carbon dioxide), again potentially limited by the availability of water. Within the gases will be trace radioactive gases including radon-222, tritiated water vapour, and carbon-14 labelled carbon-dioxide and methane. Gases will escape from the ECM via defects in the GMB in the final cover.

#### **4.1.5 Repository Factors (Facility)**

The NSDF is designed to be above the current local water table. Prior to closure of the ECM, a leachate drainage system will be in operation and will be sealed during closure. The final cover installed over the ECM is designed to promote run-off and reduce infiltration into the waste.

The low permeability components of the ECM final cover and base liner are: composite 2 mm HDPE liner with associated 5 mm GCL in the final cover; two similar composite HDPE/GCL liners and a 750 mm CCL in the base liner. The composite HDPE/GCL liners are anticipated to degrade at similar rates in the final cover as in the base liner. The CCL will not start to degrade until the HDPE/GCL have degraded, allowing water flow into the CCL. The CCL is designed to be constructed from natural clays and may resist degradation for much longer time periods than the composite liners. Since the base liner will be less permeable than the final cover for a significant time period, it is likely that water levels will rise within the ECM until the CCL degrades. This rise in water levels may cause temporary bathtubbing, persisting until the CCL degrades. Once degradation has occurred, the base liner is assumed to have flow properties similar to that of the natural drift deposits and water levels are likely to drop and bathtubbing cease. For the NES, the water level will be determined from a hydrological balance based on the parameter values used for infiltration and containment.

#### **4.1.6 Geosphere**

The NSDF will be constructed on a hillside with the upslope part of the ECM built on bedrock. Blasting will be used to excavate the bedrock to the desired elevation/profile. The downslope part of the ECM will be built on surficial drift deposits. Groundwater modelling [4-14], has shown that the water table remains below the base liner, either within rock damaged by blasting in the upslope part of the ECM, or within high permeability drift deposits below the downslope part of the ECM. Downslope of the ECM, the water table is at/just below the ground surface and there is an area of swamp between the ECM and Perch Creek.

There are two potential water pathways for radionuclides leaving the ECM:

- Groundwater flow paths from beneath the ECM to Perch Creek have been modelled [4-14] and follow the topography, with particle tracks showing that radionuclides released to groundwater beneath the ECM will discharge to Perch Creek.
- While bathtubbing occurs, water may overtop the perimeter berm. Down slope of the perimeter berm, the water table is at/very close to the ground surface and water that overtops the perimeter berm will move down slope towards Perch Creek.

Transport rates of radionuclides through the geosphere will depend on flow velocities, solubility and sorption processes.

#### **4.1.7 Biosphere**

There are three pathways of release of contaminants into the biosphere:

- Gases (containing tritium, radon-222 and Carbon-14), will be released into the soils and atmosphere above the final cover. Carbon-14 can be taken up into vegetation.
- Water overtopping the perimeter berm will release contaminants into the shallow subsurface and swamp area between the ECM and Perch Creek.
- Water released through the base liner transports contaminants into the creek bed of Perch Creek.

Gases released above the ECM, will diffuse through the soil and into the atmosphere and dispersed by wind. Carbon-14 will be taken up into vegetation and could be consumed by animals and people.

Contaminants released by overtopping the berm will move through the shallow environment by overland flow, resulting in contamination of surface soils. Exposures can arise by external irradiation, inhalation of dust, inadvertent ingestion and consumption of food stuffs grown in the soil, or consumption of animals that have grazed in the contaminated area.

Contaminants released to groundwater beneath the ECM will move through the geosphere by advection and dispersion and may sorb to sediments. Once in the aquatic environment, there will be dilution in Perch Creek and then in the Ottawa River. Contaminants may be taken up by aquatic flora and fauna.

Although land-use restrictions are expected to remain for hundreds of years into the future, for the purposes of the NES, a receptor builds a residence on top of the ECM with a deep well.

The receptor is a resident/farmer that obtains a portion of their fruits and vegetables from an on-site garden cultivated on the ECM final cover. They raise chickens atop the ECM and to graze beef cattle. The receptors may be exposed to Carbon-14 gas, as are livestock raised on top of the ECM. The swamp area is unlikely to be farmed for crops, but it is possible that livestock could be grazed on this area.

The land could also be used for recreational purposes such as hunting and fishing, or for Indigenous people pursuing a traditional lifestyle. Exposure pathways for hunting could involve consuming animals that have grazed in the area of the swamp contaminated by bathtubbing and have used Perch Creek for drinking water. Fishing is unlikely to occur in Perch Creek since it is small and has an unreliable flow, thus any fishing is assumed to occur in the Ottawa River and the fish are consumed. Collection of berries and mushrooms from the area could also lead to contamination, and occupancy of the land could result in direct exposure.

From the above discussions, the two main receptor groups of Resident/Farmer, and Hunter/Recreational were developed, along with the addition of a self-sufficient Indigenous receptor for study in a Sensitivity Case.

#### **4.1.8 Sensitivity Analyses**

Sensitivity cases are used to directly examine the effect of important uncertainties in the models and data. As many modelling aspects can in practice be expressed through parameter values, sensitivity cases focus on using alternative parameter value choices. The alternative parameter values that are assigned don't need to represent specific bounds on uncertainty (as in some cases these cannot easily be established); in other words, the alternative parameters do not need to be the 'highest' or 'lowest' possible values. Rather, they are used



to test the effect of uncertainty; for example, if parameter x is increased by a factor of 10, by what factor does the dose increase?

Sensitivity Analyses included in the PostSA [4-1] are described in the following sections:

#### **4.1.8.1 Sensitivity Analyses – Inventory x10**

The Inventory x10 sensitivity case is used to examine alternative starting radiological inventories and their effects on the performance of the system. Examining alternative inventories provides useful information about the performance of the system given the uncertainty in the inventory. Examining alternative inventories can also provide a useful optimization perspective.

The Reference Inventory [4-15] used for the PostSA was calculated assuming a ratio of about 14% packaged waste volume to 86% bulk waste volume. Scoping calculations were performed to assess how the radiological inventory would look if the packaged waste volume was increased to 50%, and bulk waste volume decreased to 50%. The result is that, on average, the amount of radioactivity increased by a factor of 3.4. Instead of using a factor of 3.4, and to remain conservative, this sensitivity analysis was performed using a factor of 10.

This sensitivity case is performed based on the NES; all other aspects are the same as for the NES.

#### **4.1.8.2 Sensitivity Analyses – Institutional Control Sensitivity**

The Institutional Control sensitivity case examines the impact of a shorter ICP of only 100 years (ending in the year 2200), as opposed to 300 years (ending in the year 2400) - i.e., allowing for less radioactive decay to occur before a given scenario is initiated. Examining an alternative ICP provides useful perspective on the role the ICP plays in terms of doses to the receptor.

This sensitivity case is performed based on the NES; all other aspects are the same as for the NES, aside from the change in ICP (and as a result, the resident/farmer establishing their residence earlier – at the year 2200, rather than at the year 2400).

Consistent with NES assumptions, this sensitivity case does not credit the fact that, as a waste disposal facility, there will be land-use restrictions placed on the property title or deed to ensure appropriate zoning restrictions, which would prevent human receptors from living on or near the Facility.

#### **4.1.8.3 Sensitivity Analyses – Sorption Coefficient Sensitivity**

Sorption is the ratio of the concentration on a solid to that in solution in a saturated medium, and controls the rate at which contaminants can travel relative to groundwater. This parameter varies by compound, and can be very uncertain because it is sensitive to groundwater chemistry and the minerals present to which sorption can occur. To provide a transparent analysis of sensitivity, in this sensitivity case sorption coefficients have been adjusted by an order of magnitude (conservative, because it involves faster release, faster transport through the geosphere, and slower transport (i.e., less *reduction*) in the biosphere).

The Sorption Coefficient sensitivity case examines the impact of reducing sorption parameters, therefore decreasing sorption and increasing releases (note there are no changes for contaminants that are not sorbed).

This sensitivity case is performed based on the NES; all other aspects are the same as for the NES.

**4.1.8.4 Sensitivity Analysis – Geosphere – Rapid Transit to Perch Creek**

The Rapid Transit to Perch Creek sensitivity case examines the impact of reduced groundwater transit time from the ECM to Perch Creek. In this sensitivity case, the lower transit time estimate of five years is used, rather than the average transit time of seven years.

This sensitivity case is performed based on the NES; all other aspects are the same as for the NES.

**4.1.8.5 Sensitivity Analysis – Enhanced Degradation of the Cover and Liner**

This sensitivity case examines alternative timings and rates of degradation of the engineered barriers. Alternative timings include, for example, the potential impacts resulting from the engineered barriers starting their degradation at an earlier point – before the end of their planned design life. Alternative rates include, for example, accelerated degradation of the barriers – beyond their postulated degradation rates. Ultimately, both of these factors would result in increased infiltration, subsequently causing releases to occur earlier.

These sensitivity cases are performed based on the NES; all other aspects are the same as for the NES.

Note that the effects of damage to the final cover and base liner systems are examined in separate Disruptive Event scenarios, whereas performance of the ECM *without* these barriers is examined in separate Defence-in-Depth scenarios.

**4.1.8.6 Sensitivity Analysis – Climate Change – Reduced Hydrologically Effective Rainfall**

The Climate Change sensitivity case examines the impact of reduced hydrologically effective rainfall (i.e., rainfall minus evapotranspiration) on the system, which may result if increased temperatures produce increased evapotranspiration rates.

This sensitivity case is performed based on the NES; all other aspects are the same as for the NES, except that because of drier conditions, the swamp is assumed to be farmable and used to grow crops (except during bathtubbing). For the Hunter/Recreational receptor, wildlife does not graze on the swamp area (after bathtubbing), because crops are grown there.

**4.1.8.7 Sensitivity Analysis – Receptors of Public Interest**

The Receptors of Public Interest sensitivity case examines the potential impacts of the Facility on additional receptor locations that are of interest, based on stakeholder feedback. Specifically, the sensitivity analysis examines the potential doses to resident receptors that obtain their water from the Ottawa River. The receptor locations represent Sheenboro and Ottawa/Gatineau communities. These receptors can represent a number of different locations along the river because the receptor characteristics are not expected to vary – only the concentration of contaminants in the water will vary. This sensitivity case is performed based on the NES; all other aspects (other than the receptors), are the same as for the NES.

**4.1.8.8 Sensitivity Analysis – Self-Sufficient Indigenous Receptor**

This sensitivity case examines a self-sufficient indigenous receptor group (including adults and children), driven by indigenous interest. The self-sufficient indigenous receptor group uses the area surrounding the ECM, including Perch Creek and the Ottawa River, for hunting, fishing and gathering following a traditional self-sufficient lifestyle. This receptor group consumes harvested plants and has increased consumption of fish and wild game compared to the receptor intakes in the NES.

#### 4.1.8.9 Sensitivity Analysis – Degradation of the Berm

This sensitivity case examines degradation of the berm to the extent it could potentially result in a partial berm failure if either a more severe seismic event than the design basis seismic event (at any point in the service life of the perimeter berm) or a design basis seismic event (later in the service life of the perimeter berm) were to occur.

This sensitivity case is not quantitatively assessed, as degradation of the berm is fully bounded by the consequences of the Series of Landslides scenario (described in Section 4.1.11).

This sensitivity case also implicitly encompasses aspects of enhanced erosion of the cover system that is potentially also the consequence of a seismic event. The effects of enhanced erosion are represented in the Series of Landslides scenario since the landslides result in removal of the cover system and exposure of the wastes. This is ultimately the impact of the enhanced erosion as well.

#### 4.1.9 Disruptive Events

Disruptive Event scenarios can be considered similar to “accidents”. They encompass disruptions of the site, system, or surroundings, and also encompasses intrusion scenarios. Disruptive Event Scenarios involve variations – e.g., principal parameter values, environmental changes, and human behaviours – which may challenge the integrity of the ECM and enhance potential exposures. Certain disruptive scenarios could be expected over very long periods of time, amounting to thousands of years. Inadvertent Human Intrusion scenarios are a subcategory of Disruptive Events. The IAEA [4-16] defines “Human Intrusion” as:

*“Human actions that affect the integrity of a disposal facility and which could potentially give rise to radiological consequences. Only those human actions that result in direct disturbance of the disposal facility (i.e. the waste itself, the contaminated near field or the engineered barrier materials) are considered.”*

The CNSC postulates that human intrusion involving direct disturbance of disposed wastes, needs to be considered, but only for inadvertent intrusion scenarios [4-3].

International organizations, such as IAEA, ICRP and OECD, provide an overall framework for defining human intrusion scenarios. In particular, international guidance [4-16], [4-17] and [4-18] states that:

- Some form of inadvertent human intrusion has to be considered in the context of disposal facilities after the end of the ICP. Intrusion should be assumed to occur at some time following the loss of knowledge about the site and its hazardous contents.
- Analysis should include stylized intrusion scenarios reflecting site-specific conditions, inventory and design. It is not required to try and predict a change in human behaviour during the post-Institutional Control period. That is, it is generally assumed that humans in the future will have similar habits to present humans.

The following subsections describe the Disruptive Scenarios in brief. A detailed description of the disruptive event scenarios is documented in the PostSA [4-1].

##### 4.1.9.1 Human Intrusion – Borehole Drilling (acute exposure)

In the Borehole Drilling scenario, a borehole is installed into the ECM which intersects the buried waste. The drill does not deflect around barriers, containers, or waste forms, nor does the drill operator recognize that

something is wrong and cease operation. This scenario examines the radioactive dose received by the drill operator. The scenario occurs at the end of the ICP, i.e., at the year 2400. The receptor in this scenario receives a dose from the exhumed material, while operating the drilling machinery.

#### **4.1.9.2 Human Intrusion – House with Basement – Resident (Chronic)**

In the House with Basement scenario, the resident/farmer constructs their residence on top of the ECM, despite the undesirable nature of its overall slope and contoured final cover, and, has excavated and built a basement for their residence. The excavated material is spread throughout the garden area used to grow garden produce. This scenario examines the dose received by the resident/farmer receptor. The scenario occurs at the year 2400, when the ICP has ended.

#### **4.1.9.3 Enhanced Erosion**

This Enhanced Erosion scenario examines accelerated erosion of the final cover compared to NES. This could be caused by wetter climate conditions, severe earthquake damage, or other causes. The ECM erodes over time and the eroded material will be deposited into the swamp, eventually the creek downstream and then into the Ottawa River.

The erosion rate selected for this case is  $4.00\text{E-}04$  m/y, which is within the upper range of erosion rates calculated for other waste disposal facilities which includes from  $4.00\text{E-}07$  m/y at Los Alamos Area G [4-19] to  $6.10\text{E-}04$  m/y at Idaho CERCLA [4-20].

#### **4.1.9.4 Localized Cover Failure**

The Localized Cover Failure scenario investigates the effects of a localized failure developing in the final cover of the Facility. This failure could result from a number of different initiating events, including settling of the waste and an earthquake. This is conservatively assumed to occur immediately following the end of the ICP, i.e., at 300 years post-closure at the year 2400. The failure of the final cover results in additional infiltration and greater flow of water through the shallow wastes and flows over the perimeter berm at a time earlier than in the NES.

#### **4.1.9.5 Localized Liner Failure**

The Localized Liner Failure scenario investigates the effects of a localized failure developing in the base liner of the Facility. This failure could result from a number of different initiating events, including settling of the waste and an earthquake. This occurs immediately following the end of the ICP, i.e., at 300 years post-closure. The contaminants that accumulate in the low point of the base liner will leak through the localized failure.

#### **4.1.9.6 Damage to Berm**

The Damage to Berm scenario investigates the effects of damage to the downslope perimeter berm on the performance of the Facility. This failure could potentially result from a severe seismic event. The damage affects the height of the perimeter berm (and therefore the amount of water that could overtop during bathtubting), as well as its ability to anchor the final cover and base liner layers. This results in transport of contaminants downgradient.

#### **4.1.10 Dose Optimization Scenarios**

During the design and modelling iterations of the NSDF Project, several optimization strategies were investigated in post-closure scoping studies [4-21] and [4-22], such as different waste inventories (i.e., removal of ILW), radon and radium contents, and waste layers and depths.

The PostSA [4-1] focuses on the following alternatives:

- The potential need to limit releases using steel liners with grouted packages.
- The potential for long-term land use restrictions to be put in place and adhered-to.
- The potential for dose optimization through changes in waste placement.

##### **4.1.10.1 Waste Packaging – Wastes Grouted into Steel Liners**

The NES and all other scenarios assume that the packaging and possible grout fill inside a waste package provide no barrier in the long-term. The PostSA [4-1] ignores the presence of waste packages and grout, and does not credit these barriers when modelling the migration of contaminants through the Facility. This scenario examines the results if the steel liners (and the grout within them), are credited in the modelling.

##### **4.1.10.2 Establishment of a Long-Term Buffer Zone**

A key assumption in the NES is that land use restrictions are forgotten and receptors can be present on-site. In contrast, this scenario examines the potential effects of long-term land use restrictions are in place and followed.

In this case, receptors do not reside within the buffer zone. Instead, an off-site receptor is used, represented by a family living in a household along the Ottawa River, at the Perch Creek discharge point. Ottawa River water is used as a source of drinking water, household uses and irrigation of the small vegetable garden used to grow fresh fruits and vegetables. Given the receptors' proximity to the river, a portion of their diet is from fish caught from the Ottawa River.

##### **4.1.10.3 Radon Optimization through Waste Placement**

Waste disposed in the ECM will generate radon gas. This case examines the potential for dose optimization by placing radon generating waste deeper in the ECM or limiting concentrations of radon generating radionuclides in upper layers of the ECM.

#### **4.1.11 Defence-in-Depth Scenarios**

Defence-in-Depth cases are aimed at building confidence in the performance of the NSDF after closure. These cases examine the extent to which the NSDF depends on key engineered barriers, and what would happen if those barriers were not present. This group of scenarios therefore, involves hypothetical combinations to analyze the barriers in the system. Each scenario involves a change in one or more parameters related to a particular barrier; by comparing the results to those of the NES, the influence of the barrier is shown.

The scenarios are:

Role of Geosphere – Sets  $K_d$  values of the geosphere to zero for all radionuclides. This effectively means that all waste is completely soluble and is transported immediately to receptors.

Role of the Cover – The final cover is assumed to be absent at the time of closure, allowing for increased water ingress into the Facility. The base liner system performs as expected, resulting in early bathtubbing of the Facility.

Role of Base Liner – The base liner is assumed to completely fail at time of closure, allowing water to leach from the Facility.

Series of Landslides – Assesses the importance of the berm by assuming that severe erosion caused by landslides, results in berm material being transported downslope. Portions of the waste become exposed, and water is able to escape the Facility without “bathtubbing.”

#### **4.1.12 “What-If” Scenarios**

“What If” cases represent a deliberately extreme set of assumptions that can be used to understand the absolute limits to safety performance. These scenarios are identified in a similar manner to the Disruptive Events, but are separated from them due to their low probability of occurrence.

Previous post-closure scoping calculations [4-21] and [4-22], examined the effects of both an archeological dig, and the construction of a highway into and on-top of the Facility.

##### Mass Excavation and Farming

The PostSA examines a new scenario: Mass Excavation and Farming. The intent of the archeological dig and road construction are fully captured – more waste is excavated, more exposure pathways are included, and the exposure durations are longer; therefore, Mass Excavation and Farming is a bounding scenario.

##### Human Intrusion – Shallow Contaminated Well

In the Shallow Contaminated Well scenario, the receptor obtains their water from a shallow well that intersects the contaminant plume. This scenario addresses the uncertainty surrounding where future receptors may obtain their water from. The additional pathways include drinking well water and irrigating with well water from the shallow well, and the farmer giving well water, instead of creek water, to the livestock.

##### Permanent Bathtub

The Permanent Bathtub scenario examines the impacts of conditions where the final cover system degrades, but the base liner system does not.

#### **4.1.13 Scenario and Receptor Summary**

The scenarios analyzed in the PostSA were selected through the FEPs screening process and through stakeholder engagement. The receptors were chosen to conservatively represent the potential critical groups that may be affected by the NSDF. Table 4-2 is a summary of how each scenario and receptor interact, reproduced from the PostSA [4-1].

Table 4-2  
Summary of Post-Closure Receptors

| Scenario                                                         | Change from Normal Evolution Scenario (NES)                             | On-site Resident/Farmer                                                                                                                                                                                   | Hunter/Recreational                                                                                                                                                                    | Off-site Resident: Perch Creek Outfall | Off-site Resident: Sheenboro, Ottawa | Driller |
|------------------------------------------------------------------|-------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|--------------------------------------|---------|
| Normal Evolution Scenario (NES)                                  | n/a                                                                     | Eats some vegetables grown in garden contaminated with C-14.<br>Inhalation of radon gas.<br>Occupancy of bathtub area.<br>Livestock are grazed in the bathtub area.<br>Drinks clean water from deep well. | Drinks small volume of water from Perch Creek.<br>Fishes Ottawa river.<br>Hunts wildlife that drink Perch Creek water and graze within the bathtub area.<br>Occupancy of bathtub area. | n/a                                    | n/a                                  | n/a     |
| S.A.: Inventory                                                  | Inventory increased.                                                    | As NES                                                                                                                                                                                                    | As NES                                                                                                                                                                                 | n/a                                    | n/a                                  | n/a     |
| S.A.: Institutional Control                                      | Shorter ICP (starts 2200 instead of 2400).                              | As NES                                                                                                                                                                                                    | As NES                                                                                                                                                                                 | n/a                                    | n/a                                  | n/a     |
| S.A.: Sorption coefficients                                      | Alternative sorption coefficients.                                      | As NES                                                                                                                                                                                                    | As NES                                                                                                                                                                                 | n/a                                    | n/a                                  | n/a     |
| S.A.: Geosphere - Rapid Transit to Perch Creek                   | Shorter transit time to Perch Creek.                                    | As NES                                                                                                                                                                                                    | As NES                                                                                                                                                                                 | n/a                                    | n/a                                  | n/a     |
| S.A.: Faster degradation of Engineered Barriers                  | Faster degradation of the cover and liner.                              | As NES                                                                                                                                                                                                    | As NES                                                                                                                                                                                 | n/a                                    | n/a                                  | n/a     |
| S.A.: Climate change - reduced hydrologically effective rainfall | Climate changes such that hydrologically effective rainfall is reduced. | As NES but farming at the swamp area after bathtub (no contamination before bathtub).                                                                                                                     | As NES<br>Wildlife does not graze bathtub area after bathtubbing.<br>Occupancy of bathtub area ceases after bathtubbing because this area is used for farming.                         | n/a                                    | n/a                                  | n/a     |

| Scenario                                       | Change from Normal Evolution Scenario (NES)                                                                                                                                                                                    | On-site Resident/Farmer                                                                                | Hunter/Recreational                                    | Off-site Resident: Perch Creek Outfall | Off-site Resident: Sheenboro, Ottawa                                                                                                         | Driller                                    |
|------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------|--------------------------------------------------------|----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------|
| S.A.: Receptors of Public Interest             | Examines receptors located in other areas, driven by public interest.                                                                                                                                                          | n/a                                                                                                    | n/a                                                    | n/a                                    | Downstream residents of Sheenboro or Ottawa-Gatineau.<br><br>Assumed to obtain their drinking water and bathing water from the Ottawa River. | n/a                                        |
| S.A.: Self-Sufficient Indigenous Receptor      | Use area surrounding the ECM, including Perch Creek and the Ottawa River, for hunting and gathering following a traditional self-sufficient lifestyle.                                                                         | n/a                                                                                                    | n/a                                                    | n/a                                    | n/a                                                                                                                                          | n/a                                        |
| S.A.: Degradation of Berm                      | Examines a case involving degradation of the berm.                                                                                                                                                                             | See scenario description.<br>Not quantitatively assessed.                                              |                                                        |                                        | n/a                                                                                                                                          | n/a                                        |
| Disruptive Events                              |                                                                                                                                                                                                                                |                                                                                                        |                                                        |                                        |                                                                                                                                              |                                            |
| H.I.: Borehole (Acute)                         | A borehole is dug into the waste at the Facility.<br>Assumed to occur at 300 years after closure (i.e., at the end of IC).                                                                                                     | n/a                                                                                                    | n/a                                                    | n/a                                    | n/a                                                                                                                                          | Exposed to waste whilst drilling borehole. |
| H.I.: House with basement - Resident (Chronic) | A basement is constructed into the top of the ECM and excavated soil/waste is spread over the garden area.<br>Assumed to occur at 300 years after closure (i.e., at the end of IC).                                            | As NES<br><br>Additional radon exposure from basement.<br><br>Garden contaminated with excavated soil. | As NES                                                 | n/a                                    | n/a                                                                                                                                          | n/a                                        |
| Enhanced erosion                               | Faster erosion of the final cover such that wastes are exposed at the ground surface and eroded materials spread downslope. Sediment transport explicitly included in the model. Driven for example, by severe seismic events. | As NES<br><br>(Lives directly on waste, allotment on waste)                                            | As NES<br><br>Bathtub area has eroded waste on surface | n/a                                    | n/a                                                                                                                                          | n/a                                        |



| Scenario                                                       | Change from Normal Evolution Scenario (NES)                                                                                                                                       | On-site Resident/Farmer | Hunter/Recreational | Off-site Resident: Perch Creek Outfall                                                                                                                                                                                                    | Off-site Resident: Sheenboro, Ottawa | Driller |
|----------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|---------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|---------|
| Localized Cover Failure                                        | Localized high infiltration through cover between 300 and 650 years after closure.                                                                                                | As NES                  | As NES              | n/a                                                                                                                                                                                                                                       | n/a                                  | n/a     |
| Localized Liner Failure                                        | Accelerated degradation of the CCL adjacent to the berm, driving by the higher flows through the CCL in this area. Reduced the extent of bathtubbing, but does not fully prevent. | As NES                  | As NES              | n/a                                                                                                                                                                                                                                       | n/a                                  | n/a     |
| Damage to the berm                                             | Berm damage during bathtubbing. No waste exposed, but increased flow over the berm.                                                                                               | As NES                  | As NES              | n/a                                                                                                                                                                                                                                       | n/a                                  | n/a     |
| Dose Optimization Cases                                        |                                                                                                                                                                                   |                         |                     |                                                                                                                                                                                                                                           |                                      |         |
| Waste Packaging - Wastes Grouted into Steel liners             | Credit is given for grout and steel liners.                                                                                                                                       | As NES                  | As NES              | n/a                                                                                                                                                                                                                                       | n/a                                  | n/a     |
| Dose Optimization - Long term buffer zone                      | Long-term land use restrictions are implemented and adhered-to.                                                                                                                   | n/a                     | n/a                 | Family living at the outfall of Perch Creek to Ottawa River. All water is obtained from the Ottawa River (because Perch Creek itself does not provide adequate quantities of water). Lifestyle is similar to the On-site Resident/Farmer. | n/a                                  | n/a     |
| Dose Optimization - Radon Optimization Through Waste Placement | Examines potential radon dose optimization if material with natural background levels of radium were used in the upper layers of the ECM (rather than bulk waste).                | As NES                  | As NES              | n/a                                                                                                                                                                                                                                       | n/a                                  | n/a     |
| Defence-in-Depth cases                                         |                                                                                                                                                                                   |                         |                     |                                                                                                                                                                                                                                           |                                      |         |
| Role of geosphere                                              | Geosphere Kd = 0                                                                                                                                                                  | As NES                  | As NES              | n/a                                                                                                                                                                                                                                       | n/a                                  | n/a     |
| Role of cover                                                  | No cover at all                                                                                                                                                                   | As NES                  | As NES              | n/a                                                                                                                                                                                                                                       | n/a                                  | n/a     |

| Scenario                     | Change from Normal Evolution Scenario (NES)                                                                                                                                                                                                                                                               | On-site Resident/Farmer                                                                                                         | Hunter/Recreational                                 | Off-site Resident: Perch Creek Outfall | Off-site Resident: Sheenboro, Ottawa | Driller |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------|----------------------------------------|--------------------------------------|---------|
| Role of Base Liner           | Base liner does not act as low permeability barrier, either due to imperfect installation or deliberate puncturing prior to closure                                                                                                                                                                       | As NES                                                                                                                          | As NES                                              | n/a                                    | n/a                                  | n/a     |
| Series of Landslides         | A series of landslides extending over a long-period of time result in material moving downslope. Starts at 650 y (max water levels) and finishes at 5000 y (wastes unsaturated). Between 650 y and 5000 y all water flows out where the berm was previously located. Driven by hypothetical berm failure. | Assessed assuming waste is spread over swamp area. Residence is not present on the ECM (due to unstable slope). Grazing occurs. | Assessed, assuming waste is spread over swamp area. | n/a                                    | n/a                                  | n/a     |
| “What-If” scenarios          |                                                                                                                                                                                                                                                                                                           |                                                                                                                                 |                                                     |                                        |                                      |         |
| H.I.: Shallow Well           | A shallow well is drilled into the contaminant plume and used for drinking and irrigation<br>Assumed to occur at 300 years after closure (i.e., at the end of IC).                                                                                                                                        | As NES<br><br>Drinks well water.<br>Irrigates garden with well water.                                                           | n/a                                                 | n/a                                    | n/a                                  | n/a     |
| HI Mass excavation & farming | Waste excavated and spread over an area with soil mixed in. Waste exposed much faster than erosion scenario.                                                                                                                                                                                              | As NES                                                                                                                          | n/a                                                 | n/a                                    | n/a                                  | n/a     |
| Permanent bathtub            | Base liner remains impermeable, either due to slow degradation or clogging of degraded areas                                                                                                                                                                                                              | As NES, during period of bathtub conditions.                                                                                    | n/a                                                 | n/a                                    | n/a                                  | n/a     |

#### 4.1.14 Post-Closure Safety Assessment Results Summary

The PostSA demonstrates that dose to receptors for the Normal Evolution and Disruptive Events, are within the established dose acceptance criteria, consistent with applicable IAEA and CNSC guidance and requirements.

The maximum predicted dose during the NES is 0.015 mSv, and occurs 4100 years after closure to the On-site Resident/Farmer Adult. The maximum predicted dose evaluated for Disruptive Events is during the Enhanced Erosion case, where the On-Site Resident/Farmer Child receives 0.14 mSv/y at year 7650 after closure. The Defence-in-Depth scenarios demonstrate that the radiological consequence (dose) are less than the 1 mSv/y public dose limit even if a primary barrier fails. The “What-If” scenarios show that even under extremely unlikely cases, radiological consequences (dose) remain acceptably low. More discussion and interpretation of the results can be found in the PostSA, and also in Section 8 of this document.

A summary of the post-closure results are given in Table 4-3 below, which presents the receptor who receives the highest dose, the time at which the dose occurs, and the key pathways and dominant radionuclide that contributes to the dose.

**Table 4-3**  
**Summary of the Peak Dose for each Scenario [4-1]**

| Scenario                                 | Receptor                            | Peak Dose (mSv/y ) | Time of Peak (years after closure) | Key pathway(s)                                                              | Dominant Radionuclide(s)                 |
|------------------------------------------|-------------------------------------|--------------------|------------------------------------|-----------------------------------------------------------------------------|------------------------------------------|
| Normal Evolution                         | On-site resident/<br>farmer - adult | 0.015              | 4100                               | External irradiation from soil.<br>Ingestion of beef.                       | Th-228, Nb-94,<br>Ra-228, Ra-226<br>C-14 |
| <b>Sensitivity Analysis</b>              |                                     |                    |                                    |                                                                             |                                          |
| Inventory Sensitivity                    | Hunter/<br>Recreational-<br>adult   | 0.12               | 650                                | Ingestion of game.<br>Ingestion of fish.<br>External irradiation from soil. | C-14<br>Pu-239<br>Nb-94, Ra-226          |
| Institutional Control Sensitivity        | On-site resident/<br>farmer - adult | 0.015              | 4100                               | External irradiation from soil.<br>Ingestion of beef.                       | Th-228, Nb-94,<br>Ra-228, Ra-226<br>C-14 |
| Sorption Coefficient Sensitivity         | On-site resident/<br>farmer - adult | 0.062              | 2300                               | External irradiation from soil.<br>Ingestion of beef.                       | Nb-94, Ra-226,<br>Th-228, Ra-228<br>C-14 |
| Geosphere – Rapid Transit to Perch Creek | On-site resident/<br>farmer - adult | 0.015              | 4100                               | External irradiation from soil.<br>Ingestion of beef.                       | Th-228, Nb-94,<br>Ra-228, Ra-226<br>C-14 |
| Enhanced Degradation of Cover and Liner  | Hunter/<br>Recreational-<br>adult   | 0.015              | 500                                | Ingestion of game.<br>Ingestion of fish.                                    | C-14<br>Pu-239                           |

| Scenario                                          | Receptor                                                               | Peak Dose (mSv/y ) | Time of Peak (years after closure) | Key pathway(s)                                        | Dominant Radionuclide(s)              |
|---------------------------------------------------|------------------------------------------------------------------------|--------------------|------------------------------------|-------------------------------------------------------|---------------------------------------|
| Climate Change - Reduced HER                      | On-site resident/ farmer – child                                       | 0.063              | 3800                               | Ingestion of swamp foodstuffs.                        | Ra-228                                |
| Receptors of Public Interest                      | Resident at Sheenboro – adult                                          | 0.000004           | 500                                | Ingestion of water.                                   | Pu-239, I-129, Po-210, Am-241         |
| Self Sufficient Indigenous Receptor Case          | Self Sufficient Indigenous – adult                                     | 0.077              | 520                                | Ingestion of fish.<br>Ingestion of game.              | Pu-239<br>C-14                        |
| Degradation of Berm                               | Not quantitatively assessed. Bounded by Series of Landslides scenario. |                    |                                    |                                                       |                                       |
| Disruptive Events                                 |                                                                        |                    |                                    |                                                       |                                       |
| H.I. Borehole (Acute)                             | Driller                                                                | 0.0008             | 100                                | Inhalation.                                           | Am-241, Th-228, Pu-239, Ac-227        |
| H.I. House with Basement – Resident (Chronic)     | On-site resident/ farmer – child                                       | 0.018              | 100                                | Ingestion of garden foodstuffs.                       | Ra-228, C-14, Sr-90                   |
| Enhanced Erosion Case                             | On-site resident/ farmer – child                                       | 0.14               | 7650                               | Ingestion of foodstuffs.                              | Ra-228                                |
| Localized Cover Failure                           | On-site resident/ farmer - adult                                       | 0.017              | 2900                               | External irradiation from soil.<br>Ingestion of beef. | Th-228, Nb-94, Th-228, Ra-226<br>C-14 |
| Localized Liner Failure                           | On-site resident/ farmer - adult                                       | 0.01               | 2600                               | External irradiation from soil.<br>Ingestion of beef. | Th-228, Nb-94, Ra-228, Ra-226<br>C-14 |
| Damage to Berm                                    | On-site resident/ farmer - adult                                       | 0.02               | 3600                               | External irradiation from soil.<br>Ingestion of beef. | Nb-94, Th-228, Ra-228, Ra-226<br>C-14 |
| Dose Optimization                                 |                                                                        |                    |                                    |                                                       |                                       |
| Waste Packages – Wastes Grouted into Steel Liners | On-site resident/ farmer - adult                                       | 0.015              | 4100                               | External irradiation from soil.<br>Ingestion of beef. | Th-228, Nb-94, Ra-228, Ra-226<br>C-14 |
| Establishment of a Long-Term Buffer Zone          | Off-site resident/ farmer – adult                                      | 0.0017             | 500                                | Ingestion of fish.                                    | Pu-239                                |
| Defence-in-Depth                                  |                                                                        |                    |                                    |                                                       |                                       |

| Scenario                                   | Receptor                            | Peak Dose (mSv/y ) | Time of Peak (years after closure) | Key pathway(s)                                                                           | Dominant Radionuclide(s)                                                      |
|--------------------------------------------|-------------------------------------|--------------------|------------------------------------|------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|
| Role of Geosphere                          | On-site resident/<br>farmer - adult | 0.015              | 4100                               | External irradiation from soil.<br>Ingestion of beef.                                    | Th-228, Nb-94,<br>Ra-228, Ra-226<br>C-14                                      |
| Role of Cover                              | On-site resident/<br>farmer - adult | 0.023              | 2600                               | External irradiation from soil.<br>Ingestion of beef.                                    | Th-228, Nb-94,<br>Ra-228, Ra-226<br>C-14                                      |
| Role of Base Liner                         | Hunter/<br>Recreational – adult     | 0.0057             | 900                                | Ingestion of game.<br>Ingestion of fish.                                                 | C-14<br>Pu-239                                                                |
| Series of Landslides                       | On-site resident/<br>farmer – child | 0.13               | 5000                               | Ingestion of garden foodstuffs.                                                          | Ra-228                                                                        |
| <b>"What-If" Cases</b>                     |                                     |                    |                                    |                                                                                          |                                                                               |
| H.I. Well Case (shallow contaminated well) | On-site resident/<br>farmer - adult | 1.7*               | 500                                | Ingestion of well water.<br>Ingestion of garden foodstuffs.                              | Pu-239, Po-210,<br>I-129, Am-241<br>Pu-239, Po-210,<br>I-129, Am-241,<br>C-14 |
| H.I. Mass Excavation and Farming           | On-site resident/<br>farmer - adult | 0.43               | 300                                | Ingestion of beef.<br>External irradiation from soil.<br>Ingestion of garden foodstuffs. | C-14<br>Th-228, Ra-226,<br>Ra-228, Nb-94<br>Ra-228                            |
| Permanent Bathtub                          | On-site resident/<br>farmer - adult | 0.04               | 10 000                             | External irradiation from soil.                                                          | Th-228, Ra-228,<br>Nb-94, Ra-226                                              |

\* This dose resulted in the PostSA recommending a reduction to the Plutonium-239 and Iodine-129 inventories, which would result in a dose of 1 mSv/y. This reduced inventory is referred to as the Licenced Inventory.

#### 4.1.15 Post-Closure Non-Radiological Impact

##### 4.1.15.1 Normal Evolution Scenario

The PostSA calculates and assesses potential impacts from non-radioactive elements or chemical species in environmental media that are relevant to human health and environmental protection. The Environmental Quality Standard (EQS) criteria for soil, sediment and water are designed to protect against adverse effects due to exposure by the food chain and/or other pathways.

During the 10 000 year assessment timeframe of the PostSA, peak concentrations of copper, lead and uranium are below the corresponding EQS for soil, sediment and water, except for the concentration of lead in groundwater adjacent to the ECM. The concentration of uranium in groundwater is approaching the EQS, and slightly exceeds the EQS for swamp soils. Aluminum is a key component of clay minerals in soils and sediments. Therefore, there are no EQSs for aluminum. The peak concentration in groundwater immediately downgradient of the ECM is only slightly elevated above background. However, the concentration is much lower in surface waters. For context, concentrations of aluminum in groundwater and surface water are well below the Health Canada proposed operational guidance value and maximum acceptable concentrations in drinking water. It is noted that these guidance values are not meant for application to environmental concentrations.

Non-radiological contaminants were assessed in the PostSA [4-1] following a very cautious approach. All non-radiological contaminants were assumed to be readily available for dissolution and leaching upon contact with water, whereas in reality most of the non-radiological inventory will be encased in iron-based matrices. Additionally, the disposal of the remaining small fraction of non-radiological inventory will meet land disposal regulations, which are protective of public health and the environment. Finally, it is noted that conventional landfills can contain significant quantities of lead. The NSDF ECM meets the design and durability requirements of Ontario landfill regulations and is consistent with best practice for a conventional landfill, and so, in the context of containment of lead, the ECM would provide similar long-term performance to a contemporary conventional landfill. Therefore, negligible residual effects are expected from non-radiological contaminants associated with the NSDF Project.

### **Aquatic Environment**

Using total concentrations based on maximum predicted incremental concentrations calculated in the PostSA [4-1], combined with background concentrations in environmental media, the EcoRA [4-23] assessed the effect of non-radiological releases on aquatic biota during the post-closure phase. Screening indices for copper and lead were above 1 for some aquatic receptors, and below 1 for uranium for all aquatic receptors. Screening indices is the ratio (i.e., unitless) of an estimated exposure level (e.g., estimated environmental concentration) divided by a corresponding toxicity reference value or benchmark value. Screening indices value greater than 1 indicates the potential for undue effects. However, the EcoRA determined that these screening indices exceedances were driven largely by the background concentrations of these contaminants as opposed to contributions from the NSDF Project. Based on the effects assessment undertaken in the EcoRA [4-23], negligible residual effects from non-radiological exposure were predicted for aquatic biota in the post-closure phase.

### **Terrestrial Environment**

Using total concentrations based on maximum predicted incremental concentrations calculated in the PostSA [4-1], combined with background concentrations in environmental media, the EcoRA [4-23] assessed the effect of non-radiological releases on terrestrial biota during the post-closure phase.

Screening Indices values for copper, and uranium were below a value of 1 for terrestrial receptors. Screening indices below 1 indicates no undue effects. For lead, the screening index value was above 1 for the Canada warbler and Eastern whip-poor-will, but these exceedances were driven largely by the background concentrations of the contaminants as opposed to contributions from the NSDF Project.

Based on the effects assessment undertaken in the EcoRA, no potential residual effects from non-radiological exposure were predicted for terrestrial biota in the post-closure phase. Overall, no potential residual effects were identified for ambient radioactivity and ecological health for the NES.

#### **4.1.15.2 Disruptive Events**

Hypothetical disruptive event scenarios were also assessed in the PostSA as mechanisms to test the robustness of the overall waste management system. Non-radiological contaminants were assessed following a very cautious approach. All non-radiological contaminants were assumed to be readily available for dissolution and leaching upon contact with water, whereas in reality, most of the non-radiological inventory will be encased in iron-based matrices. The disposal of the remaining small fraction of non-radiological inventory will meet land disposal regulations, which are protective of public health and the environment.

For non-radiological contaminants, aluminum, uranium, copper and lead screened in for all disruptive event scenarios. Screening Indices values for aluminum and uranium were below a value of 1, indicating no undue effects to terrestrial or aquatic biota. Screening Indices values for copper and lead were above 1 similar to the NES exposure assessment. Although a screening indices value greater than 1 indicates the potential for undue effects, the EcoRA further assessed these contaminants and determined that their corresponding screening indices exceedances were driven largely by the background concentrations of these contaminants as opposed to contributions from the NSDF Project. In one disruptive event case – the Enhanced Erosion Scenario – the NSDF Project also contributed to the screening index value. However, taking the low probability into account, the effective screening indices would be less than 1, and thus negligible residual effects are anticipated.

Finally, it is again noted that conventional landfills can contain significant quantities of non-radiological contaminants. The NSDF ECM meets the design and durability requirements of Ontario landfill regulations and is consistent with best practice for a conventional landfill, and so, in the context of containment of non-radiological contaminants, the ECM would provide similar long-term performance to a contemporary conventional landfill. Therefore, negligible residual effects are expected from non-radiological contaminants associated with the NSDF post-closure phase.

Table 4-4 presents the peak environmental concentrations of the non-radiological contaminants for each scenario of the PostSA. Groundwater represents the single groundwater source modelled. Soil refers to either the resident's garden or the swamp. Surface water refers to either Perch Creek or the Ottawa River. Sediment refers to either Perch Creek or the Ottawa River shore. The highest values are reported in each category as a summary. For more information, see Section 6 of the PostSA [4-1].

**Table 4-4**  
**Summary of Environmental Concentrations for PostSA Scenarios**

| Scenario                                          | Groundwater (µg/L)                                                           |          |          |          | Soil (µg/g) |          |          |          | Surface Water (µg/L) |          |          |          | Sediment (µg/g) |          |          |          |
|---------------------------------------------------|------------------------------------------------------------------------------|----------|----------|----------|-------------|----------|----------|----------|----------------------|----------|----------|----------|-----------------|----------|----------|----------|
|                                                   | Al                                                                           | Cu       | Pb       | U        | Al          | Cu       | Pb       | U        | Al                   | Cu       | Pb       | U        | Al              | Cu       | Pb       | U        |
| Normal Evolution Scenario                         | 1.80E-01                                                                     | 1.80E-02 | 2.30E+01 | 6.10E+00 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 2.20E+00 | 6.00E-06             | 7.00E-07 | 5.50E-04 | 2.10E-04 | 2.70E-05        | 2.40E-03 | 5.40E-01 | 2.20E-01 |
| Inventory Sensitivity                             | 1.80E-01                                                                     | 1.80E-02 | 2.30E+01 | 1.30E+01 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 4.50E+00 | 4.60E-03             | 5.40E-04 | 4.20E-01 | 3.20E-01 | 2.70E-05        | 2.40E-03 | 5.40E-01 | 4.60E-01 |
| Institutional Control Sensitivity                 | Unchanged from NES                                                           |          |          |          |             |          |          |          |                      |          |          |          |                 |          |          |          |
| Sorption Coefficient Sensitivity                  | 1.80E-01                                                                     | 8.00E-02 | 5.10E+01 | 1.40E+01 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 4.50E+00 | 4.60E-03             | 5.40E-04 | 7.70E-01 | 3.80E-01 | 2.70E-05        | 4.20E-03 | 2.20E+00 | 5.20E-01 |
| Geosphere – Rapid Transit to Perch Creek          | 1.30E-01                                                                     | 1.40E-02 | 1.70E+01 | 4.40E+00 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 2.20E+00 | 4.60E-03             | 5.50E-04 | 4.30E-01 | 1.60E-01 | 2.70E-05        | 3.30E-03 | 7.20E-01 | 2.20E-01 |
| Enhanced Degradation of Cover and Liner           | 1.80E-01                                                                     | 2.60E-02 | 3.00E+01 | 6.20E+00 | 2.60E-05    | 3.00E-02 | 1.20E+01 | 1.90E+00 | 4.60E-03             | 1.00E-04 | 1.60E-01 | 1.60E-01 | 2.70E-05        | 5.20E-04 | 4.60E-01 | 2.30E-01 |
| Climate Change - Reduced HER                      | 2.20E-01                                                                     | 1.50E-02 | 2.30E+01 | 7.60E+00 | 2.50E-05    | 3.90E-02 | 1.30E+01 | 2.10E+00 | 4.60E-03             | 4.10E-04 | 3.50E-01 | 1.40E-01 | 2.70E-05        | 1.30E-03 | 3.00E-01 | 2.10E-01 |
| Receptors of Public Interest                      | 1.80E-01                                                                     | 1.80E-02 | 2.30E+01 | 6.10E+00 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 2.20E+00 | 4.60E-03             | 5.40E-04 | 4.20E-01 | 1.60E-01 | 2.70E-05        | 2.40E-03 | 5.40E-01 | 2.20E-01 |
| Self-Sufficient Indigenous                        | Unchanged from NES                                                           |          |          |          |             |          |          |          |                      |          |          |          |                 |          |          |          |
| Degradation of Berm                               | Not quantitatively assessed - bounded by Role of Berm (Series of Landslides) |          |          |          |             |          |          |          |                      |          |          |          |                 |          |          |          |
| H.I. Borehole (Acute)                             | 1.80E-01                                                                     | 1.80E-02 | 2.30E+01 | 6.10E+00 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 2.20E+00 | 4.60E-03             | 5.40E-04 | 4.20E-01 | 1.60E-01 | 2.70E-05        | 2.40E-03 | 5.40E-01 | 2.20E-01 |
| H.I. House with Basement – Resident (Chronic)     | 1.80E-01                                                                     | 1.80E-02 | 2.30E+01 | 6.10E+00 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 2.20E+00 | 4.60E-03             | 5.40E-04 | 4.20E-01 | 1.60E-01 | 2.70E-05        | 2.40E-03 | 5.40E-01 | 2.20E-01 |
| Enhanced Erosion Case                             | 2.00E-01                                                                     | 2.30E-02 | 2.70E+01 | 6.10E+00 | N/A         | 1.80E+03 | 7.90E+01 | 1.40E+00 | 3.70E+01             | 3.60E+01 | 2.30E+00 | 2.00E-01 | 6.40E-05        | 6.20E-01 | 1.60E+00 | 2.50E-01 |
| Localized Cover Failure                           | 1.80E-01                                                                     | 1.80E-02 | 2.30E+01 | 6.10E+00 | 2.60E-05    | 4.20E-02 | 1.40E+01 | 2.20E+00 | 4.60E-03             | 5.50E-04 | 4.30E-01 | 1.60E-01 | 2.70E-05        | 2.50E-03 | 5.60E-01 | 2.20E-01 |
| Localized Liner Failure                           | 1.80E-01                                                                     | 1.90E-02 | 2.40E+01 | 7.20E+00 | 2.30E-05    | 3.60E-02 | 1.20E+01 | 1.90E+00 | 4.60E-03             | 3.60E-04 | 3.00E-01 | 1.90E-01 | 2.70E-05        | 2.00E-03 | 6.00E-01 | 2.70E-01 |
| Damage to Berm                                    | 1.80E-01                                                                     | 1.60E-02 | 2.20E+01 | 5.60E+00 | 2.60E-05    | 4.40E-02 | 1.50E+01 | 2.60E+00 | 4.60E-03             | 6.40E-04 | 4.70E-01 | 1.50E-01 | 2.70E-05        | 2.70E-03 | 6.10E-01 | 2.10E-01 |
| Waste Packages – Wastes Grouted into Steel Liners | 1.80E-01                                                                     | 1.80E-02 | 2.30E+01 | 5.60E+00 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 2.20E+00 | 4.60E-03             | 5.40E-04 | 4.20E-01 | 1.50E-01 | 2.70E-05        | 2.40E-03 | 5.40E-01 | 2.10E-01 |
| Establishment of a Long-Term Buffer Zone          | Unchanged from NES                                                           |          |          |          |             |          |          |          |                      |          |          |          |                 |          |          |          |
| Radon Optimization Through Waste Placement        | Unchanged from NES                                                           |          |          |          |             |          |          |          |                      |          |          |          |                 |          |          |          |
| Role of Geosphere                                 | 1.80E-01                                                                     | 2.20E-02 | 2.50E+01 | 6.20E+00 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 2.20E+00 | 4.60E-03             | 1.20E-03 | 8.90E-01 | 1.70E-01 | 2.70E-05        | 1.30E-02 | 1.90E+00 | 2.50E-01 |
| Role of Cover                                     | 1.80E-01                                                                     | 1.80E-02 | 2.40E+01 | 6.20E+00 | 2.70E-05    | 4.30E-02 | 1.40E+01 | 2.30E+00 | 4.60E-03             | 6.00E-04 | 4.50E-01 | 1.60E-01 | 2.70E-05        | 2.60E-03 | 6.00E-01 | 2.20E-01 |
| Role of Liner                                     | 1.80E-01                                                                     | 2.70E-02 | 4.00E+01 | 7.70E+00 | 4.60E-10    | 3.50E-09 | 4.90E-05 | 4.50E-05 | 4.60E-03             | 1.10E-05 | 2.60E-01 | 1.90E-01 | 2.70E-05        | 1.70E-04 | 7.50E-01 | 2.80E-01 |
| Role of Berm                                      | 2.00E-01                                                                     | 3.00E-02 | 3.10E+01 | 4.10E+00 | N/A         | 2.60E+03 | 1.00E+02 | 4.10E+00 | 3.30E+05             | 2.00E+02 | 1.10E+01 | 4.90E-01 | 6.40E-05        | 5.00E+00 | 3.80E+00 | 2.10E-01 |



| Scenario                                   | Groundwater (µg/L) |          |          |          | Soil (µg/g) |          |          |          | Surface Water (µg/L) |          |          |          | Sediment (µg/g) |          |          |          |
|--------------------------------------------|--------------------|----------|----------|----------|-------------|----------|----------|----------|----------------------|----------|----------|----------|-----------------|----------|----------|----------|
|                                            | Al                 | Cu       | Pb       | U        | Al          | Cu       | Pb       | U        | Al                   | Cu       | Pb       | U        | Al              | Cu       | Pb       | U        |
| H.I. Mass Excavation and Farming           | 2.00E-01           | 8.60E-02 | 5.00E+01 | 9.80E+00 | N/A         | 1.20E+03 | 5.90E+01 | 3.30E+00 | 1.70E-02             | 4.90E-03 | 1.70E+00 | 3.20E-01 | 6.40E-05        | 3.80E-02 | 5.00E+00 | 4.60E-01 |
| H.I. Well Case (shallow contaminated well) | 1.80E-01           | 1.80E-02 | 2.30E+01 | 6.10E+00 | 2.60E-05    | 4.10E-02 | 1.40E+01 | 2.20E+00 | 4.60E-03             | 5.40E-04 | 4.20E-01 | 1.60E-01 | 2.70E-05        | 2.40E-03 | 5.30E-01 | 2.20E-01 |
| Permanent Bathtub                          | 7.90E-02           | 5.40E-03 | 4.80E+00 | 2.80E+00 | 2.60E-05    | 4.50E-02 | 1.50E+01 | 2.30E+00 | 4.60E-03             | 1.10E-03 | 9.00E-01 | 1.30E-01 | 2.30E-05        | 7.00E-03 | 1.70E+00 | 1.50E-01 |

## **4.2 Operational Safety**

The NSDF safety analyses/assessments that are relevant to operational safety are:

- NSDF SAR [4-24].
- NSDF Criticality Safety Document [4-25].
- ALARA Assessment [4-26].
- Fire Hazard Analysis (FHA) [4-27].

### **4.2.1 Operational Safety Analysis**

The following sections describe and summarize the work performed in the SAR [4-24]. For very detailed information regarding specific inputs, the reader is directed to the SAR [4-24].

The scope of the NSDF SAR [4-24], is to present the operational safety analysis of the NSDF, based on the detailed design package, proposed operations and identified hazards. The timeframe assessed is the NSDF pre-closure phase that includes the construction period, 50 year operations period, and 30 year closure period [4-24].

The NSDF SAR assesses the safety of on-site and off-site human receptors and the environment for normal operations and accident conditions [4-24]. Nuclear safety is assessed for normal operations and the accident conditions; AOO, DBA and BDBA including DEC. Conventional health and safety is assessed for normal operations and conventional industrial accidents.

Events identified in the safety analysis are classified into the following classes [4-24]:

- Anticipated Operational Occurrences.
- Design Basis Accidents.
- Beyond Design Basis Accidents including DEC.
- Conventional health and safety (non-radiological events).

### **4.2.2 Hazard Identification and Accident Analyses.**

The Hazard Analyses [4-28], [4-29], [4-30], and [4-31], were conducted to ensure that all possible hazards were identified and assessed. The focus of the hazard analysis is on the potential accident conditions involving the hazards associated with the NSDF design and operations.

In general, the hazard analysis process consisted of:

- Systematically evaluate hazards, develop accident sequences/scenarios, and identify administrative and engineered controls.
- Qualitatively assess the frequency and consequence/severity for the mitigated hazard or event.
- The frequency and consequence/severity is combined to determine the risk ranking of the mitigated hazard or event.

The initial hazard identification was conducted based on the 30% design [4-28]. The objective of the hazard identification was to list characteristics associated with SSCs with the potential for radiological or chemical harm to people or the environment.

The WWTP hazard identification involved completing a Failure Modes and Effects Analysis (FMEA) for the WWTP components and subcomponents, based on the 30% [4-28], and the 100% design piping and instrumentation diagrams [4-29]. The Failure Modes and Effects Criticality Analysis [4-29], examined the failure or error modes for a total of 144 WWTP sub-components and identified 59 failure or error modes with radiological consequences.

The hazard analysis documented in NSDF Hazard Identification and Analysis [4-29], was based on 60% design with subsequent modifications to design details made by members of the detailed design project team until 2017 April. The hazard analysis in NSDF Hazard Identification and Analysis [4-29], only analyzed radiological hazards.

Following this hazard identification and analysis, a systematic and comprehensive approach was used to identify and assess the major hazards and PIEs associated with the design and operations of the NSDF. The “What-If” Hazard Analysis [4-30], and [4-31], analyzed the NSDF operation and 100% design using the consolidated list of hazards, initiating events and AOOs. The risk matrix, risk ratings, frequency ratings and severity ratings used is the hazard analyses [4-30], and [4-31] are presented in Table 4-5, Table 4-6, Table 4-7, and Table 4-8, respectively.

**Table 4-5**  
**Risk Matrix**

| Frequency                                       | S0 | S1 | S2 | S3 |
|-------------------------------------------------|----|----|----|----|
| AOO (Frequent or Occasional; $\geq 10^{-2}/a$ ) | R0 | R1 | R2 | R3 |
| DBA ( $<10^{-2}/a$ and $\geq 10^{-5}/a$ )       | R0 | R0 | R1 | R2 |
| BDBA ( $10^{-6}/a$ to $<10^{-5}/a$ )            | R0 | R0 | R0 | R1 |

**Table 4-6**  
**Guidelines for Interpreting Risk Ratings**

| Risk Ranking | Definition                                                                                                                                 |
|--------------|--------------------------------------------------------------------------------------------------------------------------------------------|
| R0           | The risk is negligible; no further action necessary.                                                                                       |
| R1           | The risk is tolerable; further protective measures are not essential but should be considered <sup>3</sup> .                               |
| R2           | The risk is unreasonable; engineered solutions must be put in place to protect against the hazard.                                         |
| R3           | The risk is unreasonable; the proposed process or equipment is inherently unsafe, major modifications to the proposed design are required. |

<sup>3</sup> Further measures are typically additional administrative controls and/or simple design changes.

**Table 4-7**  
**Frequency Ratings**

| Frequency Class | Frequency Range (events/year) | Definition                                                                                                                                                                                         |
|-----------------|-------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| F0              | $10^{-6}$ to $<10^{-5}$       | Selected Beyond Design Basis Accident (BDBA) that is very unlikely to occur over the lifetime of the Facility. An accident less frequent and potentially more severe than a design-basis accident. |
| F1              | $\geq 10^{-5}$ to $10^{-2}$   | Design Basis Accident (DBA) that is unlikely to occur over the lifetime of the Facility, but is considered plausible.                                                                              |
| F2              | $>10^{-2}$                    | An occasional event, Anticipated Operational Occurrence (AOO), upset condition, this event is expected to occur over the lifetime of the Facility but is not considered a normal operation.        |

**Table 4-8**  
**Severity Ratings**

| Severity Rating | Definition                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-----------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| S0              | <p><b>Industrial Consequences:</b> Consequences are negligible, minor injury requiring First Aid treatment which does not result in lost time from work <sup>(1)</sup>.</p> <p><b>Operational Consequences:</b> No operational impacts and facility does not require a shutdown (e.g., for clean-up, etc.).</p> <p><b>Radiological Consequences:</b> Effective doses up to 1 mSv (on-site) and/or 0.1 mSv (off-site).</p> <p><b>Environmental Consequences:</b> Negligible release to the environment, impact may be measurable. Impacts to the environment are very small/negligible and localized (on-site)/short duration.</p>                                                                                                                                                                                                                                                  |
| S1              | <p><b>Industrial Consequences:</b> Consequences are minor, injury or an occupational disease requiring medical treatment by a medical practitioner<sup>(2)</sup> (other than CNL health centre nurse), a disabling injury resulting in a medical practitioner prescribing work restrictions (and modified work is offered by CNL)<sup>(3)</sup> or time off from work (lost time) of up to 5 days <sup>(4)</sup>.</p> <p><b>Operational Consequences:</b> Minor operational impact and facility may require shut down for up to 1 day.</p> <p><b>Radiological Consequences:</b> Effective doses in the range of 1 to 5 mSv (on-site) and/or 0.1 to 0.5 mSv (off-site).</p> <p><b>Environmental Consequences:</b> Minor release to the environment, impact is measurable. Impacts to the environment are moderately extensive (on-site, may be off-site) and moderate duration.</p> |
| S2              | <p><b>Industrial Consequences:</b> Consequences are moderate, electric shock, toxic atmosphere, or oxygen deficient atmosphere that causes loss of consciousness. The implementation of rescue, revival or other similar emergency procedures. A disabling (non-permanent) injury/disease (to one or more workers)<sup>(5)</sup> resulting in a total lost time &gt;5 days and up to 60 days <sup>(6)</sup>.</p> <p><b>Operational Consequences:</b> Moderate operational impact and facility may require shut down for &gt;1 to 5 days.</p> <p><b>Radiological Consequences:</b> Effective doses in the range of 5 to 50 mSv (on-site) and/or 0.5 to 20 mSv (off-site).</p> <p><b>Environmental Consequences:</b> Moderate release to the environment. Impacts to the environment are extensive (on-site and off-site) and long duration.</p>                                     |
| S3              | <p><b>Industrial Consequences:</b> Consequences are severe, fatality, a disabling injury resulting in loss of a body member or a part thereof, or the complete loss of the usefulness of a body member or a part thereof, permanent impairment of a body function, a disabling (non-permanent) injury (to one or more workers)<sup>(5)</sup> resulting in a total lost time &gt;60 days.</p> <p><b>Operational Consequences:</b> Major operational impact and facility shut down for greater than 5 days.</p> <p><b>Radiological Consequences:</b> Effective doses &gt;50 mSv (on-site) and/or &gt;20 mSv (off-site).</p> <p><b>Environmental Consequences:</b> Major release to the environment. Impacts to the environment are catastrophic.</p>                                                                                                                                 |

Table Notes:

- 
1. Minor cut treated at the CNL health centre (not requiring stitches).
  2. Cut requiring stitches.
  3. Doctor prescribes 'no manual lifting' for employee whose employment requires lifting.
  4. Injury requiring medication to be prescribed which makes it unsafe to attend work.
  5. One person injured or summation of lost time for multiple injured individuals.
  6. Broken bones preventing return to work.
- 

The "What-If" hazard analysis [4-30] identified:

- 144 radiological safety consequences, 44 environmental consequences and 36 industrial safety consequences.
- 192 R0 mitigated risks, 31 R1 mitigated risks, two R2 mitigated risks and zero R3 mitigated risks.

The hazard analysis [4-31] identified:

- 11 radiological safety consequences, 35 environmental consequences and 49 industrial safety consequences.
- 82 R0 mitigated risks, 13 R1 mitigated risks, zero R2 mitigated risks and zero R3 mitigated risks.

The hazards and events from the Hazard Analyses [4-30], [4-31], [4-29], and [4-28], are grouped based on type of accident as defined in Safety Analysis for Decommissioning and Waste Management [4-32]. Events are grouped under the following main headings:

- Group A: Anticipated Operational Occurrences
- Group B: Design Basis Accidents
- Group C: Beyond Design Basis Accidents including DEC's
- Group D: Conventional Health and Safety

Groups A, B and C are events with radiological consequences, and conventional events are excluded from these groups. Group D events address conventional health and safety events with non-radiological consequences, and are assessed qualitatively, describing the impact of the event and the features in place to mitigate the event. Table 4-9 provides the event groupings and the analysis approach being qualitative and or quantitative. Table 4-10 provides a summary of the radiological consequences for the hazards that were analyzed quantitatively. The calculated radiological consequences to the on-site receptors and off-site receptors meet the dose acceptance criteria defined in Table 2-5, Dose Acceptance Criteria for Accidents.

**Table 4-9**  
**Event Grouping and Analysis Approach [4-24]**

| Event Grouping and Description |                                                    | Analysis Approach<br>(Qualitative or Quantitative) |
|--------------------------------|----------------------------------------------------|----------------------------------------------------|
| <b>Group A</b>                 | <b>Anticipated Operational Occurrences</b>         |                                                    |
| <b>A.1</b>                     | <b>External Events</b>                             |                                                    |
| A.1.1                          | Extreme Wind, Tornado and Microburst               |                                                    |
| A.1.1.1                        | ECM                                                | Qualitative                                        |
| A.1.1.2                        | WWTP, Equalization Tanks and piping infrastructure | Qualitative                                        |
| A.1.1.3                        | Building structures                                | Qualitative                                        |
| A.1.2                          | Severe Precipitation                               | Qualitative                                        |

| Event Grouping and Description |                                                    | Analysis Approach<br>(Qualitative or Quantitative) |
|--------------------------------|----------------------------------------------------|----------------------------------------------------|
| A.1.3                          | Extreme Drought                                    | Qualitative                                        |
| <b>A.2</b>                     | <b>Loss of Services</b>                            |                                                    |
| A.2.1                          | Loss of Class IV Power                             | Qualitative                                        |
| A.2.2                          | Loss of ventilation                                | Qualitative                                        |
| A.2.3                          | Loss of other services                             | Qualitative                                        |
| <b>A.3</b>                     | <b>ECM</b>                                         |                                                    |
| A.3.1                          | Containment failure                                | Qualitative                                        |
| A.3.2                          | Dropped load                                       | Quantitative                                       |
| A.3.3                          | Contamination                                      | Qualitative                                        |
| A.3.4                          | Unintended contents                                | Qualitative                                        |
| A.3.5                          | Vehicle collision                                  | Qualitative                                        |
| A.3.6                          | Intrusion of non-human biota                       | Qualitative                                        |
| A.3.7                          | Damage to structure                                | Qualitative                                        |
| A.3.8                          | Higher flow                                        | Qualitative                                        |
| A.3.9                          | Ground subsidence or erosion                       | Qualitative                                        |
| A.3.10                         | Radiation                                          | Qualitative                                        |
| <b>A.4</b>                     | <b>WWTP</b>                                        |                                                    |
| A.4.1                          | Containment failure                                | Qualitative                                        |
| A.4.2                          | Contamination                                      | Quantitative                                       |
| A.4.3                          | Dropped load                                       | Qualitative                                        |
| A.4.4                          | Vehicle collision                                  | Qualitative                                        |
| <b>A.5</b>                     | <b>VDF</b>                                         |                                                    |
| A.5.1                          | Contamination                                      | Quantitative                                       |
| A.5.2                          | Radiation                                          | Quantitative                                       |
| <b>Group B</b>                 | <b>Design Basis Accidents</b>                      |                                                    |
| <b>B.1</b>                     | <b>External Events</b>                             |                                                    |
| B.1.1                          | Seismic activity                                   |                                                    |
| B.1.1.1                        | ECM                                                | Qualitative                                        |
| B.1.1.2                        | WWTP, Equalization Tanks and piping infrastructure | Qualitative                                        |
| B.1.1.3                        | Building structures                                | Qualitative                                        |
| B.1.2                          | Wildland fire                                      | Qualitative                                        |
| B.1.3                          | Lightning                                          | Qualitative                                        |
| B.1.4                          | Extreme wind and tornado                           |                                                    |
| B.1.4.1                        | ECM                                                | Qualitative                                        |
| B.1.4.2                        | WWTP and Equalization Tanks                        | Qualitative                                        |
| B.1.4.3                        | Building structures                                | Qualitative                                        |
| <b>B.2</b>                     | <b>ECM</b>                                         |                                                    |
| B.2.1                          | Dropped load                                       | Quantitative                                       |
| B.2.2                          | Unintended contents                                | Qualitative                                        |
| B.2.3                          | Vehicle collision                                  | Qualitative                                        |
| B.2.4                          | Damage to structure                                | Qualitative                                        |
| B.2.5                          | Misdirected flow                                   | Qualitative                                        |
| B.2.6                          | Internal fire                                      | Quantitative                                       |
| <b>B.3</b>                     | <b>WWTP</b>                                        |                                                    |

| Event Grouping and Description |                                                    | Analysis Approach<br>(Qualitative or Quantitative) |
|--------------------------------|----------------------------------------------------|----------------------------------------------------|
| B.3.1                          | Containment failure                                | Quantitative                                       |
| B.3.2                          | Dropped load                                       | Quantitative                                       |
| B.3.3                          | Unintended contents                                | Qualitative                                        |
| B.3.4                          | Vehicle collision                                  | Qualitative                                        |
| B.3.5                          | Internal fire                                      | Quantitative                                       |
| B.3.6                          | Radiation                                          | Qualitative                                        |
| <b>B.4</b>                     | <b>VDF</b>                                         |                                                    |
| B.4.1                          | Internal fire                                      | Qualitative                                        |
| <b>Group C</b>                 | <b>Beyond Design Basis Accidents</b>               |                                                    |
| C.1                            | Seismic activity                                   | Qualitative                                        |
| C.2                            | Flooding                                           | Qualitative                                        |
| C.3                            | Tornado                                            | Qualitative                                        |
| C.4                            | Aircraft crash                                     | Qualitative/Quantitative                           |
| <b>Group D</b>                 | <b>Conventional Health and Safety</b>              |                                                    |
| D.1                            | Anticipated Operational Occurrences                |                                                    |
| D.1.1                          | ECM                                                |                                                    |
| D.1.1.1                        | Impact/collision                                   | Qualitative                                        |
| D.1.1.2                        | Noise                                              | Qualitative                                        |
| D.1.1.3                        | Fall                                               | Qualitative                                        |
| D.1.2                          | WWTP, Equalization Tanks and piping infrastructure |                                                    |
| D.1.2.1                        | Fall                                               | Qualitative                                        |
| D.1.2.2                        | Spill/Leak                                         | Qualitative                                        |
| D.1.2.3                        | Hazardous reaction                                 | Qualitative                                        |
| D.1.2.4                        | Confined space                                     | Qualitative                                        |
| D.2                            | Design Basis Accidents                             |                                                    |
| D.2.1                          | ECM                                                |                                                    |
| D.2.1.1                        | Impact/collision                                   | Qualitative                                        |
| D.2.2                          | WWTP                                               |                                                    |
| D.2.2.1                        | Spill/Leak                                         | Qualitative                                        |
| D.2.2.2                        | Hazardous reaction                                 | Qualitative                                        |
| D.2.2.3                        | Dropped load                                       | Qualitative                                        |
| D.2.3                          | VDF                                                |                                                    |
| D.2.3.1                        | Impact/collision                                   | Qualitative                                        |
| D.2.3.2                        | Spill/Leak                                         | Qualitative                                        |

**Table 4-10**  
**Summary of Quantitative Operational Safety Analysis [4-24]**

| Event Grouping and Description             |                                                                                                                                                                                                                                                                     | Receptor                  | Radiological Consequence (mSv)                                 | Meets Dose Acceptance Criteria                               |
|--------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------------------------------------------------|--------------------------------------------------------------|
| <b>Anticipated Operational Occurrences</b> |                                                                                                                                                                                                                                                                     |                           |                                                                |                                                              |
| A.3.2                                      | ECM Dropped Load – Potential damage to the waste package (multiple) due to dropped load, resulting in the spread of contamination.                                                                                                                                  | Worker                    | 4.0E-02                                                        | Meets criteria of < 5 mSv for on-site personnel.             |
| A.4.2                                      | WWTP worker is splashed during sampling of the tanks, resulting in potential dose to the worker.                                                                                                                                                                    | Worker                    | 3.0E-04                                                        | Meets criteria of < 5 mSv for on-site personnel.             |
| A.4.3                                      | Dropped load, dewatered residuals bin, occurs in the WWTP due to human error, resulting in the spread of contamination and potential dose to the worker.                                                                                                            | Worker                    | 7.4E-03 (10 minute exposure),<br>4.4E-02 (60 minute exposure). | Meets criteria of < 5 mSv for on-site personnel.             |
| A.5                                        | VDF - Exposure to greater than anticipated contamination on vehicle, or handling equipment resulting in potential dose to the worker dose.<br>VDF -Radiation – higher than anticipated radiation fields from the vehicle resulting in potential dose to the worker. | Worker                    | 3.53E-02 (inhalation).<br><br>3.63E-02 (60 minute exposure).   | Meets criteria of < 5 mSv for on-site personnel.             |
| <b>Design Basis Accidents</b>              |                                                                                                                                                                                                                                                                     |                           |                                                                |                                                              |
| B.2.6                                      | Internal fire - Potential waste fire at the ECM TSWRPA resulting in dose to on-site and off-site receptors, and release to the environment.                                                                                                                         | Worker                    | 2.4E+00                                                        | Meets criteria of 5 mSv to 50 mSv for on-site personnel.     |
|                                            |                                                                                                                                                                                                                                                                     | On-site at Building 700   | 5.2E-02                                                        |                                                              |
|                                            |                                                                                                                                                                                                                                                                     | Off-site adult            | 2.1E-02                                                        | Meets criteria of 0.5 mSv to 20 mSv for the off-site public. |
|                                            |                                                                                                                                                                                                                                                                     | Off-site 1 year old child | 1.4E-02                                                        |                                                              |
| B.3.1                                      | WWTP containment failure - Pressure boundary failure - Mechanical failure of the WWTP tanks, piping and/or valves could result in a spill of wastewater                                                                                                             | Worker                    | 7.6E-05                                                        | Meets criteria of 5 mSv to 50 mSv for on-site personnel      |
| B.3.1                                      | WWTP containment failure - Loss of containment (tank failure) leads to spill of IX resin and/or GAC during replacement or transfer of spent resins resulting in dose to the worker.                                                                                 | Worker                    | 5.2E-03 (10 minute exposure),<br>3.1E-02 (60 minute exposure). | Meets criteria of 5 mSv to 50 mSv for on-site personnel      |



|       |                                                                                                                                                                             |                           |                                                                      |                                                            |
|-------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------|----------------------------------------------------------------------|------------------------------------------------------------|
| B.3.2 | WWTP dropped load - Mechanical failure of handling equipment (crane) resulting in the dropped load, filter press de-watered residuals bin, and the spread of contamination. | Worker                    | 7.4E-03<br>(10 minute exposure),<br>4.4E-02<br>(60 minute exposure). | Meets criteria of 5 mSv to 50 mSv for on-site personnel    |
| B3.5  | WWTP Internal Fire - Fire in the WWTP Residuals Management Area resulting in potential dose to the on-site and off-site receptors.                                          | On-site at Building 700   | 5.6E-07                                                              | Meets criteria of 5 mSv – 50 mSv for on-site receptors.    |
|       |                                                                                                                                                                             | Off-site adult            | 2.4E-07                                                              | Meets criteria of 0.5 mSv – 20 mSv for off-site receptors. |
|       |                                                                                                                                                                             | Off-site 1 year old child | 1.5E-07                                                              |                                                            |

#### 4.2.3 Normal Operations

The estimated radiological consequence to the ECM worker based on the work tasks, ranges from 0.8 mSv/year to 10.4 mSv/year. The work task with the highest radiological consequence to workers is macroencapsulation of drummed waste. The highest worker radiological consequence is 1.3 mSv/4 week period and 10.4 mSv/year, which meets the CNL effective dose action levels of 6 mSv/4 weeks, and 20 mSv/year, presented in Table 2-7, Occupational Radiation Exposures Actions Levels for CRL.

The annual radiological consequence to the ECM worker spending 1 120 hours/year on top of the ECM waste layers was calculated using RESRAD-Offsite Version 3.2. The dose assessment using RESRAD-OFFSITE, models a disposal cell containing 150 000 m<sup>3</sup> bulk waste that is 10 m thick, and the worker is located on top for 1 120 hours/year. The exposure pathways includes external gamma, inhalation, radon and soil ingestion. The peak radiological consequence to the ECM worker is 6.37 mSv/year, and this corresponds to a dose rate of approximately 5.69E-03 mSv/h. These radiological consequences estimates assume that there is no cover over the waste, and conservatively exclude the distance and any shielding provided by the heavy equipment to the receptor.

Table 4-11 provides the estimated airborne concentrations of radon, tritium and C-14 in the disposal cell, and the estimated dose to the ECM worker [4-24]. The estimated airborne radon concentration in the disposal cell is 0.5 Bq/m<sup>3</sup>, which is lower than the current Canadian guideline of 200 Bq/m<sup>3</sup> for radon in indoor air for dwellings [4-33]. The radiological consequence to the ECM worker is negligible from ECM airborne concentrations of radon, tritium and C-14. Since the radiological consequence to the ECM worker is negligible, the radiological effect on non-human biota will also be negligible from ECM airborne concentrations of radon, tritium and C-14.

The estimated radiological consequence to the WWTP worker based on the work tasks, ranges from 1.91E-04 mSv/year to 2.66 mSv/year. The total estimated radiological consequence to the WWTP worker is 5.65 mSv/year. The work tasks contributing the most significant radiological consequence to workers are sampling the SAC resin and the transfer of the dewatered residuals bin. The WWTP worker radiological consequence of 5.65 mSv/year meets the CNL effective dose action levels of 6 mSv/4 weeks, and 20 mSv/year, presented in Table 2-7, Occupational Radiation Exposures Actions Levels for CRL.

**Table 4-11**  
**Radionuclide Airborne Concentrations and ECM Worker Dose [4-24]**

| Radionuclide | Airborne Concentration in Disposal Cell (Bq/m <sup>3</sup> ) | ECM worker dose (mSv/year) |
|--------------|--------------------------------------------------------------|----------------------------|
| Radon        | 0.5                                                          | 9.6E-04                    |
| Tritium      | 61                                                           | 1.6E-05                    |
| Carbon-14    | 0.53                                                         | 2.2E-06                    |

#### 4.2.3.1 Dose to Off-site Receptors during Normal Operations

The nearest off-site receptors are located at the cottages, 3 km away and Chalk River, 5 km away. The primary exposure pathways for the off-site receptor are inhalation of airborne contaminants and ingestion of drinking water. Cloudshine and groundshine of the waste placed in the NSDF will have a negligible effect on the off-site-receptors.

The effluent discharge targets for radionuclides are based on a 0.1 mSv/year maximum drinking water radiological consequence [4-34]. During normal operations, only treated effluent meeting the effluent discharge targets will be discharged from the WWTP [4-34]. The off-site receptor drinking water radiological consequence will be much lower than 0.1 mSv/year, also Perch Creek and Perch Lake are not used as drinking water sources.

The off-site receptor inhalation radiological consequence is expected to very low based on:

- The air emissions from the WWTP process tanks are a fraction of the CRL site Derived Release Limits (DRLs) [4-35].
- The off-site receptor inhalation dose rate is much lower than that of the ECM worker who is in direct contact with the waste.

Airborne releases of contaminants during normal operations are expected to occur during:

- Waste placement and compaction activities in the ECM.
- Filling and draining of WWTP tanks.
- Operation of the WWTP active ventilation.

During ECM operations, dust will be controlled following the Dust Management Plan [4-36], mitigating the airborne releases. During WWTP operations, where there is potential for airborne releases, the AVS is implemented to control the spread of contamination, and gaseous effluents are directed through HEPA filters to abate particulate discharges.

Canadian Nuclear Laboratories' nuclear facilities including NSDF are required to operate with radionuclide releases to the environment at a small fraction of the DRLs [4-35]. The DRLs [4-35] represent release rates that correspond to critical group exposures at the public effective and equivalent dose limits presented in Table 2-6, Regulatory Occupational and Public Dose Limits for Normal Operations. The radiological

consequences to the off-site receptors during normal operations are expected to be negligible and much lower than 0.3 mSv/year.

#### **4.2.4 Waste Water Treatment Plant Tank Airborne Emissions**

Emissions from the Equalization Tanks and the WWTP process tanks, occur because of evaporative loss of the liquid in storage and as a result of changes in liquid level. The Equalization Tanks and the WWTP process tanks are fixed roof tanks, vented directly to the atmosphere. The total radioactive material losses for organics and water phases were calculated and compared to the DRL [4-35] for roof vents on the CRL site [4-24]. If the gross alpha, gross beta and gross gamma values are compared to the most restrictive radionuclide DRL for that main emission type, (i.e., the lowest DRL which for alpha is Ra-226, for beta is Cl-36 and for gamma is Co-60), total radioactive material loss is approximately 0.04% of the DRL [4-24]. There are no appreciable radiological airborne releases from a single Equalization Tank vent [4-24].

The WWTP filter press feed tank emissions were estimated, since this tank has the largest radiological source term of the WWTP process tanks. The total radioactive material losses for organics and water phases were calculated and compared to the DRL [4-35] for roof vents on the CRL site [4-24]. If the gross alpha, gross beta and gross gamma values are compared to the most restrictive radionuclide DRL for that main emission type, (i.e., the lowest DRL which for alpha is Ra-226, for beta is Cl-36 and for gamma is Co-60), total radioactive material loss is approximately 0.004% of the DRL [4-35]. From the individual radionuclide comparison with the DRLs, it is apparent that this is entirely from the Co-60 release [4-24]. There are no appreciable airborne releases from the filter press feed tank vent [4-24].

The radiological effect on non-human biota from the NSDF wastewater tanks air emissions is expected to very low, based on the tanks air emissions being a fraction of the CRL site DRLs [4-35]. The DRLs [4-35] represent release rates that correspond to critical groups at the public dose limits.

#### **4.2.5 Near Surface Disposal Facility Criticality Safety Document**

Nuclear criticality safety of the NSDF and the associated operations, is reviewed by the CNL Nuclear Criticality Safety Panel. Nuclear criticality safety has been analysed and the limits and control measures specified in the NSDF Criticality Safety Document (CSD) [4-25].

The basis for nuclear criticality control is dependent on the following variables:

- The mass of the Fissionable Materials present.
- The presence/absence of neutron absorbers.
- The presence/absence of neutron moderator.
- The presence/absence of neutron reflection.
- Geometry for high/low neutron leakage.
- Neutron interactions with neighbouring structures.

The criticality analysis and design meets the requirements of CNSC RD-327 Nuclear Criticality Safety [4-37] and GD-327 Guidance for Nuclear Criticality Safety [4-38]. The analysis and documentation requirements for Criticality Hazard Identification and the CSD, are specified in Preparation of a Criticality Hazard Identification Study [4-39] and Preparing a New Criticality Safety Document [4-40], respectively.

The design ensures that materials used for the NSDF, the physical separation between wastes and the limits imposed on the quantities of Fissionable Material, shall comply with the CSD. Receipt of Fissionable Materials

to the Facility and movement of Fissionable Materials within the Facility, shall be recorded and shall be in conformance with limits and restrictions specified in the CSD, currently in force for the Facility.

#### **4.2.6 As Low As Reasonable Achievable Assessment**

The NSDF Project ALARA Assessment [4-26], was completed to ensure that the NSDF design, is selected so that implications for occupational and public radiation safety are ALARA, and that the planning and control of radiation work at the NSDF will provide optimized RP.

As Low As Reasonably Achievable is achieved in the development of the NSDF through integration of design and safety activities. The NSDF development follows an iterative design process, whereby, results of the safety analysis are taken into account in the development of the design to ensure adherence to ALARA. The ALARA principle in the NSDF is achieved by implementing zoning and access control measures, by providing adequate shielding for structures and waste packages with high radiation fields, by providing process equipment segregation, radiation alarms in place, continuous monitoring, and worker training and approved procedures. Further reduction in operating staff doses is achieved by minimizing releases through periodic inspection and preventive maintenance of equipment.

The NSDF ALARA Assessment [4-26] concluded that the NSDF design and operations have been developed to meet the regulatory requirements of ALARA and minimizes radiation exposures to workers, the public, and the environment.

#### **4.2.7 Fire Hazard Analysis**

The FHA [4-27], assesses the entire NSDF site and was prepared in accordance with CSA N393 [4-41] to cover “locations processing, handling and storing nuclear substances and associated non-nuclear facilities and exposures external to these areas”. Consistent with the requirements of CSA N393 [4-41], the level of complexity presented for each Facility is “directly related to the complexity of the nuclear facility and the potential impact of radioactive and other hazardous substance release on life safety and the environment” [4-27]. The timeframe assessed is the NSDF pre-closure phase that includes the active commissioning period, 50 year operations period, and 30 year closure period [4-27].

Canadian Nuclear Laboratories will meet the requirements of CSA N393 Article A11.3 [4-41], benchmarking criteria of fire response times, therefore, the basis for the FHA is that CNL fire department will be capable of establishing an incident command post within 10 minutes of notification of an emergency [4-27]. The FHA [4-27] methodology was adopted from CSA N393 [4-41].

##### **4.2.7.1 Goals and Safety Performance Criteria**

The fire protection goals of CSA N393, are applicable to the NSDF Project and have been used as a basis for the FHA [4-27]:

- Minimize the risk of radiological releases that are a result of fire.
- Protect nuclear facility occupants from death or injury due to fire.
- Minimize business interruption resulting from fire damage to structures, equipment, and inventories.
- Minimize the impact of radioactive or hazardous material on the environment as a result of fire.

#### **4.2.7.2 Qualitative Assessment – Engineered Containment Mound**

The ECM has been analyzed using a qualitative approach and the following is a summary [4-27].

The ECM fire scenarios assessed are [4-27]:

- A fire starts from a lightning strike or vehicle fire within the ECM TSWRPA.
- Lightning strike starts a forest fire which burns towards the NSDF site and the ECM cover venting system.
- During refueling of a site vehicle or filling of the diesel storage tank, diesel is spilled onto a vehicle hot surface, which ignites diesel vapors and engulfs the vehicle.

The health and safety performance criteria are met based on [4-27]:

- For on-site receptors not involved with the ECM or forest fire lightning strike scenarios, the health and safety performance criteria are met.
- For workers intimate with the event the risk of injury or death is minimized if the workers follow common working procedures during a lightning storm and or forest fire scenario.
- For workers intimate with the refueling event, the risk of injury or death is minimized if the workers follow CNL safe fuel-handling procedures, including but not limited to: no smoking, use of correct containers, and no idling during refueling.
- The total dose to the closest member of the public due to inhalation and immersion is approximately  $6.0\text{E-}04$  mSv. The exposure levels are significantly below the health and safety performance criteria.

The protection of the environment safety performance criteria are met based on [4-27]:

- Any firefighting water used, or materials spilled in the area, will be collected and directed to the WWTP and will not enter the environment.

#### **4.2.7.3 Qualitative and Quantitative Assessment – Waste Water Treatment Plant**

The WWTP has been analyzed using both qualitative and quantitative approaches based upon a review of radioactive substances present, plausible fire scenarios and levels of combustibles within the various fire compartments [4-27].

A graded approach was adopted to the WWTP fire modelling review given two fire compartments contain radiological substances and postulated fire events in a number of spaces, will not result in the Safety Performance Criteria being exceeded [4-27].

The health and safety performance criteria are met based on [4-27]:

- The building is constructed from non-combustible materials, there are limited quantities of dangerous goods stored and used within (lube oil present within the forklift is not classed as flammable), as such the postulated fire events are not expected to be of rapid fire growth. Sufficient time does exist for occupants not intimate with the fire event, to exit the building [4-27].
- For workers intimate with the event, the risk of injury or death is minimized if the workers follow CNL work procedures for lock-out-tag-out, hot works, and confined space entry [4-27].

The radiological and protection of the environment safety performance criteria are met based on:

- Fire water used in extinguishing a WWTP fire will be contained within the building footprint [4-27].

### 4.3 Site and Engineering

This section is the safety assessment of the site and engineering aspects.

#### 4.3.1 Demonstration of the Adequacy of the Site and Engineering

The following provides demonstration of the adequacy of the NSDF site and NSDF engineering:

- Design Planning – The Design Plan [4-42] identifies the Design Requirements [4-43] to support the NSDF design phases and provides the general design approach. In addition, the Design Plan [4-42] documents the design deliverables, QA requirements, and applicable design codes and standards.
- The NSDF Design Description [4-44], documents the Design Requirements Traceability Matrix that maps the NSDF Design Requirements [4-43] to the design showing that the design requirements have been met. The Design Requirements Traceability Matrix [4-44] addresses the design requirements [4-43] related to demonstrating compliance with applicable codes and standards or related to safety, RP environmental protection, overpressure protection, loads and load combinations and the control of NSDF under accident conditions. For each requirement listed in the matrix information on acceptance/performance criteria, supporting calculations, supporting design documents, primary codes and standards, drawings, and specifications are provided [4-44]. The acceptance criteria in conjunction with the supporting design documents (e.g., drawings, calculations, and specifications), listed in the matrix, demonstrates both how and where the supporting information for each design requirement is addressed and reflected in the design [4-44].
- Structural stability analysis – The analyses in the Seismic Analysis [4-7] and Slope Stability Analysis [4-45], demonstrate that the NSDF design meets the DBE and OBE seismic requirements.
- The NSDF Human Factors (HF) Verification and Validation Report [4-46], demonstrates that HF consideration in design conform to accepted HF design principles to enable operating personnel perform their tasks safely and meet operational goals. The results of the HF verification and validation activities demonstrate that the proposed NSDF design is considered acceptable based on Human Factors [4-46].
- Comprehensive site investigations including non-intrusive and intrusive surveys, were completed for the NSDF Project to provide data and information for site selection, developing detailed design and numerical models. The Geotechnical Report [4-47] summarizes the site characterization.
- The Operational Safety Analysis [4-31], shows that the radiological consequences to the on-site and off-site receptors from the NSDF under normal and postulated accident conditions, meet the safety acceptance criteria and pose an acceptable risk for the public, workers and the environment.
- The Post-Closure Safety Assessment [4-1], shows that the radiological consequences from NESs, and disruptive scenarios to the critical receptors meet the long-term safety acceptance criteria.
- The overall safety objective for the NSDF is to protect individuals, society and the environment by establishing and maintaining an effective defence against radiological and non-radiological chemical hazards. The Safety Analyses [4-24] and [4-1], demonstrates that the overall safety objective for the NSDF has been satisfied, and demonstrates that the design, controls and processes are adequate for the radiological protection of workers, the public and the environment.

### 4.3.2 Defence-in-Depth

Defence-in-depth is incorporated in the NSDF design by having [4-44]:

- At least two barriers between the disposed LLW and the environment and members of the public.
- Two barriers between the leachate/contaminated water and the environment and members of the public, until the treated water meeting the effluent discharge targets [4-34] is released to the environment.

Five levels of defence-in-depth are defined by the CNSC for consideration when designing nuclear power plants as described in CNSC REGDOC-2.5.2, Design of Reactor Facilities: Nuclear Power Plants [4-48]. These levels of defence-in-depth are applicable to safety analyses performed for nuclear facilities as described in REGDOC-2.4.1, Deterministic Safety Analysis [4-49]. Table 4-12 shows the safety classified SSCs incorporated into the NSDF design that provide defence-in-depth. In addition, Table 4-12 provides the corresponding defence-in-depth level determined in using the guidance in [4-48], and the safety function of the SSCs. The NSDF design has used three levels of defence-in-depth: Levels 1 – 3 based on the guidance in [4-48].

The NSDF safety classified SSCs, coupled with implementation of planned operational requirements during NSDF operations, are designed to protect potential receptors (workers, members of the public, and the environment) by limiting release of radioactive material and/or hazardous material, or limiting radiation exposure during and following normal, anticipated transient and accident conditions.

**Table 4-12**  
**Near Surface Disposal Facility Defence-in-Depth**

| Structure, System, Component                                                                                                                                                                                                    | Safety Function(s)                            | Defence-in-Depth Level of Structure, System, Component     |                                                                                                                                                                      |                                      |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------|------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|
|                                                                                                                                                                                                                                 |                                               | Level 1                                                    | Level 2                                                                                                                                                              | Level 3                              |
| ECM final cover                                                                                                                                                                                                                 | Containment, retardation, isolation           | Final cover system (multi-layered engineered cover system) | NA                                                                                                                                                                   | NA                                   |
| ECM base liner system                                                                                                                                                                                                           | Containment retardation, Structural stability | Primary composite liner, LCS                               | Secondary composite liner, LDS                                                                                                                                       | Compacted clay liner, Perimeter berm |
| Below grade HDPE double-walled piping for leachate and contact water conveyance system structures:<br>(i) Leachate extraction boxes;<br>(ii) Sediment box;<br>(iii) Wet wells (CWPSs #1 and #2);<br>(iv) Contact water chambers | Containment                                   | Primary containment wall                                   | Secondary containment wall                                                                                                                                           | NA                                   |
|                                                                                                                                                                                                                                 | Monitor and control                           | NA                                                         | LCS Sump High-High Level, LDS Sump High-High Level, CWPS #1 Overflow Prevention Pumps Trip, CWPS #2 High-High Level Alarm, low-point leak detection ports of piping. | NA                                   |

|                                                     |                     |                                            |                                                                                             |    |
|-----------------------------------------------------|---------------------|--------------------------------------------|---------------------------------------------------------------------------------------------|----|
| Above Grade Leachate/CW Pump/Piping Transfer System | Containment         | Primary containment wall                   | Secondary containment wall                                                                  | NA |
|                                                     | Monitor and control | Heat tracing                               | Low-point leak detection, Low Wastewater Temperature Alarm                                  | NA |
| WWTP Process tanks and piping                       | Containment         | Tank wall, Primary containment piping wall | Active drain system                                                                         | NA |
|                                                     | Monitor and Control | NA                                         | Interlocks, Hydrogen sulphide monitors                                                      | NA |
| Influent storage                                    | Containment         | Equalization Tanks' wall                   | Concrete secondary containment, Equalization Tank Level Control and Overflow                | NA |
|                                                     | Monitor and control | Equalization tanks heaters                 | Containment sump is equipped with a leak detection sensor, Low Wastewater Temperature Alarm | NA |
| WWTP Filter Press                                   | Containment         | Ventilated enclosure, Active ventilation   | HEPA filter                                                                                 | NA |
|                                                     | Monitor and control | NA                                         | Radiation Monitoring System in enclosure                                                    | NA |
| WWTP Fume Hood                                      | Containment         | Ventilated enclosure, Active ventilation   | HEPA filter                                                                                 | NA |
| Active drain system                                 | Containment         | Primary containment wall                   | Secondary containment wall                                                                  | NA |
| Electrical power                                    | Monitor and control | Class IV power                             | Class III power, Class II power                                                             | NA |
| Chemical feed system                                | Containment         | Primary containment wall                   | Secondary containment wall, Chemical Storage Room Secondary Containment                     | NA |
| Vehicle Decontamination Facility                    | Monitor and Control | NA                                         | Carbon monoxide monitor                                                                     | NA |

### 4.3.3 Safety Functions

The fundamental safety functions that the NSDF ECM must fulfill during the pre-closure phase are:

- Containment of radioactive and non-radiological materials.
- Control of operational discharges of radioactive and non-radiological materials, as well as limitation of accidental releases.
- Monitoring of safety critical parameters to guide worker actions.



The additional fundamental safety functions that the NSDF ECM must fulfill during the post-closure phase are:

- Isolation of radioactive and radiological materials.
- Retardation of migration of radioactive and non-radiological materials.

Waste containment and isolation is achieved through the Facility's design, based on multiple barriers providing defence-in-depth and controlling the Facility's operational releases to the environment. The layers of protection for containment and isolation include structure design/materials, and Facility inspections, supported by RP monitoring and the GWMP.

A nuclear system important to safety, performs a nuclear safety function and failure of the system has a potential radiological consequence to on-site and/or off-site receptors.

Table 4-13 lists the ECM SSCs that are passive engineered safety features and systems important to safety during the pre-closure phase and long term safety in the post-closure phase. The passive engineered safety features are the base liner system (see Section 3.2.1.3), perimeter berm (see Section 3.2.1.4) and final cover (see Section 3.2.1.5). The NSDF design relies on passive systems to ensure long-term safety. The safety functions fulfilled by the passive systems are containment, isolation and retardation. The NSDF design relies on both active and passive systems to ensure safety during the pre-closure period. The safety functions fulfilled by the active systems are monitoring and control. The NSDF design, based on multiple safety functions, ensures that safety is not dependent on a single safety function.

Table 4-13 summarizes the ECM passive engineered safety features that are systems important to safety during the operations period [4-24]. Table 3-15 summarizes the WWTP engineered safety features that are systems important to safety during the operations period and closure period (few years only) [4-24]. Table 3-16 summarizes the WWTP engineered safety features that are systems important to non-nuclear or conventional safety during the operations period and closure period (few years only) [4-24].

Active systems are systems whose functioning depends on an external input such as actuation, mechanical movement or supply of power. Passive systems are systems that function without depending on an external input such as actuation, mechanical movement or supply of power.

**Table 4-13**  
**ECM Passive Systems Important to Safety**

| System, Structure, Component (SSC)                   | Safety Function | Basis for Selection/Justification                                                                                                                                                                                                                                     |
|------------------------------------------------------|-----------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Base Liner System                                    | Containment     | The base liner system provides containment for leachate, water that comes into contact with the radioactive waste.                                                                                                                                                    |
|                                                      | Retardation     | The GCL's low hydraulic conductivity retards the flow of leachate that leaks through the primary liner and the secondary liner into the sub-layers of the base liner system.<br>The CCL's low hydraulic conductivity retards the flow of leachate into the geosphere. |
| Base Liner System - Primary Liner (HDPE GMB) and GCL | Containment     | The liner provides first layer of containment for leachate, water that comes into contact with the radioactive waste.                                                                                                                                                 |

| System, Structure, Component (SSC)                                 | Safety Function      | Basis for Selection/Justification                                                                                                                                                                                                                                                                  |
|--------------------------------------------------------------------|----------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                    | Retardation          | The GCL's low hydraulic conductivity retards the flow of leachate that leaks through the primary liner into the sub-layers of the base liner system.                                                                                                                                               |
| Base Liner System - Secondary Liner (HDPE GMB) and GCL             | Containment          | The liner provides a second layer of containment for leachate, water that came into contact with the radioactive waste, and leaks through the first liner.                                                                                                                                         |
|                                                                    | Retardation          | The GCL's low hydraulic conductivity retards the flow of water that leaks through the secondary liner into the next sub-layer of the base liner system.                                                                                                                                            |
| Base Liner System - CCL                                            | Retardation          | The CCL's low hydraulic conductivity retards the flow of leachate into the geosphere.                                                                                                                                                                                                              |
| Perimeter Berm                                                     | Structural Stability | The perimeter berm's primary function is to provide structural stability to the ECM to withstand a 1:10 000 year seismic event after closure (DBE). The perimeter berm is designed withstand a 1:2 500 year seismic event during operations (OBE), prior to installation of the final cover.       |
|                                                                    | Containment          | The perimeter berm is lined with a single layer HDPE membrane/GCL combination on the side slopes to contain the waste and leachate/water that comes into contact with the waste. The GCL's low hydraulic conductivity will retard the flow of leachate in the sub-layers of the base liner system. |
|                                                                    | Isolation            | The perimeter berm forms the sidewalls of the ECM, deterring intrusion and thereby isolating the waste from the biosphere.                                                                                                                                                                         |
| ECM Final Cover System - ECM Final Cover Liner (HDPE GMB) and GCL. | Containment          | The final cover system provides containment by preventing infiltration of precipitation into the waste cell.<br>The final cover system adds structural stability to the ECM to withstand a 1:10 000 year seismic event after closure (DBE).                                                        |
|                                                                    | Retardation          | In the event of water/precipitation leaking through the final cover GMB, the GCL's low hydraulic conductivity retards the flow of water into the waste cells.                                                                                                                                      |
|                                                                    | Isolation            | The final cover components together form an intrusion deterrence barrier, isolating the waste from the biosphere.                                                                                                                                                                                  |

#### 4.3.4 Characteristics of Natural and Engineered Safety Barriers

The characteristics of the ECM engineered barriers, base liner system, perimeter berm and cover system are provided in Section 3.2.1.

The base liner system is comprised of a primary and secondary liner and to provide redundancy in case of premature failure in the primary liner, and includes a combination of natural earthen materials and

geosynthetic barrier systems to support a 550 year design life. The primary function of the base liner system is to provide containment of leachate, generated during and following operation of the ECM to minimize the potential for impacting groundwater from a release of leachate from the ECM. The secondary liner system is designed to contain leakage that may occur through the primary liner with an additional HDPE liner and GCL layer and minimizes the potential for leachate contamination beneath the ECM. Materials for constructing the composite base liner system, LCS, and LDS components are selected based on their compatibility with the expected leachate characteristics in the ECM and the material's service life. It's expected that the service life of earthen materials exceeds the design life of 550 years.

The thickness of 0.75 m for a CCL in the base liner system, is consistent with the standard of practice for waste containment facilities. Furthermore, this thickness meets the requirements of Ontario Regulation 232/98 for non-hazardous waste facilities and is the same as that used for the Port Granby and Port Hope LLRW Facilities that are currently being constructed. For the NSDF Project, the 0.75 m CCL, combined with the overlying GMB and GCL components of the secondary liner system, provide an effective barrier system to protect against long-term contaminant releases from the ECM.

#### **4.4 Non-Radiological Environmental Impact**

The non-radiological contaminants in the NSDF emissions, could affect the environment. The NSDF safety analyses/assessments that are relevant to the aspect of non-radiological environmental impact include:

- NSDF SAR [4-24].
- NSDF Post-closure Safety Assessment [4-1].
- NSDF Ecological Risk Assessment [4-23].
- Environmental Impact Statement [4-11].
- Conventional Safety Assessment [4-50].

##### **4.4.1 Air Quality**

Landfill gases generated in the ECM are anticipated to have low concentrations of methane and carbon dioxide and will largely dissipate through air flow across the working area, with a small portion of LFGs being retained in the waste beneath the daily cover material [4-51]. The LFGs generated in the ECM may contain small amounts of tritium or C-14.

The peak generation rates of LFGs occurs at the time, 1 year after closure of the ECM, and the LFGs and peak generation rates are [4-51]:

- Landfill gases generation rate is  $2.517\text{E}+05 \text{ m}^3/\text{year}$ .
- Methane generation rate is  $1.258\text{E}+05 \text{ m}^3/\text{year}$ .
- Carbon dioxide generation rate is  $1.258\text{E}+05 \text{ m}^3/\text{year}$ .

Gas generation increases as the ECM is filled with waste over the 50 year operations period. After closure of the ECM and construction of the final cover, gas generation decreases, as there is reduced availability of moisture and oxygen in the waste [4-51].

The indicator compounds emissions from the NSDF Project include: suspended particulate matter, particulate matter (PM<sub>10</sub>, and PM<sub>2.5</sub>), carbon monoxide (CO), sulfur dioxide (SO<sub>2</sub>), and nitrogen oxides (NO<sub>x</sub>) [4-11].

Airborne emissions have the potential to affect the health of humans, aquatic biota and terrestrial biota. The

NSDF Project particulates airborne emissions are primarily fugitive dust emissions. In addition to the indicator compounds emissions, hydrogen sulfide ( $\text{H}_2\text{S}$ ), vinyl chloride ( $\text{C}_2\text{H}_3\text{Cl}$ ), lead, mercury ( $\text{Hg}$ ), and odour emissions have been considered as indicator compounds [4-21]. Acrolein ( $\text{C}_3\text{H}_4\text{O}$ ) was included to represent Volatile Organic Compounds from combustion [4-21].

Vehicle exhaust and fugitive dust from unpaved roads, is the largest contributor to suspended particulate matter and  $\text{PM}_{10}$  during both the construction and operations phases. Vehicle exhaust during the construction of the ECM is the largest contributor of  $\text{PM}_{2.5}$ ,  $\text{NO}_x/\text{NO}_2$  and CO [4-21].

Airborne particulate emissions from the NSDF Project are monitored using two particulate matter monitors, located north-west and south-east of the NSDF Project perimeter boundary. In addition, the airborne particulate emissions from the NSDF Project are mitigated by the implementation of the Dust Management Plan [4-36].

#### **4.4.1.1 Tank Emissions**

Airborne emissions of non-radiological contaminants from the Equalization Tanks and the WWTP process tanks, occur because of evaporative loss of the liquid in storage and as a result of changes in liquid level. The non-radiological airborne emissions from the Equalization Tank and the filter press feed tank were calculated [4-24].

The calculated annual airborne emissions of non-radiological organic compounds from the Equalization Tank and filter press feed tank are 1 910 kg and 8.2 kg, respectively [4-24]. The calculated annual airborne emissions of non-radiological organic compounds are less than the volatile organic compound emission reporting threshold of the National Pollution Release Inventory (NPRI), which is 10 tonnes.

#### **4.4.1.2 Greenhouse Gas**

The Greenhouse Gases (GHG) that will be emitted during the NSDF Project include: carbon dioxide, methane and nitrous oxide [4-11]. The NSDF Project GHG annual emissions, expressed as carbon dioxide equivalent (tonnes/year), for the construction phase including site preparation and the operations phase, are estimated to be approximately 28 800 tonnes/year and 9 200 tonnes/year, respectively [4-11]. The annual GHG emissions for the construction phase are 0.004% of the Canada-wide total and 0.02% of the Ontario total emissions [4-11]. The annual GHG emissions for the operations phase are 0.001% of the Canada-wide total and 0.006% of the Ontario total emissions [4-11].

The predicted residual effects to CRL site GHG emissions were estimated to increase because of the NSDF Project [4-11]. Emissions of GHGs from the CRL site are estimated to increase approximately 94% during the construction phase and approximately 30% during the operations phase. However, the change is estimated to be less than a 0.02% increase in total provincial GHG emissions and less than a 0.005% increase in total national GHG emissions [4-11]. Consequently, the residual effects from the NSDF Project GHGs emissions was determined to be not significant [4-11].

#### **4.4.2 Groundwater**

Changes to groundwater quantity and quality are considered to be important aspects of the natural and human environment. The assessment of hydrogeology focused on predicting changes in the groundwater flow patterns, groundwater table elevations and concentrations of selected non-radiological substances [4-11].

Discharge of treated effluent from the WWTP to the East Swamp Wetland could cause changes to groundwater quality [4-11]. The effluent discharge targets for non-radiological constituents, are derived from Federal and Provincial water quality guidelines for the protection of the environment and human health [4-39]. Effluent treatment targets for radiological constituents are derived from Health Canada drinking water guidelines. Impacts to the groundwater during the operations period will be negligible, as the discharged effluent will meet the effluent discharge targets, which are based on the protection of biota and/or human health.

The design of the NSDF engineered liners systems will limit the potential for changes to groundwater and surface water quality from the NSDF site during the operations and closure phases.

The residual effects on hydrogeology are related to the alteration of groundwater levels/flows due to the NSDF Project construction activities and potential changes to groundwater quantity/quality, due to leakage from the ECM following post-closure activities. Residual effects to groundwater from leakage of leachate from the ECM during operations, are not anticipated, due to the implementation of environmental design features, mitigation and operational monitoring plans.

#### **4.4.2.1 Groundwater Monitoring**

The NSDF GWMP will be developed, including installation of groundwater monitoring wells to monitor hydraulic and chemical conditions in the area downgradient of key NSDF locations, in both vertical and horizontal orientations. The NSDF GWMP, will be integrated into the overall CNL GWMP, and will be compliant with CSA N288.7-15 (the Standard for Groundwater Protection at Nuclear Facilities) [4-69]. The Standard indicates the need for both upgradient (background) and downgradient monitoring well locations. The CSA N288.7-15 Standard also includes a process step where contaminants of potential concern are evaluated for sampling [4-69]. The GWMP will begin prior to operations. Baseline groundwater data will be collected and used to confirm groundwater conditions. Groundwater monitoring will continue through operations, closure and post-closure. The number of parameters and locations may change based on annual review of monitoring data. Initial sampling frequency will likely be twice per year (spring and fall), consistent with the existing site GWMP.

#### **4.4.3 Terrestrial Environment – Pre-closure Phase**

Residual effects to terrestrial VCs due to the NSDF Project during the pre-closure phase, are primarily associated with:

- Vegetation clearing/grubbing and the loss or alteration of existing vegetation and topographical features.
- Increased risk of injury/mortality on roads to Blanding's turtle and eastern milksnake, due to equipment and vehicle traffic.

#### **4.4.4 Post-Closure Phase**

The EcoRA [4-23], uses the environmental concentration data generated by the PostSA modelling to assess the environmental risk of the key constituents of potential concern (COPC) contaminants present in the waste. This section presents a summary of the EcoRA methodology and results. For detailed information about toxicological benchmarks and the calculation of screening indices, the reader is directed to the EcoRA report [4-23].

#### 4.4.4.1 Methodology

With the exception of human intrusion scenarios, throughout the duration of the various post-closure scenarios assessed in the EcoRA [4-23], chemical contaminants are generally released directly into groundwater beneath the ECM, which in turn impacts the aquatic environment (groundwater, sediment and surface water) downgradient of the NSDF site (Perch Creek) and further downstream (Ottawa River). Also, when bathtubbing occurs as part of the normal evolution process, the ECM overflows with water, which then flows to the downgradient "Grazing Area" where it infiltrates and contaminates the soil. The impacted soil in turn contaminates the surrounding air, fruits and vegetables grown on the soil, and animals grazing in the area. In the human intrusion scenarios, biota are exposed to excavated contaminated soils that are dispersed in surface soils [4-23].

For each post-closure scenario, maximum contaminant concentrations predicted over time (i.e., 10 000 year assessment period) in each environmental medium (i.e., soil in the "Grazing Area" between the NSDF and Perch Creek and the "Garden Area" on the ECM, groundwater in the "Grazing Area", and Perch Creek and Ottawa River sediment and surface water) were provided from the 3rd Iteration PostSA [4-1]. The maximum predicted environmental concentrations (i.e., incremental) were summed with the background concentrations. The total environmental concentrations were then compared to the most conservative criterion for each medium, to identify COPCs for inclusion in the EcoRA [4-23]. Criteria from the Ontario Ministry of the Environment, Conservation and Parks (MECP) and Canadian Council of Ministers of the Environment (CCME) were considered in the COPC screening. A contaminant was 'screened-in' and assessed for a particular scenario if an exceedance of the respective criterion was noted in at least one environmental medium for that scenario and a Toxicity Reference Value (TRV) was available. This screening approach is consistent with N288.6-12, Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills [4-52].

Table 4-14 below summarizes the non-radiological COPCs selected for inclusion in the EcoRA [4-23].

**Table 4-14**  
**Summary of Non-Radiological COPCs Selected for Inclusion in the EcoRA**

| Scenario                                                                                                                                                                                                                                                                                                                                                         | Non-Radionuclide COPCs | Comment                                                                                                                                                                                                                                                                                                                                                                              |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (1) NES<br>(1a) NES Sensitivity Analysis - Inventory Sensitivity<br>(1b) NES Sensitivity Analysis - Institutional Control Sensitivity<br>(1c) NES Sensitivity Analysis - Sorption Coefficient Sensitivity<br>(1d) NES Sensitivity Analysis - Geosphere - Rapid Transit to Perch Creek<br>(1e) NES Sensitivity Analysis - Enhanced Degradation of Cover and Liner | Al                     | 'Screened-in' for scenarios (4) and (14) because the surface water criterion was exceeded in Perch Creek and Ottawa River; there are no screening criteria for soil and sediment; total aluminum concentrations in the remaining scenarios are completely dominated by background levels and for this reason, aluminum is not carried through the EcoRA for the remaining scenarios. |
|                                                                                                                                                                                                                                                                                                                                                                  | Cu                     | 'Screened-in' for all scenarios because the surface water criterion was exceeded in                                                                                                                                                                                                                                                                                                  |

|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |    |                                                                                                                                                                                                                                                                                                                                                      |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| (1f) NES Sensitivity Analysis – Climate Change - Reduced HER<br>(3) Disruptive Event - Human Intrusion, House with Basement - Resident (Chronic)<br>(4) Disruptive Event - Enhanced Erosion Case<br>(5) Disruptive Event - Localized Cover Failure<br>(6) Disruptive Event - Localized Liner Failure<br>(7) Disruptive Event - Damage to Berm<br>(8) Dose Optimization - Wastes Grouted into Steel Liners<br>(10) Dose Optimization - Confidence in Land Use Restrictions (same as NES)<br>(12) Defence-in-Depth - Role of Geosphere<br>(13) Defence-in-Depth - Role of Cover<br>(14) Defence-in-Depth - Role of Base Liner<br>(15) Defence-in-Depth - Series of Landslides<br>(16) What If - Human Intrusion, Mass Excavation and Farming<br>(17) What If - Permanent Bathtub |    | Perch Creek and Ottawa River and the sediment criterion in Ottawa River; the soil criterion was also exceeded in the Grazing Area in scenarios (4), (14) and (15) and in the Garden Area in scenario (15); total concentrations are dominated by background levels in most media and scenarios.                                                      |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Pb | 'Screened-in' for all scenarios because the surface water criterion was exceeded in Perch Creek and Ottawa River and the sediment criterion in Perch Creek; the soil criterion was also exceeded in the Grazing Area in scenarios (4) and (14); total concentrations are dominated by background levels in most media and scenarios.                 |
|                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | U  | With the exception of scenario (13), 'screened-in' for all scenarios because the soil criterion was exceeded in the Grazing Area as well as in the Garden Area in scenario (15); total concentrations are dominated by incremental concentrations from the NSDF Project in Perch Creek surface water and soil in the Grazing Area in most scenarios. |

Ecological toxicity benchmark values for non-radiological COPCs were obtained via multiple sources, which include recognized references that are used in EcoRAs as common industry practice, including the U.S. EPA ECOTOX Database, Canadian Council of Ministers of the Environment (CCME), Ontario Ministry of the Environment (OMOE), and EC. A more detailed explanation can be found in Section 4 of the EcoRA [4-23].

The ecological toxicity benchmarks were used to evaluate the relative risk of contaminant concentration to aquatic biota, aquatic birds, terrestrial vegetation and invertebrates, and terrestrial mammals and birds. Ecological risks were assessed by calculating screening index values and comparing the estimated exposures to the toxicity benchmarks.

#### **4.4.4.2 Results**

With respect to non-radiological COPCs, aluminum was only assessed for the Enhanced Erosion Case and Series of Landslides, and only for aquatic pathways as meaningful aluminum concentrations in soil were not predicted for these scenarios. Copper, lead and uranium (except Role of Base Liner) were assessed for all scenarios. The detailed assessment results are presented in the EcoRA [4-23].

No potential issues are identified from exposure to uranium for all scenarios and receptors as all Screening Index values are below the threshold value of 1. Also, with the exception of the Series of Landslides scenario, there are no issues identified for aquatic birds – great blue heron, mallard, and belted kingfisher – in the

Ottawa River or Perch Creek resulting from exposure to copper, lead or uranium. In the Series of Landslides scenario, potential effects are identified for all three birds in Perch Creek and for mallard in the Ottawa River due to aluminum as well as for mallard resulting from copper exposure in Perch Creek. The screening index values are as high as 1 170 for mallard exposed to aluminum in Perch Creek. While exposures in this scenario are being driven by Project emissions (>95% in Perch Creek), it is noted that this scenario represents an extreme circumstance that is highly unlikely to occur.

The screening index threshold is exceeded for copper exposure to benthic invertebrates, pelagic fish (Perch Creek only), zooplankton and tadpole (Perch Creek only) and lead exposure to benthic invertebrates for all scenarios. With the exception of the Enhanced Erosion case and the Series of Landslides scenario, these exposures are completely dominated by background levels. In the Enhanced Erosion case, all aquatic organisms in Perch Creek are potentially affected by exposure to copper mainly due to releases from the Project (about 90%). In the Series of Landslides scenario, all organisms in Perch Creek are potentially affected by exposure to aluminum and copper as well as lead for benthic invertebrates, pelagic fish and tadpole, predominantly driven by releases from the Project; in the Ottawa River, benthic invertebrates and zooplankton are potentially affected by aluminum releases from the Project. Screening index values are as high as 1 020 for benthic invertebrates in Perch Creek resulting from aluminum exposure. The Enhanced Erosion case is simulating a disruptive event and the Series of Landslides scenario is simulating a defence-in-depth case. Both represent extreme circumstances that are highly unlikely to occur.

Screening index results for terrestrial receptors with small home ranges located either in the Grazing Area or Garden Area on the ECM were calculated. Receptors included in this category are Canada warbler (species at risk), purple finch, ruffed grouse, short-tailed shrew, meadow vole, earthworm and terrestrial vegetation. With the exception of the Enhanced Erosion case, Series of Landslides scenario, and the Mass Excavation and Farming scenario, exposure to lead dominated by background levels resulted in screening index values above 1 for the Canada warbler in all scenarios for both the Grazing Area and Garden Area. Exposure to copper dominated by releases from the Project resulted in screening indices values greater than 1 for all receptors in the Grazing Area and Garden Area (Mass Excavation & Farming scenario only) in the Enhanced Erosion case, the Series of Landslides scenario, and the Mass Excavation & Farming scenario. This was also the case for lead exposure to Canada warbler. Again, it is noted that the Enhanced Erosion case and the Series of Landslides scenario, as well as the Mass Excavation & Farming scenario simulating a 'What-If' case, all represent extreme circumstances that are highly unlikely to occur.

Site-wide receptors are assumed to roam the entire site, while being exposed to COPCs in all aquatic and terrestrial assessment areas – Ottawa River, Perch Creek, Grazing Area and Garden Area. Site wide receptors include the bald eagle, black bear, little brown myotis (bat) (species at risk), eastern-whip-poor-will (species at risk), eastern wolf (species at risk), moose and white-tailed deer. The screening index results for site-wide receptors were calculated. With the exception of the Enhanced Erosion case, the Series of Landslides scenario the Mass Excavation & Farming scenario, the lead screening index value for eastern-whip-poor-will exceeded the threshold value of 1 in all scenarios resulting predominantly from background exposure. Estimated exposures in the Enhanced Erosion case, the Series of Landslides scenario, and the Mass Excavation & Farming scenario are again dominated by Project releases with copper exposure to all organisms except the bald eagle resulting in screening index values above 1; this is also the case for lead exposure to eastern-whip-poor-will.

Potential effects from exposure to copper and lead are identified for many aquatic and terrestrial receptors in all scenarios – almost all of these exposures are dominated by background levels in environmental media. The



three scenarios where exposures are dominated by Project activities are the Enhanced Erosion case, Series of Landslides, and the Mass Excavation and Farming. These three scenarios share similar characteristics:

- The scenarios all represent cases where waste material is spread from the Facility into the environment.
- The scenarios assume a level of failure in the barriers, or a deliberate act of intrusion and disruption of the waste materials.
- The scenarios all assume conservative source terms for the contaminants, and very conservative characteristics about the biota (e.g., that the biota spend all of their time in a single, contaminated area).
- The scenarios are all very low probability events.

Much of the lead at NSDF will be embedded in structural steel (and thus would likely not be released until the steel is corroded), and otherwise treated to meet land disposal requirements of Ontario Regulation 347. These processes have not been accounted for in the EcoRA [4-23]. If these processes were accounted for, they could further delay releases and potentially also reduce the peak flux of lead.

Finally, it is noted that conventional landfills can contain significant quantities of lead. The engineering design for the ECM is consistent with best practice for a conventional landfill, and in the context of containment of lead, will provide similar long-term performance to a conventional landfill.

#### **4.4.5 Conventional Safety Assessment**

The Conventional Safety Analysis [4-50], identifies the conventional hazards to human health and describes the NSDF design mitigation measures. The approach used to identify process-related conventional hazards is shown in Figure 4-3 [4-50]. In addition, the NSDF Facility is divided into four design elements: the ECM, the WWTP, site buildings, and site infrastructure. The process-related conventional hazards and design mitigations are grouped by design element.

Conventional hazards excluded from this assessment [4-50] are:

- Any hazards represented by radiation or radioactivity, as these are covered by the SAR [4-24].
- Any hazards associated with fire protection, and are covered by the FHA [4-27].
- Any hazards that are not process-related, such as hazards associated with general building design and operation, which are routinely addressed through the national building code, electrical code, structural code, and occupational safety features.

Table 4-15 provides a summary of the conventional hazards and the design mitigation for the hazard.

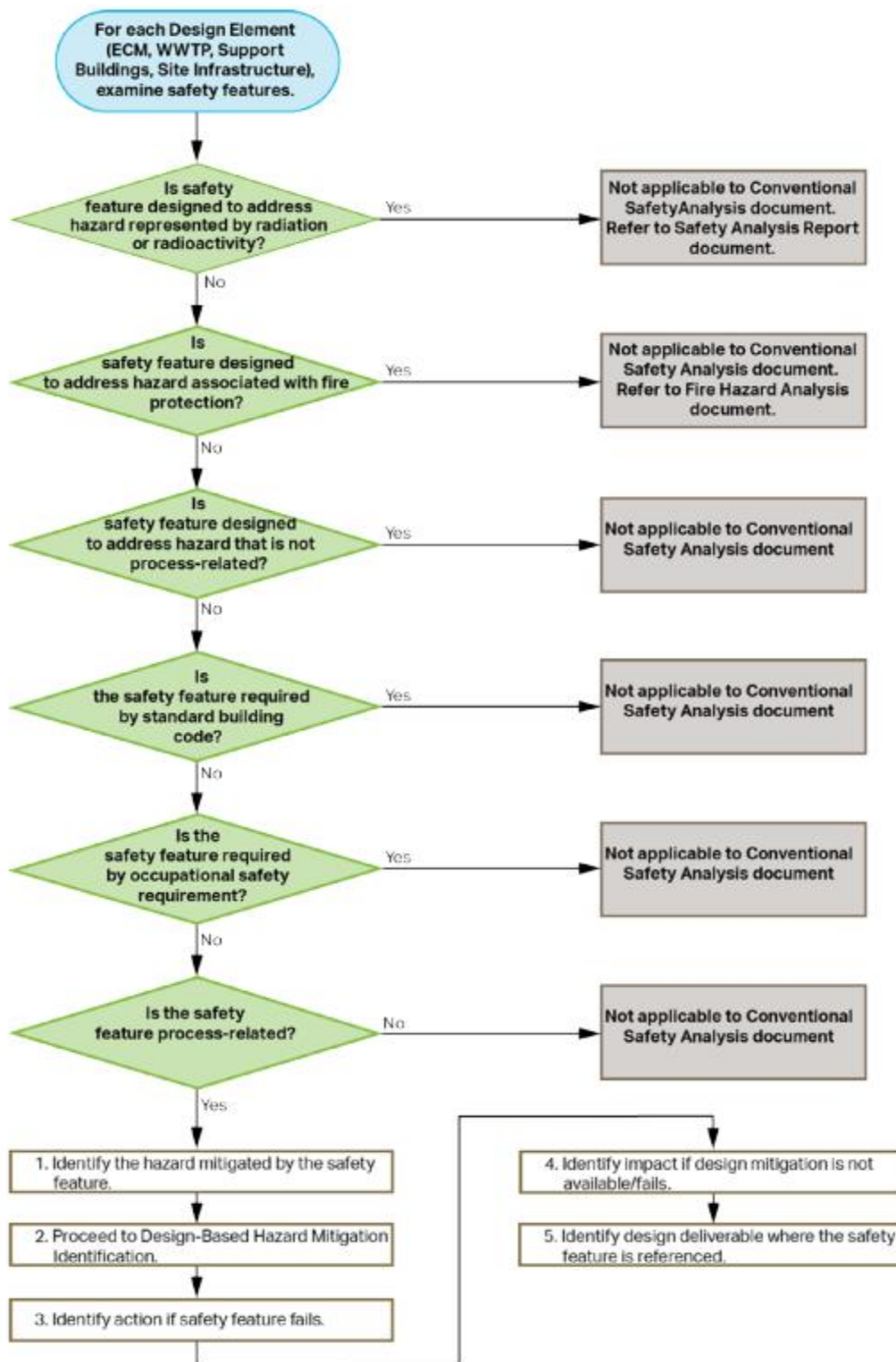
**Figure 4-3 Approach used to Identify Process-Related Conventional Hazards**

**Table 4-15**  
**Summary of Design Element Conventional Hazard and Design Hazard Mitigation Feature**

| Design Element |      | Potential Conventional Hazard                                                                       | Design Mitigation for Hazard                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
|----------------|------|-----------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1              | WWTP | Hydrogen sulphide gas could be formed by mixing of incompatible chemicals.                          | Hard-wired control interlocks to prevent dosing of sodium sulphide and sulphuric acid to the same chemical precipitation tank at the same time.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
| 2              | WWTP | Hydrogen sulphide gas could be formed by mixing of incompatible chemicals.                          | Hard-wired control interlocks to prevent dosing of sodium sulphide to a chemical precipitation tank with pH less than 8.5.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| 3              | WWTP | Inhalation of toxic hydrogen sulphide gas that could be formed by mixing of incompatible chemicals. | <p>Hydrogen sulphide monitors with alarms. Additional design mitigative provisions: Process tanks are covered and vented to the outside of the building.</p> <p>Hydrogen sulphide monitors are installed in the headspace of the chemical precipitation and polishing system pH adjustment tanks to expedite the sensing of hydrogen sulphide gas. Hydrogen sulphide monitors are also located outside of the building because the tanks are vented to the outside.</p> <p>Detection of hydrogen sulphide gas above the set-point limit of 10 ppm results in activation of strobes and alarms both inside and outside of the WWTP building.</p> <p>Signs are provided to warn personnel to evacuate the building and the area outside upon hydrogen sulphide gas detection.</p> |
| 4              | WWTP | Contact with incompatible hazardous chemicals would result in violent reaction.                     | Two separate chemical storage rooms for separation of incompatible chemicals.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| 5              | WWTP | Contact with hazardous chemicals due to breach of feed tank.                                        | <p>Dual-walled tank with interstitial leak detection.</p> <p>Acid-resistant epoxy flooring materials used in Chemical Rooms 1 and 2.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| 6              | WWTP | Contact between water and concentrated chemicals would result in violent reaction.                  | <p>There are no service water or process wastewater connections to the chemical feed tanks. Addition of water to the chemical feed tanks is not a possible event.</p> <p>Further, in the event of a fire, the area is supplied by a dry fire suppression system, thereby further preventing any contact of water with these chemicals.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                      |

| Design Element |      | Potential Conventional Hazard                                                                                           | Design Mitigation for Hazard                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------|------|-------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7              | WWTP | Hazards associated with filling chemical feed tanks from totes and drums.                                               | <p>Several features are included to mitigate hazards associated with filling chemical feed tanks:</p> <p>A high-level alarm is present in each chemical feed tank to prevent overfilling.</p> <p>Signs are provided to ensure the transfer of chemicals from tote to tank is correctly executed.</p> <p>Operational procedures will be instituted to ensure the operators fill the correct chemical feed tank, such as first collecting a sample to confirm tote or drum contents match the tank to be filled.</p> <p>If personnel ignore the high-level alarm for the chemical feed tank during transfer, the tank will overflow through the overflow line to the associated chemical storage room dry sump.</p> <p>An acid resistant epoxy floor coating will be used on the chemical storage room floor to minimize reaction between the chemicals and concrete floor.</p> <p>Fittings present on drums and totes will be dissimilar, preventing the transfer of sulphuric acid into anything other than the sulphuric acid tank.</p> |
| 8              | WWTP | Hazards associated with movement of sulphuric acid drums.                                                               | <p>Line path where sulphuric acid drums travel with absorbent booms.</p> <p>Use correct material handling pallet.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| 9              | WWTP | Contact with hazardous chemicals due to leak at chemical feed system.                                                   | Acrylic splash guard with hinged access to chemical feed pumps.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
| 10             | WWTP | Contact with hazardous chemicals due to breach of chemical feed piping.                                                 | Dual-walled piping with interstitial leak detection.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 11             | WWTP | Filter press plates must be separated after de-watering to allow dewatered cake to fall to disposal container.          | Semi-automatic plate spreader.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
| 12             | WWTP | Leak or potential pinch hazard from filter press (human intrusion between plates during closing or shifting operation). | <p>Light curtain present to prevent hydraulic closure of the filter press when the plane of the curtain is breached.</p> <p>An easily-accessible emergency stop button is provided at the filter press.</p>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |

| Design Element |                                        | Potential Conventional Hazard                    | Design Mitigation for Hazard                                                                                                                                                                                                                                                      |
|----------------|----------------------------------------|--------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 13             | WWTP                                   | Explosive dust generation during storage of GAC. | GAC material selected on basis of minimal dust generation. GAC particle size, storage in steel box, vacuum transfer from within box to vessel, and ventilation rate of air exchange in both areas preclude buildup of GAC dust concentration that would reach combustible levels. |
| 14             | WWTP                                   | Release of hazardous chemicals into atmosphere.  | Scheduled maintenance and replacement of HEPA filters.                                                                                                                                                                                                                            |
| 15             | ECM                                    | No process-related hazards.                      | Not applicable.                                                                                                                                                                                                                                                                   |
| 16             | Vehicle Decontamination Facility (VDF) | Vehicle exhaust.                                 | Detection systems alarm and send the air handling systems into high speed should carbon monoxide, nitric oxide, or nitrogen dioxide concentrations reach unacceptable levels.                                                                                                     |

#### 4.5 Management System

Canadian Nuclear Laboratories' Management System has established functional support area programs to ensure that CNL operates in full compliance with statutory and legislative requirements, while promoting and supporting performance excellence underpinned by a strong safety culture [4-53]. Assuring safety at CNL encompasses nuclear safety, as well as the broader Health, Safety, Security and Environment (HSSE) landscape including operations, maintenance, chemistry, engineering, OPEX, human performance, RP, OSH, fire protection, environmental protection, security, EmP, and decommissioning and waste management [4-53]. Combining a strong safety culture (human behaviour), and effective safety management (processes and oversight), prevents events and assures the safety and security of people, facilities and the environment during normal and accident conditions [4-53].

The HSSE&Q, Engineering, and Environmental Remediation Management functional lead areas, are in accordance with the principles of defence-in-depth and QA, and include:

- Emergency Preparedness.
- Environmental Protection.
- Fire Protection.
- Nuclear Criticality Safety.
- Nuclear Materials and Safeguards Management (NM&SM).
- Occupational Safety and Health.
- Performance Assurance.
- Pressure Boundary.
- Radiation Protection.
- Security.

- Transportation of Dangerous Goods.
- Waste Management.

The Pressure Boundary program is part of the Engineering, functional lead area. The Waste Management program and Transportation of Dangerous Goods program are part of the Environmental Remediation Management functional lead area. The other programs listed are within the HSSE&Q functional lead area. Additional information on the CNL Management System [4-53], and how it aligns with Safety and Control Areas from the LCH [4-54] is available in Appendix A.

#### **4.6 Scientific and Engineering Principles**

Principles of good engineering practice have been applied in the NSDF design, and the selection of construction materials. The construction techniques and materials foreseen for the disposal facility are well understood, and knowledge gained from similar applications confirms that these materials are well suited for the intended use. The primary engineering guiding principles are:

- Clearly documented processes and procedures.
- Competent and qualified technical staff.
- Continuous communications.

There are two overarching principles associated with the design of the NSDF: defence-in-depth and sustainable development. The facilities have been designed considering Leadership in Energy and Environmental Design (LEED) principles and building for energy efficiency.

The NSDF design process of conceptual design to detailed design (design plan, 30%, 60%, 90%, 100% then ongoing design optimization), demonstrates good engineering practice.

Principles of good scientific practice have been applied to the assessments and analysis that support the NSDF Design. The principles of good scientific practice include making observations, developing and testing hypotheses, assessing reproducibility, and peer review.

Peer review is an important aspect of the application of scientific and engineering principles, and is discussed further in Section 6.8. All documents are subject to at least one round of internal review by a specialist member of the project team who is not the main author of the report. The review considers the technical details from the perspective of their appropriateness to the scope of work and the associated justification. This also includes checking that the work addresses the relevant regulatory standards and applies national and international best practice guidance.

Key documents were reviewed by an independent third party. Comments and suggestions from the third party review are considered and addressed before releasing the document for use. Formal records of the comments and how they have been addressed are stored in accordance with CNL's document control processes.

Data used for the NSDF has been developed from the results of site characterization activities and obtained from a number of sources, including NSDF Project documents, published literature, and CNL documents. Where possible, site specific data is used. If unavailable, data has been selected from the most recently published and relevant information sources. Safety data has been selected from recognized peer reviewed sources and has been checked independently to ensure it is reasonable, justified and adopts an appropriate degree of conservatism. Where assumptions have been made the validity and justification of the assumption

are documented and traceable. The appropriateness of the data selected is confirmed by peer reviews and Independent Third Party Review (ITPR).

The NSDF Project has utilized good scientific and engineering principles.

#### **4.7 Quality of Site Characterization**

After evaluating the existing site data, a data gap analysis was performed for the NSDF detail design, and additional field exploration activities and laboratory testing studies (i.e., geotechnical, hydrogeology, hydrochemistry, seismic) were requested [4-47]. The main objective of the site characterization was to provide sufficient multidisciplinary data/information from the NSDF site to inform the NSDF detail design. The NSDF site characterization was carried out following a phase approach, described in Section 5.2. The approach and criteria used in the site selection is described in Section 5.1.

Fundamental to the site characterization process is data quality that enables goals and objectives for site characterization to be met [4-55]. The quality control and quality assurance aspects of the NSDF site characterization documented in the site characterization reports, [4-47], [4-56], [4-57],[4-58], [4-59], [4-60], and [4-61], to ensure the appropriate data quality includes:

- Work completed following ISO 9001 and CNL's Management System [4-53].
- Field and laboratory testing used ASTM standard testing methods [4-47].
- Field samples collected in accordance with standard environmental sampling protocols to ensure reliable and representative results. Field equipment was decontaminated as required to prevent the transfer of contaminants from equipment to sampled media, and limit cross-contamination between sampling points. The use of improperly decontaminated equipment can directly affect data quality.
- Laboratory testing quality control and quality assurance includes Certificate of Analysis, duplicate samples, reference material, blank matrix and spike matrix with acceptable limits (lower/upper).
- Cone penetration testing – multiple wave traces are recorded for quality purposes [4-57].
- Data quality – quality control checks, data management, and data quality requirements.
- Field testing results were compared to published data. As a quality control measure, the hydraulic conductivity results were compared to ranges of published values for similar grain sizes [4-61].
- Soil assessment criteria are the CCME Soil Quality Guidelines [4-62] for commercial properties and soil metal analytical results were evaluated to the Ontario Soil, Groundwater and Sediment Standards for Use Under Part XV.1 of the EPA [4-63].

Modelling of the NSDF has been used to support the understanding of the possible behaviour of the NSDF:

- Operations phase [4-24].
- Post-closure phase [4-1].
- Seismic activity and behavior of the ECM [4-6] and [4-7].
- Groundwater Model to understand the behavior of the groundwater [4-14].

Confidence in the site characterization results [4-47], [4-56], [4-57], [4-58], [4-59], [4-60], [4-61], and [4-64] are enhanced based on:

- The site characterization [4-47] and safety assessment programmes [4-1] and [4-24], are of high quality (i.e., work completed following ISO 9001 and CNL's Management System [4-53]).
- The site data collected are consistent with other existing data in terms of parameter values and the measurement methodology applied.
- The safety assessment models developed are consistent with the properties of the NSDF site and the conceptual understanding of the site based on scientific principles [4-1], [4-6], [4-7], [4-14] and [4-24].
- The conceptual understanding of the NSDF site and the safety assessment models continue to be compatible with and appropriate for any new information about the site that may become available, subject to only minor refinement.

#### **4.8 Operational Safety Aspects**

Operational safety is ensured by the following the governance documentation listed in Section 3.12. The conventional hazards during construction, operations and closure are controlled and managed by the OSH Program [4-65]. Measures described in CNL's Radiation Protection Requirements [4-66], and procedures given in the RP Governing Document Index [4-67], are used in the NSDF Facility to monitor and control radiation, radioactive contamination and worker exposure. Compliance with the NSCA [4-68] and associated Regulations, ensure appropriate RP and provide a system of dose limitation.

#### **4.9 Conclusions**

The overall safety objective for the NSDF is to protect individuals, society and the environment by establishing and maintaining an effective defence against radiological and chemical hazards. This safety assessment demonstrates that the overall safety objectives and safety requirements for the NSDF has been satisfied, and demonstrates that the design, controls and processes are adequate for the radiological protection of workers, the public and the environment.

The Operational Safety Analysis [4-24], shows that the radiological consequences to the on-site and off-site receptors from the NSDF under normal and postulated accident conditions during the pre-closure phase, meet the dose acceptance criteria and do not pose an unreasonable risk for the public, workers and the environment.

The Post-Closure Safety Assessment [4-1], shows that the radiological consequences from NESs, Disruptive Events and alternative scenarios to the critical receptors during the post-closure phase meet the long-term safety acceptance criteria.

The NSDF relies on both active and passive systems for safety during the pre-closure phase and relies only on passive systems for the long-term safety.

The NSDF will provide and will perform the following safety functions during operations:

- Containment of radiological and non-radiological materials.
- Control of operational discharges of radiological and non-radiological materials, as well as limitation of accidental releases.



- Monitoring of safety critical parameters to guide worker actions.

The NSDF will provide and will perform the following safety functions during the long-term:

- Containment of radiological and non-radiological materials.
- Isolation of radiological and non-radiological materials.
- Retardation of migration of radiological and non-radiological materials.

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- [4-66] *Radiation Protection, 900-508740-PRD-001, Revision 3, 2018 June.*
- [4-67] *Radiation Protection Governing Document Index, 900-508740-GDI-001, Revision 2, 2018 June.*
- [4-68] *Nuclear Safety and Control Act, S.C. 1997, c. 9.*
- [4-69] *CSA, CSA N288.7-15, Groundwater Protection Programs at Class I Nuclear Facilities and Uranium Mines and Mills, 1<sup>st</sup> Edition, 2015.*

## 5. ITERATION AND DESIGN OPTIMIZATION

Canadian Nuclear Laboratories has selected a near surface disposal facility as the preferred design for the disposal of LLRW at the CRL site. This design includes an ECM and a WWTP. The ECM provides containment and isolation of the disposed LLW during both pre-closure and post-closure phases. The NSDF Project will enable CNL to move from the current practice of interim waste storage to disposal for LLW. This provides full life cycle radioactive waste management from generation to disposal in alignment with Canada's Radioactive Waste Policy Framework [5-1].

The NSDF Project is a waste management objective and a strategic priority as defined in CNL's 10-Year Integrated Plan Summary [5-2] and CNL Integrated Waste Strategy [5-3]. The NSDF Project will enable the clean-up mission of CRL site and the closure of WL, as well as demonstrate a safe and cost-effective disposal method for LLW in Canada [5-2].

This section describes the iteration and design optimization of the NSDF Project which is a process to ensure the optimization of protection and safety has been applied and implemented. The application of iteration and design optimization included:

- Design safety features and functions.
- Understanding the site characteristics.
- Numerical simulations including dose assessments and seismic modelling.
- Management and administrative measures.
- Degradation of design engineered features.

The iteration and design optimization in the NSDF Project considered internal and external inputs. The NSDF Project applied current best practice, international and national guidelines, standards, and Research & Development (R&D) results. The project involved SMEs from CNL, consultants and the nuclear industry, as well as SME from academic institutions to provide unbiased ITPRs on the project. Stakeholder and Indigenous group feedback was considered as part of the iteration and design optimization.

Furthermore, this section also provides a clear overview of CNL's decision making process for a wide variety of topics, as per IAEA SSG-23 paragraph 6.85 [5-4]. These topics include:

- The alternative means to carrying out the Project that were considered, and how CNL made decisions leading to the preferred options.
- The site characterization and site selection process.
- Optimization of the engineered containment mound based on site-specific characteristics.
- Optimization of the waste water treatment plant based on project-specific requirements.
- The iterative process in which the radiological inventory was calculated and refined, leading to a decision to lower the inventory, resulting in the Licensed Inventory.
- The refinement of the post-closure modelling processes.
- The integration of data and models across analyses.

## 5.1 Alternative Means for Carrying Out the Project

The EIS for the NSDF Project presents a discussion of the alternative means of carrying out the project, as required by the *Canadian Environmental Assessment Act, 2012* [5-5] and CNSC REGDOC-2.9.1 Environmental Principles, Assessments and Protection Measure [5-6].

This section of the Safety Case will also present a discussion on alternative means, but will focus on meeting the guidance of IAEA SSG-23 *The Safety Case and Safety Assessment for the Disposal of Radioactive Waste* [5-4].

This section, and Section 2.5 of the EIS [5-7], will contain an overlap of information, but are presented with the goal of meeting their respective requirement or guidance documentation.

In accordance with IAEA SSG-23 Section 3.70 [5-4], the presentation of alternatives is organized to answer the following three questions:

- What are the alternatives?
- What are the impacts, in particular the advantages and disadvantages associated with each alternative?
- What is the rationale for selecting the preferred alternative?

Each alternative is presented with sufficient detail to provide clear answers to the above questions, as per the guidance of IAEA SSG-23, Section 4.71 [5-4].

Each alternative is assessed and the most preferable option is selected after a systematic consideration of technical feasibility, economic feasibility and environmental effects. Public engagement is a key aspect of the decision making process. A summary of the alternative means assessment was made available to the public and Indigenous peoples, and input received was taken into consideration for the final NSDF design. Topics addressed included:

- The alternative site locations for the potential NSDF Project were presented. The public requested additional information on the site selection process including “Why the CRL site.” Additional information has been included in Sections 5.1.4 and 5.1.6 regarding the process used and the sites considered.
- Alternative means for NSDF’s effluent management strategy was explored as a one-day session with a focus group. Participants included stakeholders who expressed concern with respect to the NSDF Project’s effluent management strategy and specifically included members of the public, local municipalities and non-governmental organizations. The purpose of the session was to elicit stakeholder insights and evaluation of the NSDF Project’s proposed effluent management strategy. Canadian Nuclear Laboratories solicited the participants’ evaluation of the effluent discharge options using focus group developed criteria. The discussions from the focus group session have been considered by CNL for potential improvements to the NSDF, and have been incorporated into discussions within Section 5.1.7 (leachate management), Section 5.1.8 (effluent discharge options) and Section 5.1.9 (discharge type).

A social acceptability criterion was also included as part of the alternative means analysis to provide weight to any concerns and preferences expressed by the public and Indigenous peoples.

The alternative means considered in the EIS are grouped into seven categories, as presented in Table 5-1.

**Table 5-1**  
**Evaluated Alternative Means of Carrying out the NSDF Project**

| Aspect of the Facility                  | Alternatives Considered                                                                                                                                                                                                                                                                                                                                                                      |
|-----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Facility type                           | <ul style="list-style-type: none"> <li>• No facility – On-going Waste Storage</li> <li>• Very Low Level Waste Disposal Facility</li> <li>• Near surface</li> <li>• Geologic waste management facility (GWMF)</li> </ul>                                                                                                                                                                      |
| Facility Design of Near Surface Options | <ul style="list-style-type: none"> <li>• Engineered containment mound (ECM)</li> <li>• Shallow cavern</li> <li>• Above ground concrete vault (AGCV)</li> </ul>                                                                                                                                                                                                                               |
| Facility Location                       | <ul style="list-style-type: none"> <li>• On-site (CRL)</li> <li>• Off-site (Whiteshell Labs (WL) or Nuclear Power Demonstration (NPD))</li> </ul>                                                                                                                                                                                                                                            |
| Site Selection                          | <ul style="list-style-type: none"> <li>• 15 potential sites at CRL</li> </ul>                                                                                                                                                                                                                                                                                                                |
| Leachate Treatment Systems              | <ul style="list-style-type: none"> <li>• Existing wastewater treatment facility</li> <li>• WWTP (new)</li> <li>• Discharge option – leachate evaporation ponds</li> </ul>                                                                                                                                                                                                                    |
| Effluent Discharge Options              | <ul style="list-style-type: none"> <li>• Discharge to ground</li> <li>• Discharge to surface water (Perch Creek, Perch Lake and Ottawa River)</li> <li>• Co-discharge with the NSDF stormwater system and discharge to ground</li> <li>• Discharge to ground and discharge to surface water</li> <li>• No liquid discharge (i.e., thermal evaporator)</li> </ul>                             |
| Discharge Type                          | <ul style="list-style-type: none"> <li>• Discharge by surface spray onto Perch Lake</li> <li>• Piped outfall to Perch Lake (submerged outlet in Perch Lake)</li> <li>• Piped outfall to Perch Lake (above-water discharge)</li> <li>• Submerged diffuser in Perch Lake (alignment along lakebed)</li> <li>• Submerged diffuser in Perch Lake (diffuser suspended in water column)</li> </ul> |

### 5.1.1 Evaluation Criteria

In accordance with IAEA SSG-23 [5-4], Section 4.68, the selection of the preferred design option is chosen by means of a define, rational procedure. To determine the preferred or most favourable means of developing the disposal facility, each alternative is evaluated first for its technical feasibility. For those alternatives deemed technically feasible, a comparison of economic feasibility (i.e., cost) and the likely environmental effects is completed. Criteria for evaluating each of the alternatives are summarized in [5-5], with further rationale provided in the following sections.

**Table 5-2**  
**Criteria for Evaluating Alternatives**

| Category              |                       | Criteria                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------|-----------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Technical Feasibility |                       | <ul style="list-style-type: none"> <li>Does the alternative meet the project purpose?</li> <li>Does the alternative meet the required storage capacity?</li> <li>Is the alternative an example of best available technology?</li> <li>Does the design incorporate compatible construction materials for the radioactive wastes planned for disposal to provide sufficient design robustness to protect the environment?</li> <li>What is the complexity of monitoring requirements for the alternative?</li> </ul> |
| Economic Feasibility  |                       | <ul style="list-style-type: none"> <li>How does the life cycle cost of each alternative compare in relation to each other?</li> </ul>                                                                                                                                                                                                                                                                                                                                                                              |
| Environmental Effects | Biophysical           | <ul style="list-style-type: none"> <li>Environmental setting - does the alternative result in new disturbance (i.e., Greenfield site) or is it located within a previously disturbed area (i.e., brownfield site)?</li> <li>How do the likely effects on biophysical VCs compare (e.g., atmospheric environment, aquatic biodiversity, and terrestrial biodiversity)?</li> <li>Can it be constructed, operated, and decommissioned in a manner that provides long-term protection of ecological health?</li> </ul> |
|                       | Social                | <ul style="list-style-type: none"> <li>How do the effects on socio-economic VCs compare (e.g., land and resource use, heritage resources, socio-economic)?</li> <li>How are the alternatives perceived by the public and Indigenous peoples and is one alternative preferred over another?</li> </ul>                                                                                                                                                                                                              |
|                       | Human Health & Safety | <ul style="list-style-type: none"> <li>Can the alternative be constructed/operated in a manner that provides protection of public health and safety?</li> <li>How does the long-term protection of public health and safety compare?</li> <li>Can the alternative be constructed/operated in a manner that provides protection of worker health and safety?</li> </ul>                                                                                                                                             |

The alternatives are described using the above criteria (where applicable) and are summarized in a matrix illustrating the relative preference of each alternative, as shown below. If the alternative has a high chance of successfully addressing a particular criterion, it is rated as most favourable. Similarly, if the alternative has a moderate likelihood of addressing a criterion, it is rated as favourable, while if the alternative is assessed as having a low likelihood of success or having unacceptable risk with a particular criterion, a least favourable rating is used. For the technical criteria, a rating of “least favourable” was also generally considered to be the threshold for an alternative to not be technically feasible.





### 5.1.1.1 Technical Feasibility

The following criteria were developed for the technical feasibility category:

- **Project Purpose:** The purpose of the NSDF Project is to substantially reduce the risks associated with the CNL legacy wastes, liabilities and the cost of CNL operations to taxpayers and to facilitate CNL's cleanup mission, which allows for the revitalization of the CRL site. The most favourable alternative will satisfy the NSDF Project purpose, while the least favourable alternative will not satisfy the project purpose. Alternatives were considered to be favourable if they partially satisfied the purpose of the NSDF Project.
- **Storage Capacity:** The alternative must accommodate 1 000 000 m<sup>3</sup> of LLW, the majority of which is impacted soils and demolition waste. This volume is based on waste forecasting from future facilities and approaches to waste management. Alternatives that accommodated 1 000 000 m<sup>3</sup> were most favourable. Alternatives that did not accommodate 1 000 000 m<sup>3</sup> of waste were assessed as not technically feasible.
- **An Example of Best Available Technology:** This criterion evaluated the technology to be implemented with the alternative being considered relative to the types of wastes to be disposed. A best available technology was most favourable, while an available technology was considered to be favourable. An alternative was considered to be least favourable if the technology was unavailable, outdated or not appropriate for the type of waste to be disposed.
- **Disposal Facility Design Robustness:** This criterion considers the compatibility of the disposal facility construction materials with the LLW to be disposed as well as the design life of the facility. It is known that certain materials deteriorate over time when subjected to exposure to certain chemicals that may be contained in the leachate that is expected to be generated within the Facility. The most favourable alternative will use construction materials compatible with the radiological and chemical characteristics of leachate that is expected to be generated such that the Facility will perform effectively for a 500 year or greater post-closure period. A favourable alternative includes use of compatible construction materials that would result in the performance of the Facility for less than a 500 year post-closure but more than a 300 year post-closure period. An alternative was assessed as not technically feasible if the construction materials were considered to be incompatible with the leachate and would result in deterioration of the construction materials during the operations phase or near-term post-closure period (i.e., less than 100 years).
- **Complexity of Monitoring:** This criterion considered the monitoring requirements that may be needed in support of each alternative. Standard monitoring requirements were considered most favourable, while a slight increase in monitoring requirements and/or complexity of the program was considered to be favourable. Least favourable alternatives were those that require complex or substantially increased monitoring requirements.

### 5.1.1.2 Economic Feasibility

The economic feasibility was evaluated by comparing the life cycle cost estimate for each alternative. This estimate includes costs for construction of the Facility and supporting infrastructure, operations, and on-going monitoring and maintenance activities. Additionally, costs incurred during decommissioning and closure, and those associated with long-term monitoring and maintenance activities required during the post-closure period were also considered. Cost information used for other projects and types of facilities can be highly

variable depending on where the project is in its lifecycle and certainty in cost estimates (e.g., conceptual design versus construction complete).

Economic feasibility is discussed here because it is an important aspect in any large project's decision making process, especially when the Canadian taxpayer is ultimately liable. However, economics are always considered secondary to meeting all applicable safety requirements and acceptance criteria for the Facility.

#### **5.1.1.3 Impacts and Environmental Effects**

The evaluation of impacts and environmental effects is based on a qualitative comparison of biophysical and socio economic effects on VCs and potential effects on public and worker health and safety. Valued Components refer to environmental features that may be affected by a project and that have been identified to be of concern by the proponent, government agencies, Indigenous people, the scientific community or the public. The selection of appropriate VCs allows the assessment to be focused on those aspects of the natural and human environment that are of greatest importance to society.

#### **5.1.2 Facility Type**

Various types of disposal facilities have been constructed and are in operation around the world. These facility types have different degrees of containment and isolation capability appropriate to the radioactive waste that they will receive and its associated risk. However, regardless of the facility type selected, the specific aims of disposal remain the same according to IAEA's SSR-5 [5-8]:

- To contain the waste.
- To isolate the waste from the accessible biosphere and to reduce substantially the likelihood of, and all possible consequences of, inadvertent human intrusion into the waste.
- To inhibit, reduce and delay the migration of radionuclides at any time from the waste to the accessible biosphere.
- To confirm that the amounts of radionuclides reaching the accessible biosphere due to any migration from the disposal facility are such that possible radiological consequences are acceptably low at all times.
- To meet the requirements of IAEA's SSR-5 [5-8], CNL has defined the near surface disposal within its Integrated Waste Strategy as the primary disposal path for LLW that meet the WAC.

##### **5.1.2.1 Alternatives**

###### **5.1.2.1.1 No Facility – On-going Waste Storage**

###### **Technical Feasibility**

When developing the NSDF Project, CNL also considered maintaining the status quo which would involve the continued use of ongoing or interim waste storage. This could involve the existing configuration of the CRL waste management areas which includes the use of bunkers and storage buildings as well as rolling stewardship or monitored retrievable storage. In accordance with Canada's Radioactive Waste Policy Framework [5-9], the waste producers and owners of radioactive waste are responsible for the funding, organization, management and operation of disposal facilities required for their wastes. As such, CNL does not consider the on-going waste storage as technically feasible as it is not aligned with national policies.

Furthermore the historic WMAs have none to minimal engineered barriers to contain their inventory. Although the releases and groundwater impact from these WMAs is currently being managed, the risk of future releases and environmental impacts the inventory poses could be substantially reduced through improved containment and isolation of the source term. Leaving the historic WMAs in their current configuration as an alternative to LLW disposal is not technically feasible as it is unlikely to satisfy regulatory and licensing requirements for long-term waste management, specifically those specified within REGDOC-2.11.1 Volume III (Assessing the Long-Term Safety of Radioactive Waste Management) [5-10].

#### **5.1.2.1.2 Very Low Level Radioactive Waste Disposal Facility**

##### **Technical Feasibility**

Very-low-level waste is considered a subcategory of LLW as per CSA standard for the nuclear industry N292.0-19 General Principles for the Management of Radioactive Waste and Irradiated Fuel. Canadian Nuclear Laboratories previously considered the development of a VLLW disposal facility at the CRL site and implemented a trial to demonstrate the viability of segregation and storage of VLLW [5-11]. The trial demonstrated that the fraction of the total LLW that could be segregated as VLLW was disproportionate to the time, effort and storage requirements that were expended to realize any net benefit from the work. In addition, the LLW with higher activity that is segregated from the VLLW will still require a separate LLW disposal facility. Therefore, the development of a VLLW disposal facility does not meet the Project purpose, which recognizes the need for a LLW disposal facility and a VLLW disposal facility is not considered technically feasible.

##### **Economic Feasibility**

The planned cost of developing a disposal facility for VLLW site is expected to be similar to the cost of an NSDF; however, an NSDF would avoid the time and effort involved in the segregation and management of VLLW at the CRL site [5-11]. The development of a LLW disposal facility, including an NSDF, would eliminate duplication of effort, time, dose and facility construction, operation and closure costs and would enable reduction of Canada's liabilities earlier than it would have if a small percentage of the total inventory had been segregated and disposed separately. Therefore, the development of a VLLW disposal facility is not considered economically feasible when compared to the cost savings associated with the development of a LLW facility, including an NSDF.

#### **5.1.2.1.3 Near Surface Disposal Facility**

##### **Technical Feasibility**

The IAEA definition of a near surface disposal is the placement of solid, or solidified, radioactive waste in a disposal facility located at or near the land surface [5-12]. The preferred option for disposal of LLW is in near surface disposal facilities [5-13]. An NSDF is a suitable and technically feasible means of disposing of LLW and the effectiveness of such facilities for disposal of LLW has been demonstrated as illustrated through the following near surface facilities currently in operation North America. Within Canada, CNL is implementing the Port Hope and Port Granby Projects, on behalf of AECL, in eastern Ontario for the safe, long term management of historic LLW arising from the operations of the former Crown Corporation Eldorado Nuclear Ltd and its private-sector predecessors. These projects are building facilities for the long-term storage of LLW that are similar in design to the NSDF proposed for CRL.

Selected examples of NSDFs for LLW are provided in Table 5-3, which provides a summary of the key attributes for these facilities. A number of these are located in wet climates and in close proximity to surface waterbodies similar to the NSDF proposed for CRL.

The NSDF has been designed as a permanent disposal facility, incorporating best available technologies and industry practices, including documented experience from the IAEA and other similar national and international facilities (as described above). In accordance with Requirement 5 of IAEA's SSR 5 [5-8], the NSDF would also be sited, designed and operated to provide features that are aimed at the isolation of the radioactive waste from people and the environment. Subsurface investigations have concluded that the geology and hydrology on the selected CRL site is acceptable for the construction and operation of the NSDF. Designed and operated in accordance with applicable codes and best practices, the NSDF technology will feature a multilayer, base-liner and cover system to contain the waste, a WWTP with dual process trains to treat the leachate generated, and robust safety monitoring systems such as leak detection, radiation monitoring and environmental monitoring to ensure the safety of workers and the public and the protection of the environment during the operations and post-closure periods.

The safety of the NSDF during post-closure is provided by means of passive features (e.g., berm, final base-liner and cover systems) that will end the need for active management, which is in alignment with Requirement 5 of IAEA's SSR 5 [5-8]. The features of the selected site and the performance of the combined natural and engineered barriers assure safety following the closure of the ECM [5-12]. For example, a primary barrier material, the high-density polyethylene geomembrane, has been specifically tested for compatibility with the leachate quality and concentrations expected during NSDF operations. In addition, institutional controls, including restrictions on land use, and a program for monitoring, will be implemented in the post-closure period to provide long-term safety of the public and the environment.

Adaptive management is a means by which uncertainties in outcomes can be reduced through monitoring. The role of adaptive management is to evaluate the results of monitoring programs to develop appropriate responses on an ongoing basis. As such, the potential for applying adaptive management to the NSDF Project has been implicitly incorporated into project design; thus, facilitating future modifications should monitoring indicate that changes are necessary.

In summary, the NSDF design addresses all of the relevant technical feasibility criteria set out in Table 5-2.

### **Economic Feasibility**

The estimated cost of licensing and constructing the NSDF using an ECM (i.e., Phase 1 as well as initial development of the Phase 2 footprint) is approximately \$365 million (M) (2018 Class 1 estimate). This estimate includes site preparation and construction of the ECM, WWTP, site development and infrastructure and support facilities. Installation of capping over Phase 1 as well as completing construction of Phase 2 to operate will cost approximately \$110 M.

Operating costs associated with a 50 year operating life that includes both Phases 1 and 2, site closure costs, and surveillance and long-term maintenance costs for a 30 year period following end of operations are estimated at \$275 M. This cost is broken down into \$240 M for 50 years of operation and maintenance of both Phases 1 and 2 including replacement of operational equipment, \$5 M for surveillance and long-term maintenance (30 Years beyond the 50 Years Operation), and \$30 M for final closure costs.

This results in a total lifecycle cost of approximately \$750 M for the NSDF alternative using an ECM, which is more than an order of magnitude less than the cost of a GWMF alternative. The total life cycle cost for above

ground concrete vaults, another type of near surface disposal facility, is \$3,414.8M, which is also less than a GWMF alternative (Section 5.1.2.1.4). The reduced cost of either type of NSDF is more preferable as it further contributes to the reduction of the cost of laboratory operations to the Government of Canada and Canadian taxpayers.

**Table 5-3**  
**Attributes of Selected Near Surface Facilities in Canada and USA for Long Term Management of Low Level Waste**

| Facility                                                                           | Location        | Built              | Status             | Capacity (m <sup>3</sup> ) | Waste Type                                                                           | Climate | Annual Precipitation | Terrain    | Distance to Nearest Surface Water Body          |
|------------------------------------------------------------------------------------|-----------------|--------------------|--------------------|----------------------------|--------------------------------------------------------------------------------------|---------|----------------------|------------|-------------------------------------------------|
| Proposed CNL Near Surface Disposal Facility                                        | Ontario, Canada | Proposed           | Proposed           | 1,000,000                  | LLW from past operations, environmental remediation and decommissioning              | Wet     | 87 cm                | On a ridge | ~0.35 km to Perch Creek, 1.2 km to Ottawa River |
| Port Granby Long Term Waste Management Facility                                    | Ontario, Canada | 2017               | In Operation       | 774,000                    | LLW, hazardous and mixed waste from uranium processing and environmental remediation | Wet     | 83 cm                | Flat       | 0.7 km Lake Ontario                             |
| Port Hope Long Term Waste Management Facility                                      | Ontario, Canada | 2017               | In Operation       | 1,200,000                  | LLW, hazardous and mixed waste from uranium processing and environmental remediation | Wet     | 83 cm                | Flat       | 0.1 km to Brand Creek, 3 km to Lake Ontario     |
| Oakridge National Laboratories, Environmental Management Waste Management Facility | Tennessee, USA  | 2002               | In Operation       | 1,300,000                  | LLW, hazardous waste from environmental remediation and decommissioning              | Wet     | 140 cm               | On a ridge | 0.5 km to Bear Creek & Clinch River             |
| Hanford Environmental Restoration Disposal Facility                                | Washington, USA | 1996               | In Operation       | 16,800,000                 | LLW, hazardous and mixed waste from environmental remediation and decommissioning    | Arid    | 16 cm                | Flat       | 12 km to Columbia River                         |
| Portsmouth On-site Waste Disposal Facility                                         | Ohio, USA       | Under Construction | Under Construction | 1,000,000                  | LLW, hazardous and mixed waste from uranium processing                               | Wet     | 102 cm               | On a ridge | 2.4 km to Sciota River                          |
| Fernald On-site Disposal Facility                                                  | Ohio, USA       | 1996               | Closed             | 2,250,000                  | LLW and mixed waste from uranium processing                                          | Wet     | 105 cm               | Flat       | ~1 km to Great Miami River                      |

#### 5.1.2.1.4 Geologic Waste Management Facility

##### Technical Feasibility

A GWMF provides an alternative to the NSDF Project as proposed in [5-14]. Geologic Waste Management Facilities are designed for the long term management of LLW, ILW and High-Level Waste (HLW). Wastes are processed and packaged for disposal in deep underground repositories in stable geological formations.

While there are no GWMFs currently operating in Canada, the US Department of Energy's Waste Isolation Pilot Plant developed a Deep Geologic Repository (DGR) (more than 700 m deep) for ILW and HLW, which has been in operation since 1999. There are a number of GWMFs that are either under construction or with licence applications to construct under regulatory review, including:

- Finland's DGR for used fuel from Olkiluoto and Loviisa, approximately 400 to 450 m below ground in the Olkiluoto bedrock, as proposed by Posiva.
- Sweden's Final Repository for Short-Lived Radioactive Waste for operational wastes (up to ILW), is approximately 50 m below the bottom of the Baltic Sea near Forsmark. Sweden is also proposing an underground repository for disposal of spent fuel, approximately 500 m below ground near Forsmark.
- The French National Radioactive Waste Management Agency's proposed 500 m DGR complex in clay at Bure, France for HLW and long lived ILW.
- Ontario Power Generation's (OPG) proposed DGR for LLW and ILW on the Bruce Site in Tiverton, Ontario, approximately 680 m below ground surface. Although this project had successfully satisfied the technical reviewers of the federal government and joint review panel, but the project was withdrawn by the proponent for non-technical reasons.

In addition, China, Germany, India, Japan, Switzerland, the United Kingdom, United States and Canada are also pursuing geologic repositories for the long term management and disposal for used fuel and other HLW. The use of GWMF as the preferred disposal solution is primarily for HLW and long lived ILW, where additional barriers for protection are warranted.

Canadian Nuclear Laboratories conducted assessments of its site geology and confirmed that the geologic characteristics required for a GWMF are present on the CRL site. Significant surface and subsurface investigations including approximately 12 000 m of borehole drilling, core logging, geological mapping, geophysical surveys, hydrogeological surveys, and various geotechnical tests were performed on the CRL site since the 1970s to examine the suitability of the crystalline bedrock to host a GWMF for the permanent disposal of CNL's ILW at a depth between 500 and 1 000 m. Both shallow boreholes (less than 300 m) and deeper boreholes (approximately 1 200 m) were drilled as part of the investigations.

Information derived from characterization activities was used to define bedrock structures on both macroscopic and mesoscopic scales. A descriptive hydrogeological model of the CRL site was developed, outlining the hydrogeological properties and 3D spatial distribution of all important hydrogeological units and features within the bedrock of the CRL site. The rock mass characterization conducted to date provides a reasonable basis for a positive decision to proceed to siting studies for a GWMF at the CRL site. As for the GWMFs discussed above, CNL would need to undertake comprehensive siting assessments and develop a robust design that protects the environment.

Because GWMFs are built subterranean, provided suitable geology is available, there are no practical limitations on the size of the repository. As such, the GWMF can be designed to provide a total waste volume of 1 000 000 m<sup>3</sup>.

In GWMFs, isolation is provided primarily by the host geological formation and the depth of disposal. The passive safety features (barriers) of the GWMF design have to be sufficiently robust so as not to require repair or upgrading, in keeping with requirements that disposal facilities for radioactive waste not rely on active institutional control [5-8]. However, institutional controls may contribute to safety by preventing or reducing the likelihood of human actions that could inadvertently interfere with the waste or degrade the safety features of the GWMF. In addition, a program for monitoring would be needed in the post-closure period to demonstrate long-term safety of the public and the environment.

In summary, the GWMF facility type meets most technical feasibility criteria, as set out in Table 5-2. The GWMF has been demonstrated to provide an adequate level of environmental protection through international experience (as described above). It would satisfy the purpose of the NSDF Project in that it would provide the needed disposal capacity for CNL's LLW. The technology for GWMFs is proven and a robust design with monitoring systems that meet international requirements for disposal facilities could be developed at the CRL site based on available geologic data.

### **Economic Feasibility**

The costs associated with constructing a GWMF are considerably higher than a NSDF. Similarly, the operating costs for a GWMF would also be greater than that of the NSDF due to the need for additional waste packaging and handling of all waste. For example, the total waste volume to be disposed in OPG's DGR Project is 200 000 m<sup>3</sup> of LLW and ILW [5-15]. The estimated capital costs for the DGR Project are estimated at \$1 000 million. Annual operating costs are estimated at \$25 million [5-16]. Using these values, the inferred lifetime expenditure for a GWMF with a total waste volume of 1 000 000 m<sup>3</sup> and 50 year operations phase could be greater than \$6 250 million.

#### **5.1.2.2 Impacts**

The do-nothing scenario, where no Facility is constructed, has the potential for greatest environmental impact. While most wastes are currently stored and managed appropriately posing very little risk, some of the wastes currently exist in the environment with no engineered barriers, slowly migrating into their surroundings.

The key pathways by which a NSDF (containing VLLW or LLW), or GWMF may interact with the environment is through surface water and groundwater intrusion, migration of contaminated water (leachate), inadvertent intrusion, release of radioactive particulates to the atmosphere, and disturbance to the terrestrial environment from the project footprint. Regardless of whether the Facility is a NSDF or GWMF, engineered barriers and mitigation measures would be implemented to prevent or delay the migration of contaminants, protect human and ecological health, and limit effects to the aquatic and terrestrial environments. These barriers and mitigation measures represent an important component of the safety from the operations phase through the period of institutional control.

The majority of effects to air quality would occur during the construction and operations phases for both alternatives. Blasting activities would be required for the construction of both an ECM and a GWMF and fugitive dust emissions would be generated during earth moving activities. During operations and post-closure of the ECM, radioactive gases (e.g., radon and tritium) and radioactive particulates may be



released from the wastes within the Facility during the operations and post-closure phases. During operations, there would be differences in atmospheric emissions between the two alternatives; the ECM would have heavy equipment placing wastes and cover material at surface, whereas the majority of the equipment during operations of the GWMF will be below ground, and emissions managed through ventilation shafts. Both alternatives would have different types of effects on air quality; they would each implement mitigation that provides for worker and public health and safety and protection of the environment. Greenhouse gas emissions are expected to be of the same order of magnitude for both alternatives.

Potential effects on hydrogeology are related to the alteration of groundwater levels and flows due to the construction of the Facility and potential changes to groundwater quality due to migration of leachate following post closure activities. Subsurface investigations at the CRL site have concluded that the geology on site is acceptable for the construction and operation of an NSDF. The surface geology of the CRL site is composed of four types of glacial and post-glacial sediments including till, water-deposited sands (fluvial), wind-deposited (Aeolian) sands and organic deposit. To limit potential effects to groundwater, engineered barriers to control for infiltration of surface water, groundwater intrusion, and migration of contaminated water (leachate), would be implemented. Engineered barriers can be used as physical and/or chemical obstructions and can provide either partial containment or complete isolation of the waste or both [5-13]

In GWMF facilities, the waste is normally placed below the ground water table and will thus, have a water saturated environment outside the engineered barriers soon after closure of the repository [5-17]. A study has been performed to gather sufficient facts for the resultant geoscientific interpretations and analyses to determine whether or not suitable bedrock conditions likely exist at CRL for a GWMF. Hydraulic testing was completed which suggests that intrablock regions of the CRL rock base is generally low to very low below the 400 to 500 m depth. In accordance with the groundwater flow models, the deeper bedrock at the CRL site appears to be able to provide moderately strong natural barrier against transport of contaminants from a GWMF. In summary, although both alternatives would be designed to be protective of groundwater; a GWMF is considered to be more favourable as it would provide additional barriers against potential groundwater transport.

Both facility types may affect existing availability of the spatial and temporal distribution of water quantity for aquatic and terrestrial ecosystems. For both the NSDF and GWMF facility types, surface water drainage would be managed within the project footprint. Proposed design features would be based on proven surface water management practices controlling erosion, capturing sediment, and for safely conveying flows associated with a back to back 1:100 year or regional storm event. Because the GWMF design would not be prone to infiltration of precipitation through the waste during placement, only the NSDF alternative would require some form of water treatment to mitigate potential effects to surface water quality associated with the seepage of leachate from the facility (i.e., changes to groundwater quality). The NSDF's water treatment facility would be designed to meet site specific risk-based effluent quality criteria to be protective of the environment and humans. In conclusion, there are no anticipated differences between the NSDF and GWMF alternatives when considering potential effects to the surface water environment from each Facility except the infiltration of water to the waste and related need for treatment to mitigate effects.

Potential effects to terrestrial biodiversity are primarily related to the amount of surface disturbance to vegetation and wildlife habitat. The footprint for a NSDF large enough to accommodate 1 000 000 m<sup>3</sup> of LLW is approximately 37 ha. The surface footprint required for a GWMF is dependent on the size of the underground repository and the volume of waste rock to be managed at surface. As a comparison, the surface footprint required for the DGR Project is approximately 30 ha for management of 200 000 m<sup>3</sup> of waste

[5-15]. Therefore, the footprint required for waste rock management at the CRL site for 1 000 000 m<sup>3</sup> could be much larger. This larger footprint would result in greater indirect effects on the terrestrial environment. However, in both cases, mitigation will be implemented to eliminate or reduce potential effects on Species at Risk that may be found or critical habitat.

The objective of the design of a disposal facility is to ensure the Facility can be built and the waste received, handled, and disposed without undue risk to human health and the environment, both during facility operation and after facility closure. There are numerous examples of both NSDF and GWMF type facilities that have been successfully constructed and operated. Within Canada, CNL is implementing the Port Hope and Port Granby Projects for the safe, long term management of historic LLW arising from the operations of the former Eldorado Nuclear Ltd. These projects are building near surface management facilities similar to the design proposed for the NSDF Project. Public dose estimates were calculated in 2018 for Port Hope and Port Granby. The public dose estimate at Port Hope is 0.0275 millisievert per year (mSv/y) based on 60 hours at the east fence [5-18] and the public dose at Port Granby is 0.020.0 mSv/y based on 60 hours at south fence line [5-19]. Both public dose estimates are well below the CNSC dose limit of 1 mSv/y for members of the public. Radiation doses to members of the public for the long-term maintenance and monitoring phase are predicted to be indistinguishable from the background conditions [5-20].

A detailed safety assessment, performed for OPG's Deep Geologic Repository Preliminary Safety Report [5-21], concluded that the results of the analysis indicate very low doses to the public, far below the CNSC regulatory limit of 1 mSv/y. A preliminary post-closure performance and safety assessment for OPG's long term management of LLW and ILW in a GWMF type facility examined the long-term evolution of the performance post closure. Results from the simulation showed that estimated dose rates were orders of magnitude below 0.3 millisieverts (mSv), and concluded that there were no results found which would preclude the safe disposal of the six LLW and ILW groups which were used in this study. For a similar GWMF facility (i.e., OPG's Deep Geologic Repository) for the Human Intrusion scenario, a borehole is drilled into the repository and gases and material are released [5-15]. The calculated doses were estimated to be about 1 mSv for the future person farming on the site; however, the likelihood of inadvertent human intrusion into the waste will be low as a consequence of the chosen depth for a GWMF [5-21].

Regardless of the type of facility, the design would aim to ensure that such releases do not exceed applicable regulatory limits during either the operations or post-closure phases and are protective of humans and the environment. However, given the nature of the GWMF located at a nominal depth, this facility type may be considered more robust against surface activities and therefore is more favourable.

Both a NSDF and GWMF facility type would meet all regulations and be constructed in a manner that protects worker health and safety. Operations at the NSDF will be similar to those applied by CRL at the WMAs for over 70 years. It is expected that the majority of environmental remediation and decommissioning waste will be disposed as bulk material, in unpackaged form. Approximately 13% of LLW will have sufficiently high radionuclide content to require use of packaging in the NSDF. Conversely, increased packaging would be a requirement for a GWMF, and the additional handling and packaging of wastes may result in increased exposure to workers. The design process provides for worker health and safety by maintaining occupations exposures ALARA regardless of which facility type is selected; however, because of the reduced handling and packaging requirements, the NSDF type facility is most favourable.

While both an NSDF and a GWMF can be constructed in a manner that protects public and worker safety, a GWMF includes a natural geologic barrier that provides additional isolation of the wastes. This is expected to

be viewed more favourably and considered safer by the public and Indigenous peoples even though this extra layer of protection is not required for the disposal of LLW.

Overall, mitigation through the implementation of the above-described engineered barriers for an NSDF or GWMF facility are anticipated to reduce or limit environmental effects and subsequently risk to human and environmental health. Effects to ecological health are expected to be similar between alternatives (e.g., air and dust emissions and employment and business opportunities generated for both design options are assumed to be similar; both design options would avoid lakes and streams, sensitive and/or critical habitat, and significant cultural resources, and both would require restrictions on future land use).

### 5.1.2.3 Rationale

Both the NSDF and GWMF alternatives meet CNL's overall need and are environmentally feasible options. However, the GWMF does have substantially higher life cycle costs, which are potentially an order of magnitude higher than for an NSDF. Although a GWMF would provide increased barriers for potential releases to the environment in the long term, the nature of the waste (i.e., LLW), the majority of which is impacted soils and demolition waste, does not warrant the need for these barriers. Low-level waste requires isolation and containment for periods of time up to a few hundred years. A GWMF also requires additional waste handling for waste placement whereas LLW does not require shielding during handling or interim storage. Geologic Waste Management Facilities are most typically proposed for HLW and ILW, which are not within the scope of the NSDF Project.

Near surface disposal facilities, as proposed for the NSDF Project, have been demonstrated globally to be an effective disposal solution for LLW. Therefore, a NSDF is the most feasible and most favourable alternative. Table 5-4 provides a summary of the evaluation of alternatives. The table does not include discussion of the "do-nothing" option, as it is not technically an alternative to carrying out a disposal project. Furthermore, the evaluation for the NSDF in Table 5-4 also applies to a VLLW facility, as they are similar in design/cost.

**Table 5-4**  
**Evaluation of Alternatives – Facility Type**

| Criteria                                | Near Surface Disposal Facility (NSDF)                                                                                                                                                                                                                              | Geologic Waste Management Facility (GWMF)                                                                                                                                       |
|-----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Technical Feasibility</b>            |                                                                                                                                                                                                                                                                    |                                                                                                                                                                                 |
| Project Purpose                         | The NSDF satisfies the project purpose and allows for the planned decommissioning and site restoration activities and reduces liabilities associated with the CNL legacy wastes.                                                                                   | Construction of a GWMF allows for the planned decommissioning and site restoration activities and reduces liabilities associated with the CNL legacy wastes.                    |
| Storage Capacity                        | The NSDF can be designed to provide a total waste volume of 1,000,000 m <sup>3</sup> .                                                                                                                                                                             | The GWMF can be designed to provide a total waste volume of 1,000,000 m <sup>3</sup> .                                                                                          |
| An Example of Best Available Technology | The NSDF facilities have been applied for the disposal of LLW globally (e.g., Oak Ridge Tennessee EMWM Facility) and is recognized by the IAEA as a suitable disposal option for LLW (IAEA 2009), especially for non-consolidated waste (e.g., soil and demolition | The GWMF facilities have been applied for the disposal of ILW (e.g., Waste Isolation Pilot Plant). The GWMF offers a level of containment that exceeds the requirement for LLW. |

| Criteria                                   | Near Surface Disposal Facility (NSDF)                                                                                                                                                                                                                                                                |                                                                                     | Geologic Waste Management Facility (GWMF)                                                                                                                                                                                                                                                                  |                                                                                       |
|--------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
|                                            | material).                                                                                                                                                                                                                                                                                           |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Design Robustness                          | The NSDF incorporates proven technologies and best industry practices, including documented experience from the IAEA and other similar national and international facilities. It is the performance of the combined natural and engineered barriers that provides safety after closure for the NSDF. |    | Conceptually, a GWMF has been demonstrated to provide an adequate level of environmental protection through international experience, thus is considered to be robust and technically feasible. The natural geologic barrier of a GWMF provides additional isolation of the wastes, as compared to a NSDF. |    |
| Monitoring Complexity                      | Environmental monitoring is straightforward and could be incorporated into the monitoring program at an existing site (e.g., CRL site).                                                                                                                                                              |    | Environmental monitoring (i.e., groundwater monitoring) is expected to be more complex given the depth of the facility.                                                                                                                                                                                    |    |
| Economic Feasibility                       |                                                                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Life Cycle Cost                            | Approximately \$750 million (ECM) to \$3,400 million (AGCV)                                                                                                                                                                                                                                          |    | Up to approximately \$6,250 million                                                                                                                                                                                                                                                                        |    |
| Environmental Effects                      |                                                                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Biophysical                                |                                                                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Atmospheric Environment                    | No anticipated difference between alternatives.                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Geological and Hydrogeological Environment | Engineered barriers to control infiltration of surface water and prevent release of contaminated water (leachate) from the NSDF, would be implemented.                                                                                                                                               |  | The natural geologic barrier of a GWMF provides additional isolation of the wastes, as compared to a NSDF.                                                                                                                                                                                                 |  |
| Surface Water Environment                  | There are no anticipated differences between the alternatives.                                                                                                                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Aquatic Biodiversity                       | There are no anticipated differences between the alternatives.                                                                                                                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Terrestrial Biodiversity                   | The footprint required for a NSDF is anticipated to be 37 ha; however, mitigation would be implemented to eliminate or reduce potential effects on Species at Risk that may be found or critical habitat.                                                                                            |  | The footprint required for waste rock management of a GWMF could be much larger. Mitigation would be implemented to eliminate or reduce potential effects on Species at Risk that may be found or critical habitat.                                                                                        |  |
| Ecological Health                          | No anticipated difference between alternatives.                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Social                                     |                                                                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Socio-economics                            | No anticipated difference between alternatives.                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Land and Resource Use                      | No anticipated difference between alternatives.                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Social Acceptability                       | A GWMF is expected to be perceived more favourably compared to an NSDF due to the perception that a GWMF is safer.                                                                                                                                                                                   |  | A GWMF is expected to be perceived more favourably compared to an NSDF due to the perception that a GWMF is safer.                                                                                                                                                                                         |  |

| Criteria                                             | Near Surface Disposal Facility (NSDF)                                                                                                                                                                  |                                                                                   | Geologic Waste Management Facility (GWMF)                                                                                                                                                                                                                                                                |                                                                                     |
|------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Environmental Effects                                |                                                                                                                                                                                                        |                                                                                   |                                                                                                                                                                                                                                                                                                          |                                                                                     |
| Human Health and Safety                              |                                                                                                                                                                                                        |                                                                                   |                                                                                                                                                                                                                                                                                                          |                                                                                     |
| Public Health & Safety (construction and operations) | Both alternatives can be developed in a manner that protects public health and safety during construction and operations.                                                                              |                                                                                   |                                                                                                                                                                                                                                                                                                          |                                                                                     |
| Public Health & Safety (long-term)                   | Institutional controls, including restrictions on land use, and a program for monitoring will be implemented in the post-closure period to confirm long-term safety of the public and the environment. |  | Institutional controls, including restrictions on land use, and a program for monitoring will be implemented in the post-closure period to confirm long-term safety of the public and the environment. However, given the nature of the GWMF located at a greater depth, human intrusion is less likely. |  |
| Worker Health & Safety                               | Because of the reduced handling and packaging requirements, the NSDF type facility is most favourable.                                                                                                 |  | All waste will require packaging which increases potential exposure and risk to workers.                                                                                                                                                                                                                 |  |

### 5.1.3 Facility Design

This section evaluates the proposal of disposing waste within three types of NSDF's: Above-ground Concrete Vault (AGCV) design, shallow caverns, and an ECM design.

#### 5.1.3.1 Alternatives

##### 5.1.3.1.1 Engineered Containment Mound

Disposal facilities constructed on the surface, typically in the form of a mound or hill, primarily use engineered barriers to prevent water from infiltrating the disposed waste, thus maintaining diffusion-controlled transport of radionuclides, which is an extremely slow process [5-22]. To meet the above-mentioned design principles and objectives, the ECM design features composite final cover and base liner systems comprising natural and synthetic materials. The base liner contains both engineered leachate collection and leak detection systems as well as natural drainage elements. The performance of the ECM will be monitored to provide early indications of any need for maintenance or repair. The design of the ECM for the NSDF Project is fundamentally consistent with those for the Port Granby and Port Hope Long-term Waste Management Facilities now in operation.

#### Technical Feasibility

An advantage of this mound-type repository design is that the waste is placed above the groundwater table and the waste stays dry as long as the protective barriers are intact, which may be on the order of hundreds of years [5-17]. These mound-type disposal facilities also have relatively moderate technical requirements for the site, so it is usually easy to find places to locate them. For the proposed ECM, soil will be used to fill the space between the waste packages. This type of fill material will help to stabilize the waste in the ECM. This added stability is also important in the long-term as the waste degrades and there is potential for the final

cover to settle. These fill materials also allow easy removal of the waste, if such action ever became necessary after disposal.

The vast majority of the waste streams are comprised of impacted soils and demolition debris, which can be readily placed into compacted layers within the ECM. This type of less consolidated waste is typically disposed in ECMs (examples of other ECM facilities are provided in Table 5-3). When compaction rates are adhered to, the facility throughout its life cycle behaves as a single “entity” and will survive significant seismic events without much damage or implication. Although ECM facilities may require extensive monitoring; these monitoring programs are relatively straight-forward and similar programs are currently in place at CRL site.

The main disadvantage for surface disposal is that the protective cover of the waste is exposed to weathering and erosion that can endanger the integrity of the repository. The cover is designed to divert the precipitation away from the ECM. Available literature on geomembrane service life under the conditions expected for the ECM (i.e., temperature, leachate quality, radiation and stresses) indicates that HDPE geomembrane liner (i.e., primary composite liner and final cover liner) is expected to remain functional over the 500 year post-closure design life of the ECM. The cover liner is also the feature of the Facility that is the easiest and cheapest to repair or replace if infiltration does occur [5-23].

### **Economic Feasibility**

The estimated cost to build (i.e., capital expenditures,) the NSDF for the 1 000 000 m<sup>3</sup> of CNL waste is \$475M. This estimate includes site preparation and construction of the ECM, supporting facilities and buildings, and access roads. Operating costs associated with a 50 year operating life, site closure costs and surveillance and long-term maintenance costs for a 30 year period following end of operations are estimated at \$275 M. This results in a total lifecycle cost of \$750 M for the NSDF Project.

#### **5.1.3.1.2 Above Ground Concrete Vaults**

Above-ground concrete vaults (AGCV) are another type of disposal facility employing engineered multi barrier concrete structures set partially into the ground. With this technology, isolation is provided by a reinforced-concrete building constructed on the surface. Waste containers may be loaded into a vault through an open side or top, which is sealed after the vault has been filled. Concrete containment vaults add structural stability to the disposal unit, help to prevent any infiltrating water from coming in contact with the waste and provides an intrusion barrier around the waste. The waste in the building would be isolated from humans and the environment as long as the integrity of the building is maintained.

### **Technical Feasibility**

Although AGCV facilities may require extensive monitoring; these monitoring programs are relatively straightforward and similar programs are currently in place at the CRL site.

Disposal facilities using AGCV provide concrete barriers to the waste and are therefore, not as heavily impacted by weathering and erosion, when compared to the ECM-type; however, there are disadvantages [5-17]. Above-ground facilities are subject to deterioration through exposures to wind, rain, and freeze-thaw cycles and are vulnerable to cracking as a result of uneven settlement and seismic events. While some of these trigger events could be mitigated by earth covers surrounding the AGCV, not all can be reduced. Design features such as reinforcement, expansion joints, sealants and drainage collection would serve to mitigate the impacts of these forces. Further, concrete has been extensively studied and can be made durable enough to last for a few hundred years and perhaps longer [5-24]. Some predictive models even indicate that concrete

will last longer than 1 000 years; however, beyond about 500 years, the uncertainty of such predictions increases [5-24].

There are several international examples of the use of AGCV, including facilities in France and Spain. The facility located at Centre de l'Aube in France, which began operations in 1992, has been designed to be Europe's largest repository for LLW and ILW. Waste are placed in concrete vaults constructed on the surface under a movable shelter that protects the wastes from weather during placement. Once a vault is full, a concrete cover is poured in place to completely isolate the waste from the environment. This Facility is designed for 1 000 000 m<sup>3</sup> of LLW and ILW, with a future forecast of 1 900 000 m<sup>3</sup>, so a future facility will be required at some point. The Centre l'Aube Facility receives waste from power plants, research activities and fuel manufacturing and reprocessing plants. This type of waste is suitable for an AGCV given the packaged nature of the waste. The majority of the waste proposed for the NSDF Project is impacted soils and demolition waste which is less consolidated and would be easier to manage in a facility like the ECM (i.e., unconsolidated waste can be moved around more easily).

### **Economic Feasibility**

The construction cost estimate for AGCV option was developed from the 1999 Organization for Economic Co-operation and Development report titled Low Level Waste Repositories: An Analysis of Cost [5-25] using information from El Cabril facility for LLW in Spain. The construction cost, including research and development, site screening, facility design, 28 disposal vaults, supporting buildings and facilities, for a 100 000 m<sup>3</sup> Facility was approximately \$229 million (Canadian dollars), plus \$762 for every additional cubic metre of waste. For the CNL waste volume of 1 000 000 m<sup>3</sup>, the cost to construct an AGCV design would be approximately \$914.8 million, which is considerably higher than the ECM design. Annual operating costs are estimated at \$2 500/m<sup>3</sup> of waste placed (present day value) [5-25]. Using these values, the inferred lifetime expenditure for the AGCVs with a waste volume of 1 000 000 m<sup>3</sup> and 50 year operations phase is estimated. This results in a total life cycle cost of \$3 414.8 million (\$914.8 million for construction and \$2 500 million operations); over 4.5 times the cost of the ECM alternative.

#### **5.1.3.1.3 Shallow Caverns**

### **Technical Feasibility**

Another type of NSDF includes the disposal of LLW in shallow caverns. However IAEA guidance [5-12] recognizes that in the siting process of a near surface disposal facility, the facility design ought to consider the hydrogeological characteristics of the siting location. Specifically the hydrogeological characteristics of the host site should include low groundwater flow paths and long flow paths to restrict the migration of radionuclides. As such, shallow caverns were eliminated from consideration for CNL's LLW facility design primary due to the CRL site characteristics.

In the SSA, average groundwater depths range from 0.06 meters below ground surface (mbgs) to 15.95 mbgs, with an average of 4.81 mbgs under normal conditions, and 3.61 mbgs during seasonal high conditions (EIS [5-7], Section 5.3.2.1.2.1). Near-surface caverns constructed in, or near the water table, are at a very high risk of immediate flooding, and are therefore not appropriate or technically feasible for the disposal of radioactive waste. Furthermore, no single cavern could be excavated to meet the volume of 1 000 000 m<sup>3</sup>, resulting in multiple caverns and multiple designs to suit the localized hydrogeology.

Wastes placed into shallow caverns on the CRL site are more likely to come into contact with groundwater very quickly, providing a very short flow path for the migration of radionuclides into the environment. Thus,

the shallow cavern facility design at the CRL site does not align with IAEA guidance [5-12], and is therefore not suitable or technically feasible.

#### **5.1.3.2 Impacts**

The pathways by which contaminants from a NSDF may migrate or be brought into contact with humans and biota is through infiltration of surface water, groundwater intrusion, migration of contaminated water (leachate), inadvertent intrusion and escape of radioactive gas [5-13]. Regardless whether the Facility incorporates an ECM or AGCV, engineered barriers will be implemented to prevent or delay the migration of contaminants via these pathways. These barriers represent an important component of the NSDF safety from the operations phase through the period of institutional control. The design of the NSDF will provide that all safety and regulatory requirements are met such that the ECM or AGCV would be constructed and operated in a manner that is safe to the public and workers.

Engineered barriers to control for infiltration of surface water, groundwater intrusion, migration of contaminated water (leachate), inadvertent intrusion and escape of radioactive gas for the ECM include installation of a primary and secondary liner, and a final cover at closure. For the ECM, most of the waste placed in the Facility will be unpackaged (i.e., loose/bulk); although some wastes may be packaged (e.g., in high integrity containers) to provide additional short-term containment. Most of the waste to be disposed will arise from the decommissioning of buildings and is lightly contaminated and safe to be disposed in bulk form (i.e., without double-handling and packaging), reducing unnecessary processing and packaging decreases potential exposure and risk to workers.

Greenhouse gas emissions for the AGCV Facility are expected to be above that of the ECM because of concrete production. The AGCV Facility is constructed of reinforced concrete that offers structural stability and provides an intrusion barrier around the waste. The AGCV also deters infiltration of water to the wastes, and therefore does not generate leachate which requires treatment. The footprint required for the AGCV is 1.5 to 2 times that required for an ECM due to the need to package all waste for an AGCV and constraints on the stacking of waste packages. Based on constructible areas available at the CRL site, it would be necessary to develop at least two sites/locations to establish disposal capacity for 1 000 000 m<sup>3</sup> of waste in an AGCV type Facility. Developing multiple sites would have a greater biophysical effect.

Overall, mitigation through the implementation of the above described engineered barriers for an ECM or AGCV Facility are anticipated to reduce or limit environmental effects and subsequently risk to human and environmental health. Effects to all other VCs are expected to be similar between alternatives (e.g., air and dust emissions and employment and business opportunities generated for both design options are assumed to be similar; both design options would avoid lakes and streams, sensitive and/or critical habitat, and significant cultural resources, and both would require restrictions on future land use). Because the pathways through by which contaminants may migrate or be brought into contact with humans and biota are similar for both alternatives, similar monitoring programs would also be required during operations and through the ICP to demonstrate long-term safety of the public and the environment. In terms of worker safety, an ECM reduces unnecessary processing and packaging which would be required for an AGCV, thereby decreasing potential exposure and risk to workers.

#### **5.1.3.3 Rationale**

As summarized in Table 5-5, both alternatives are technically and environmentally feasible. Both alternatives can be constructed such that they meet the purpose of the NSDF Project and both alternatives can be



constructed to accommodate up to 1 000 000 m<sup>3</sup> of radioactive waste. The AGCV and ECM Facility designs are proven technologies and there are several international examples of each. Both have relatively moderate technical requirements and can be sited on the CRL site. The AGCV is expected to be more vulnerable to seismic events compared to an ECM which behaves as a single “entity” and is more resilient to seismic events. The monitoring requirements for these surface-located options are similar and employ conventional environmental technologies. The life cycle costs associated with an AGCV design are approximately 4.5 times the cost of the ECM alternative. In addition, the additional packaging and containment is not required for most of the LLW intended to be disposed on the CRL site. Therefore, the most favourable alternative facility design for the NSDF is an ECM.

**Table 5-5**  
**Evaluation of Alternatives – Facility Design**

| Criteria                                | Engineered Containment Mound (ECM)                                                                                                                                                                                                                                                   |                                                                                     | Above-ground Concrete Vaults (AGCV)                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                       |
|-----------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Technical Feasibility                   |                                                                                                                                                                                                                                                                                      |                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Project Purpose                         | Both alternatives meet the technical requirements.                                                                                                                                                                                                                                   |                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                       |
| Storage Capacity                        | The ECM would require approximately 17 ha to contain 1,000,000 m³ of radioactive waste within the engineered mound, and approximately 20 additional ha for the WWTP, support facilities and site infrastructure. All NSDF Project elements can fit on a single site on the CRL site. |  | The AGCV would require 1.5 to 2 times the spatial area of an ECM for the disposal of the same quantity of waste. The concrete vault has limitations on stacking of waste containers resulting in a larger footprint needed to contain CNL’s 1,000,000 m³ volume. Due to the large number of surface waterbodies and wetlands, CRL does not have a single site large enough for an AGCV sized to hold 1,000,000 m³ of waste and would need to develop (at least) two sites. |  |
| An Example of Best Available Technology | ECM is an example of a best available disposal technology and widely used internationally for disposal of LLW which is mainly composed of impacted soils and demolition waste.                                                                                                       |  | AGCVs are a proven disposal technology and have been used for packaged LLW and ILW. The AGCV offers a level of containment that exceeds the requirement for LLW.                                                                                                                                                                                                                                                                                                           |  |
| Design Robustness                       | The ECM offers multiple engineered barriers including a double composite base liner system with redundant leachate systems, and a composite cover system. Natural and manmade materials are employed for system robustness.                                                          |  | The AGCV offers multiple engineered barriers that provide design robustness. These include high strength concrete structural elements and engineered packages for all wastes.                                                                                                                                                                                                                                                                                              |  |
| Monitoring Complexity                   | Both alternatives may require extensive monitoring; however, these monitoring programs are relatively straight-forward and are currently in place at the CRL site.                                                                                                                   |                                                                                     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                       |

| Criteria                                             | Engineered Containment Mound (ECM)                                                                                                     |                                                                                     | Above-ground Concrete Vaults (AGCV)                                                                                                                                                                                                                |                                                                                       |
|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Economic Feasibility                                 |                                                                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Life Cycle Cost                                      | Approximately \$750 million                                                                                                            |    | Approximately \$3,400 million                                                                                                                                                                                                                      |    |
| Environmental Effects                                |                                                                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Biophysical                                          |                                                                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Atmospheric Environment                              | No anticipated difference between alternatives.                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Geological and Hydrogeological Environment           | Leachate will be generated by the ECM during operations which will require treatment and management to ensure effects are mitigated.   |    | Minimal leachate will be generated by an AGCV during operations.                                                                                                                                                                                   |    |
| Surface Water Environment                            | No anticipated difference between alternatives.                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Aquatic Biodiversity                                 | No anticipated difference between alternatives.                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Terrestrial Biodiversity                             | The disturbance footprint would be designed to avoid wetlands and limit disturbance to the natural environment to the extent feasible. |    | The disturbance footprint would be designed to avoid wetlands and limit disturbance to the natural environment to the extent feasible, however AGCVs are likely to have a larger footprint as a result of additional packaging requirements.       |    |
| Ecological Health                                    | No anticipated difference between alternatives.                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Social                                               |                                                                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Socio-economic                                       | No anticipated difference between alternatives.                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Land and Resource Use                                | No anticipated difference between alternatives.                                                                                        |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Social Acceptability                                 | An AGCV is expected to be perceived more favourably compared to an ECM due to the perception that it is safer                          |  | An AGCV is expected to be perceived more favourably compared to an ECM due to the perception that it is safer. Further, operation of an AGCV generates minimal leachate requiring treatment, and may therefore also be perceived to be preferable. |  |
| Public Health & Safety (construction and operations) | Both alternatives can be developed in a manner that protects public health and safety in during construction and operations.           |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |
| Public Health & Safety (long-term)                   | Both alternatives can be developed in a manner that protects public health and safety in the long-term.                                |                                                                                     |                                                                                                                                                                                                                                                    |                                                                                       |

| Criteria                       | Engineered Containment Mound (ECM)                                                                   | Above-ground Concrete Vaults (AGCV)                                               |                                                                                          |                                                                                     |
|--------------------------------|------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Environmental Effects (cont'd) |                                                                                                      |                                                                                   |                                                                                          |                                                                                     |
| Human Health and Safety        |                                                                                                      |                                                                                   |                                                                                          |                                                                                     |
| Worker Health & Safety         | Reduces unnecessary processing and packaging which decreases potential exposure and risk to workers. |  | All waste will require packaging which increases potential exposure and risk to workers. |  |

Notes:



### 5.1.4 Engineered Containment Mound Elevation

In relation to the near surface disposal designs referenced in IAEA guidance (SSG-29) [5-12], CNL considers the NSDF design to be an engineered structure constructed just below the ground surface but extending above the ground surface. However variations in the ECM floor elevation were evaluated as part of the design optimization completed for NSDF [5-26]. Three ECM floor elevation alternatives were developed and evaluated to determine the preferred ECM floor elevation. The three alternatives for elevation of the floor of the ECM were considered for the NSDF Project:

1. Lower floor elevation.
2. Higher floor elevation.
3. Mid-level floor elevation.

The NSDF Design Requirements [5-27] also includes the following specific functional requirements of the ECM:

- The overall design of the ECM will be compatible with CRL site topography. The geometric profile and height of ECM shall be designed to ensure that ECM is not visible either from Ottawa River, plant road or CRL campus.
- The base of the ECM (i.e., top of the primary liner) shall be designed to maintain a minimum of 1.5 m above the seasonal high groundwater table.

#### 5.1.4.1 Lower ECM Floor Elevation

The first alternative for the ECM design establishes the floor elevation to keep berm below the sight line from the CRL campus, which will require blasting existing rock outcrop.

##### 5.1.4.1.1 Technical Feasibility

Material and blast bedrock will be excavated to achieve specified base grades for constructing the ECM containment system. Excavation and blasting of bedrock keeps the berm heights lower and the elevation of the top of the ECM near the ridgeline at an elevation approximately 1 m below the sight line from the CRL campus. The rock blasting could occur at one time for the entire ECM footprint. Effective design and controls of the rock-blasting program can minimize vibrations and reduce environmental impacts. Rock removal will be performed for the entire ECM footprint, expansion can then occur in the future without additional blasting.

However due to the seasonal groundwater elevations across the NSDF site, as well as the NSDF footprint constraints, this alternative would result in construction of the ECM into the groundwater table. An under-drain system could be installed to maintain the shallow groundwater table below the base liner system. However the under-drain system would require a passive groundwater controls that require minimum maintenance and consideration for possible climate change over the next 500 years; thus introducing significant design, construction and maintenance complexities. As such the lower ECM floor elevation was eliminated from consideration for CNL's NSDF design primary due to the CRL site characteristics combined with the required storage capacity and footprint constraints.

Additionally the public has also repeatedly expressed concerns with respect to protection of the groundwater, thus the design requirement of an ECM above the groundwater elevation table is reflective of public input into the design.

#### **5.1.4.1.2 Economic Feasibility**

This alternative is relatively the least expensive option compared to the other two ECM floor elevation designs since there is a cost savings from the utilization of site generated fill rather than importing materials.

#### **5.1.4.2 Higher ECM Floor Elevation**

The second alternative for the ECM design establishes the floor elevation to eliminate bedrock removal.

##### **5.1.4.2.1 Technical Feasibility**

Site work would include clearing and grubbing of the ECM footprint area and placing and compacting engineered fill to create a compacted earthen subgrade layer up to 8 m above bedrock. Due to the footprint constraints this would raise the overall elevation of the ECM. The ECM would exceed the elevation of the sight line from the CRL campus by approximately 10 meters, therefore making the ECM visible from the CRL campus thus, not meeting the NSDF design requirements. As captured in Appendix R of the Stakeholder Engagement Report [5-28], several comments from the public expressed concerns with respect to the overall height of the facility which led to CNL's commitment that the Facility would not be visible from the Ottawa River. As such, the higher ECM floor elevation was eliminated from consideration for CNL's NSDF design primary due to the CRL site characteristics combined with the required storage capacity and footprint constraints.

Furthermore the purpose of keeping a geometric profile compatible with the CRL site topography is to ensure the facility evolves uniformly with its surroundings. An ECM completely above ground surface will likely experience higher risks through exposure to the potentially detrimental external natural processes and events (e.g., seismic events, erosion, physical instability of the site/mound) affecting the disposal facility, which may degrade the containment and isolation capacity over shorter periods of time. A facility design with a higher topography will require significantly taller embankments triggering stability issues thus potentially requiring designed reinforcement. The berms of such a design would also require more material, thus increasing the area needed for the construction of the ECM.

##### **5.1.4.2.2 Economic Feasibility**

This alternative is relatively more expensive than the other two ECM floor elevation designs due to the increased cost of subgrade preparation and berm construction.

### **5.1.4.3 Mid-level ECM Floor Elevation**

The third alternative for the ECM design establishes the floor elevation to minimize impact of berm from the CRL campus sight line and eliminate the need for an underdrain system.

#### **5.1.4.3.1 Technical Feasibility**

Excavate material and blast bedrock to achieve specified base grades for constructing the ECM containment system. Excavation and blasting of bedrock keeps the berm heights lower and the elevation of the top of the ECM near the ridgeline at an elevation approximately 3 m below the sight line from the CRL campus. The rock blasting will occur at one time for the entire ECM footprint. Effective design and controls of the rock-blasting program will minimize vibrations and reduce environmental impacts. Rock excavation may be performed in the winter prior to beginning berm construction. Rock removal will be performed for the entire ECM footprint, expansion can then occur in the future without additional blasting. This design accommodates all NSDF design requirements and satisfies the storage capacity required thus, has been deemed technically feasible.

#### **5.1.4.3.2 Economic Feasibility**

Although this alternative is relatively more expensive than the lower ECM floor elevation, it is less expensive than the higher ECM floor elevation.

#### **5.1.4.4 Rationale**

Of the three alternatives assessed for the ECM floor elevation, two of the alternatives (i.e., lower ECM floor elevation and higher ECM floor elevation) cannot meet the NSDF design requirements as well as accommodate the 1 000 000 m<sup>3</sup> of LLW storage capacity within the NSDF footprint which reflects the required wetland setbacks. Thus for this reason, as well as others captured above, the lower and higher ECM floor elevations have been deemed technically not feasible. The mid-level floor elevation was selected as the preferred ECM design, because this alternative is compliant with design requirements, reduces the impact to the groundwater level table and addresses social acceptability considerations.

### **5.1.5 Facility Location**

A few of the factors affecting siting decisions for radioactive disposal include national policies, scale of geography, and volumes of waste to be disposed. The Canadian Federal government has chosen not to mandate a national repository for disposal of LLW and ILW radioactive wastes, and this policy has implications for disposal choices for various waste owners. Nonetheless, the different approaches in siting or design of the disposal facility will always consider of the level of risk the respective waste inventory poses for current and future generations. For example, long-lived radioactive inventories require substantially more collaboration with the public due to the associated hazard and uncertainties of future land use planning. Whereas siting decisions for short-lived radioactive inventories, which decay within approximately 100 years to ranges representative of naturally occurring materials, necessitate less public involvement if reasonable land-use planning by the owner can be demonstrated within the timeframe of decay.

Atomic Energy of Canada Limited and CNL's preference for a LLW disposal was a technically feasible site on lands currently under AECL ownership and CNL control, ideally close to the location of generation and/or storage of the waste and in an area that is already covered by a nuclear licence.

Previous endeavours by AECL in planning and siting for radioactive waste disposal had already deemed the CRL site technically sufficient. The CRL site is the most suitable host site for AECL/CNL's LLW disposal due to its complex history (e.g., past waste management practices) and the vast majority of waste is already at or will be generated at the CRL site thereby, significantly reducing the need for transportation. Low-level waste is by far the largest volume among radioactive waste categories (i.e., in the millions of cubic meters), thus facility siting must underpin the impact of transportation. Similar to national research sites in the US, the CRL site is fairly complex with higher levels of environmental contamination and large volumes of waste; thus, amalgamation of the associated liabilities at this location is practical. As the owner of the CRL site and associated liabilities, AECL (a federal Crown corporation) will continue to put in place measures to ensure that the site is managed and controlled (e.g., restricting the land use of the NSDF Project footprint) for as long as necessary.

Canadian Nuclear Laboratories also considered locating the Facility at alternative sites owned by AECL for the Government of Canada and operated by CNL, specifically WL in Pinawa, Manitoba, and the NPD prototype reactor site in Rolphton, Ontario. The land at these sites is controlled by CNL and are likely to have suitable technical characteristics to safely manage the waste. The non-CRL options are more likely to raise public concerns related to transportation safety of larger volumes of LLW radioactive wastes. Also, both WL and NPD are scheduled to be closed within the next decade, and therefore, will not have the services and management infrastructure required to safely and securely operate the NSDF.

This section evaluates the proposal of disposing waste at sites owned by AECL either on-site at CRL or off-site at WL or NPD. When evaluating the technical feasibility of the facility location, many of the criterion can be satisfied by both alternatives.

#### **5.1.5.1 On-site location at Chalk River Laboratories**

The CRL site (approximately 4 000 ha), extends approximately 6.5 km inland from the Ottawa River. The controlled WMAs are located within the CRL site. The CRL main campus contains the majority of buildings, laboratories, and nuclear facilities on-site and is located adjacent to the Ottawa River.

##### **Technical Feasibility**

More than 90% of the CNL waste to be managed in the ECM is already on the CRL site thereby, reducing the distance the waste needs to be transported.

Subsurface investigations on the CRL site have concluded that the geology on site is acceptable for the construction and operation of an ECM. The surface geology of the CRL site is composed of four basic types of glacial and post glacial sediments including till, water deposited sands (fluvial), wind deposited (aeolian) sands and organic deposit.

Access within the CRL site is well established and upgrades required for heavy equipment and truck traffic would be minimal. Mandatory services (i.e., Class IV power, water for sanitary and process requirements, gas or other heating sources) are also readily accessible. A robust environmental monitoring program is already in place at the CRL site and the monitoring requirements specific to the NSDF Project could be incorporated into this program.

##### **Economic Feasibility**

The total life cycle cost of an NSDF facility on the CRL site is approximately \$750 million.

### 5.1.5.2 Off-site Location (CNL Sites excluding Chalk River Laboratories)

The non-CRL off-site locations selected for the alternative means evaluation are those operated by CNL: WL in Pinawa, Manitoba, and the Prototype Reactor Site NPD in Rolphton, Ontario.

#### Technical Feasibility

Both WL and NPD sites have sufficient area available on-site to accommodate the construction and operation of a NSDF facility with a storage capacity of 1 000 000 m<sup>3</sup>. In addition, both locations may be geologically suitable sites for a NSDF.

Both NPD and WL sites are scheduled to be decommissioned within the next decade. As a result, these sites would need to continue to provide the physical services (i.e., Class IV power, water for sanitary and process requirements, gas or other heating sources, or other nuclear operating infrastructure) and management infrastructure required to support the operation of the NSDF for the 50 year operating period. Both sites have robust environmental monitoring programs in place, but would need to be expanded to address the additional requirements of a NSDF. Shipping of the waste to NPD or WL by transport truck and/or rail is a feasible option.

#### Economic Feasibility

Both alternatives are assumed to have similar capital costs for site characterization needed to confirm the suitability for a NSDF. Operational costs would be higher for an off-site facility as the majority of the wastes are located at CRL and would require packaging and transportation. Approximately 90% of the proposed waste for the NSDF Project originate from the CRL site and would require off-site transport. In addition, management and maintenance of services would be higher for sites that would be otherwise decommissioned. Overall, the costs associated with transporting radioactive waste to an off-site facility makes this alternative less favourable. Eventual closure of the NSDF Facility and post closure monitoring and maintenance costs are assumed to be similar for both alternatives.

### 5.1.5.3 Impacts

The CRL site is located in the Central Gneiss belt of the Grenville Structural Province of the Canadian Shield. The bedrock consists of highly altered gneissic rock and felsic igneous rock of late Precambrian-early Paleozoic age. The overburden of the CRL site consists of boulder, silty sand till deposited during the most recent glaciation, overlain with fine to medium sands. The till contains a wide range of size fractions, from large blocks of rock to fine silts and clay. The general geology of the region is the Precambrian shield with old folding and faulting of the metamorphic rocks (gneiss).

The surface of the NPD site is covered by a boulder pavement (i.e., large boulders), which in most areas has been left as a result of water scouring the area and removing the finer fraction of the river-lain sediments. The base rock is quartz and granite gneiss with some overburden of alluvial sand and gravel. The small amount of overburden and relatively steep incline of the base rocks makes ground and subsurface water run-off very quickly to the river.

At the WL site, the regional surficial geology comprises widespread deposits of till and glacio-fluvial and glaciolacustrine materials. The stratigraphic units in sequence from bedrock upwards are silty sand till, clayey silt till, silty clay and an upper soil complex comprised of laminated clayey silt with minor interbeds of massive silty clay and finally surface organics.

Subsurface investigations on the CRL site have concluded that the geology on site is acceptable for the construction and operation of an ECM. Both WL and NPD locations may be geologically suitable sites for a NSDF. It is expected that a Facility could be constructed safely at either of the locations based on similar geology at the sites.

All three sites support a diverse mix of upland and wetland habitats. Vegetation on the CRL site includes deciduous and coniferous forest and a wide variety of plant species, including eight provincial species at risk plant species. The NPD site is mainly wooded with the exception of open wetland areas. Wooded uplands generally range from 40 to 80 years old and wetlands are mainly found on the western half of the NPD site.

The WL site is primarily under treed cover, consisting of a mixture of wetlands and forests of broadleaf, mixed and coniferous stand types. A large area contains a complex of bog, fen and swamp wetlands spanning the center and east portions of the WL site. The disturbance footprint of the NSDF would be similar for all sites, and similar mitigation would be implemented to reduce or limit effects to the terrestrial biodiversity. For example, the disturbance footprint would be designed to avoid wetlands and limit disturbance to the natural environment to the extent feasible.

Wildlife species found on the CRL and NPD sites are generally typical for a boreal region in Ontario. At the CRL site, a total of 23 federal and/or provincial species at risk have been confirmed including four species of turtles, three species of bats, several forest songbirds, eastern milksnake (*Lampropeltis triangulum*), western chorus frog (*Pseudacris triseriata*), and monarch butterfly (*Danaus plexippus*) (Species at Risk Act Schedule 1: List of Wildlife Species at Risk; O.Reg. 230/08 Species At Risk In Ontario List).

Seven federal species at risk (Species at Risk Act, Schedule 1: List of Wildlife Species at Risk) have been confirmed on the overall NPD site: little brown myotis (*Myotis lucifugus*), northern myotis (*Myotis septentrionalis*), eastern milksnake, monarch butterfly, and three bird species, eastern wood-pewee (*Contopus virens*), common nighthawk, (*Chordeiles minor*) and, most notably, chimney swift (*Chaetura pelagica*).

Over 50 species of mammals can be expected to be found around the WL site; many of the mammals are common and widespread. The Winnipeg River is an important migratory corridor for many bird species and there are important bird migration staging areas on, or near the WL site, centering on the Winnipeg River. Five federal species at risk have been confirmed on the overall WL site, including little brown myotis, northern myotis, snapping turtle (*Chelydra serpentina*), Canada warbler (*Wilsonia canadensis*) and barn swallow (*Hirundo rustica*).

Although the footprint for each alternative would be similar, the wildlife habitat potentially affected is different. A portion of the CRL site has identified critical habitat for Blanding's turtle (*Emydoidea blandingii*), whereas there is no critical habitat identified by Environment and Climate Change Canada at the WL or NPD sites with the exception of a stack at the NPD site which is proposed critical habitat for chimney swift. However, as mentioned above, the disturbance footprint would be designed to avoid wetlands and limit disturbance to the natural environment to the extent feasible. Other potential effects are similar between the alternatives and include short term sensory effects of noise on bats and songbirds, and increased injury and mortality to wildlife from traffic, particularly turtles. Mitigation to be implemented is standard at all CNL sites and includes, for example, implementation of a Blasting Plan and enforcement of reduced speed limits on-site, respectively.



The Ottawa River is the dominant drainage feature in the area for both the CRL and NPD sites, and all surface drainage on these sites ultimately drains to the river. The CRL and NPD sites are located in the Allumette Lake and Lac Coulonge reach of the Ottawa River, which extends approximately 90 km between La Passe and the Des Joachims hydroelectric dam. The Ottawa River supports diverse warm-water and cool-water fish communities consisting of at least 85 documented species. Typical catches from the Ottawa River include Walleye (*Sander vitreus*), Northern Pike (*Esox lucius*), Channel Catfish (*Ictalurus punctatus*), Smallmouth Bass (*Micropterus dolomieu*) and Lake Sturgeon (*Acipenser fulvescens*), Channel Catfish being the most abundant. The provincial and federal fish Species At Risk in the Ottawa River are American Eel (*Anguilla rostrata*), Lake Sturgeon, Northern Brook Lamprey (*Ichthyomyzon fossor*), and River Redhorse (*Moxostoma carinatum*). Fish in inland lakes on the CRL site include Pumpkinseed (*Lepomis gibbosus*), Northern Pike, bass species, and Yellow Perch (*Perca flavescens*). Minnow species such as shiner, dace, and chub are abundant in streams and lakes on the CRL site.

The Winnipeg River is the dominant drainage feature in the area of the WL site, where all surface water runoff drains into the Winnipeg River. The Winnipeg River supports a variety of forage fish species such as carp and minnow species. Predator fish in the area include Walleye, Northern Pike, Smallmouth Bass, mooneye species, and Lake Trout (*Salvelinus namaycush*). The Carmine Shiner (*Notropis percobromus*), listed as Threatened under the Species at Risk Act, is likely to occur in the vicinity of WL site. No differences are anticipated between the alternatives as mitigation would be implemented to reduce or eliminate effects to aquatic diversity. For example, regardless of whether or not the facility is constructed and operated on-site or off-site, leachate from the ECM would be collected and treated via a WWTP prior to discharge to the receiving environment.

Shipping nearly 1 000 000 m<sup>3</sup> of waste from CRL to WL or the NPD site, at an average of 20 m<sup>3</sup> of waste per truck, would result in 50 000 shipments. The potential environmental effects of transporting such large volumes by truck will be greater than disposal in an on-site facility at CRL. The off-site transport of large amounts of radioactive waste on public roads (i.e., 50 000 shipments travelling roughly 1 900 km from CRL to WL or 35 km from CRL to NPD) may raise perceived safety concerns amongst the public.

#### **5.1.5.4 Rationale**

The comparative evaluation between facility location alternatives is provided in Table 5-6. All three sites are anticipated to have the suitable geology and area needed for the safe construction and operation of a NSDF. Building a disposal facility on the CRL site has the advantages of being closest to future decommissioning waste and legacy waste stored at CRL WMAs. The associated cost of transporting waste to a facility at CRL is considerably less than transporting the waste to a WL or NPD location. Moreover, the non CRL options are more likely to raise public concerns related to transportation safety of large volumes of LLW radioactive wastes. Both WL and NPD are scheduled to be closed within the next decade, and therefore, will not have the services and management infrastructure required to safely and securely operate the NSDF. As such, WL and NPD off site locations are less favourable.

**Table 5-6**  
**Evaluation of Alternatives – Facility Location**

| Criteria                                   | Alternative 1 – On-site at CRL                                                                                                                                                                                                                    | Alternative 2 – Off-site at Non-CRL sites                                           |                                                                                                                                                                                              |                                                                                                                                                                                                           |
|--------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Technical Feasibility                      |                                                                                                                                                                                                                                                   |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Project Purpose                            | The CRL site satisfies the project purpose and allows for the planned decommissioning and site restoration activities and reduces liabilities and the cost of CNL operations to taxpayers.                                                        |    | As closure is planned at WL and NPD and will be completed within the next decade, these sites are not considered technically feasible without continuation of the support services required. |                                                                                                                        |
| Storage Capacity                           | Both alternatives have sufficient area available to develop a facility with a storage capacity of 1,000,000 m³.                                                                                                                                   |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| An Example of Best Available Technology    | Both alternatives would be using the same best available technology for the NSDF design.                                                                                                                                                          |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Design Robustness                          | Design requirements would be the same for a NSDF facility at CRL or off-site.                                                                                                                                                                     |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Monitoring Complexity                      | Robust monitoring is currently in place at the CRL site which can be expanded to accommodate any additional monitoring requirements for the NSDF.                                                                                                 |    | Both sites have monitoring programs in place. Additional resources may be required to implement monitoring for a NSDF during the 50 year operating period at these sites.                    |                                                                                                                        |
| Economic Feasibility                       |                                                                                                                                                                                                                                                   |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Life Cycle Costs                           | Total life cycle costs are estimated to be approximately \$750 million for a facility on the CRL site.                                                                                                                                            |  | Operations costs would be much higher at a non-CRL site as a result of the additional packaging and transportation of waste off-site that would be required.                                 | <br>(WL site)<br><br>(NPD site) |
| Environmental Effects                      |                                                                                                                                                                                                                                                   |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Biophysical                                |                                                                                                                                                                                                                                                   |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Atmospheric Environment                    | Decreased air emissions and greenhouse gases as most of the waste to be disposed in the NSDF is from the CRL site.                                                                                                                                |  | Additional transportation of waste would result in increased air emissions and greenhouse gases.                                                                                             |                                                                                                                      |
| Geological and Hydrogeological Environment | Subsurface investigations on CRL site have concluded that the geology on-site is acceptable for the construction and operation of an ECM.                                                                                                         |  | Geotechnical investigations to support in-situ disposal have been conducted at both WL and NPD and confirm that these sites are suitable for an NSDF type facility.                          |                                                                                                                      |
| Surface Water Environment                  | No differences are anticipated between the alternatives; all three sites are located within close proximity to a major water feature (i.e., Winnipeg River or Ottawa River).                                                                      |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Aquatic Biodiversity                       | No differences are anticipated between the alternatives.                                                                                                                                                                                          |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Environmental Effects (cont'd)             |                                                                                                                                                                                                                                                   |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Biophysical (cont'd)                       |                                                                                                                                                                                                                                                   |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |
| Terrestrial Biodiversity                   | Critical habitat for species at risk have been identified at CRL, whereas it is not at WL or NPD. However, the disturbance footprint would be designed to avoid wetlands and limit disturbance to the natural environment to the extent feasible. |  | No critical habitat for species at risk is present on the NPD or WL site with the exception of a stack at the NPD site which is proposed critical habitat for chimney swift.                 |                                                                                                                      |
| Ecological Health                          | No differences are anticipated between the alternatives.                                                                                                                                                                                          |                                                                                     |                                                                                                                                                                                              |                                                                                                                                                                                                           |

| Criteria                                             | Alternative 1 – On-site at CRL                                                                                                                                                                                       |                                                                                    | Alternative 2 – Off-site at Non-CRL sites                                                                                                                   |                                                                                      |
|------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Social                                               |                                                                                                                                                                                                                      |                                                                                    |                                                                                                                                                             |                                                                                      |
| Socio-economics                                      | New employment and business opportunities associated with the NSDF Project.                                                                                                                                          |   | New employment and business opportunities associated with the NSDF Project.                                                                                 |   |
| Land and Resource Use                                | No off-site transport of waste required therefore minimizing energy use.                                                                                                                                             |   | Transport of waste is an energy intensive activity.                                                                                                         |   |
| Social Acceptability                                 | Most waste to be disposed is already located at the CRL site which limits the transportation of waste off-site and is expected to be more acceptable to the public and Indigenous peoples compared to Alternative 2. |   | The off-site transport of large amounts of radioactive waste on public roads may raise perceived safety concerns amongst the public and Indigenous peoples. |   |
| Human Health and Safety                              |                                                                                                                                                                                                                      |                                                                                    |                                                                                                                                                             |                                                                                      |
| Public Health & Safety (construction and operations) | Most waste to be disposed is already located at the CRL site which limits the transportation of waste off-site.                                                                                                      |   | The off-site transport of large amounts of radioactive waste on public roads may raise perceived safety concerns amongst the public.                        |   |
| Public Health & Safety (long-term)                   | Transport of waste on public roads is minimized reducing the risk of traffic accidents                                                                                                                               |  | Higher risk of traffic accidents from transport of waste on public roads (50,000 trips)                                                                     |  |
| Worker Health & Safety                               | Both alternatives can be developed in a manner that protects worker health and safety.                                                                                                                               |                                                                                    |                                                                                                                                                             |                                                                                      |

### 5.1.6 Site Selection

The selection process for the siting of the NSDF at CRL included the identification of 15 potential sites within the CRL site for initial screening. This screening process included the development of mandatory criteria that must be satisfied by candidate locations; mandatory criteria included:

- Minimum area of 14 ha.
- Site must be at least 200 m wide.
- Access to Class IV electricity for power.
- Access to water for sanitary and process requirements.
- Access to gas or other heating source.

Exclusion criteria were then applied to remove any locations that were constrained by NSDF Project requirements or by pre-defined factors; exclusion criteria were physical, cultural, and biological features that would eliminate a location from the list of potential sites because development is either not permitted or poses a risk for the intended use/project [5-29]. Exclusion criteria included:

- Ottawa River Floodplain:
  - Areas which are below the 1 in 100 year Ottawa River flood elevation of 115 metres above sea level (mASL).
  - Areas that are below the flood elevation of 130 mASL which would result from a hypothetical failure of the Des-Joachims hydroelectric dam and McConnell Lake Control Dam.
- Areas with a slope in excess of 25%; areas with a slope of less than 10% are desirable.
- Areas within 50 m of Plant Road. The three key reasons for this setback are:
  - Protection of CRL workers in transit on Plant Road during waste placement.
  - Limiting visibility of structures from Plant Road.
- Geotechnical Characteristics:
  - Areas with outcrops and organics less than 20% of the proposed siting area.
  - Areas with liquefaction potential and active fault lines.
- Species at Risk:
  - Areas of nationally or provincially significant plant or tree species, in small groups or stands, in accordance with the Federal Species at Risk Act and habitat of those threatened or endangered species as per the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) listing. Research plantations at CRL may contain these species.
  - Known or likely habitats of national or provincially significant wildlife species in accordance with the Federal Species at Risk Act or COSEWIC listing as per guidance by CNL Environmental Protection.
- Wetlands:
  - Areas that are seasonally or permanently inundated with water.
  - Areas within 30 m from watercourses or wetlands.
  - Located adjacent to provincially registered archaeological sites.
- Areas within 100 m from existing CRL site boundaries.
- Sites of existing or previously sited facilities.

Table 5-7 summarizes the candidate sites and provides rationale for the exclusion of select sites, and identifies those sites carried forward for further evaluation based on the mandatory and exclusion criteria listed above. Two candidate locations were identified for further evaluation after the application of the mandatory attribute criteria and the exclusion criteria; 1) the East Mattawa Road (EMR) site; and 2) the Alternate site (11A). The locations of the two sites are shown on Figure 5-1 and described below. When evaluating the technical feasibility of the facility location, many of the criterion can be satisfied by both alternatives. For example, both alternatives can be constructed such that they meet the purpose of the NSDF Project and both alternatives can be constructed to accommodate 1 000 000 m<sup>3</sup> of LLW. Key differences in the alternatives are primarily related to monitoring complexity, life cycle costs and potential environmental effects; as such, the evaluation focuses on these criterion.

**Table 5-7**  
**Potential Sites for the Project Considered by CNL**

| Site Number | Description                                                                                                                                                                                                                                                                                                                                                                                                                                         | Rationale for Exclusion or Inclusion                                                                                                                 |
|-------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1           | <ul style="list-style-type: none"> <li>42 ha in size;</li> <li>Located at the north end of the CRL site; and</li> <li>Located in the Balmer Bay drainage basin.</li> </ul>                                                                                                                                                                                                                                                                          | Excluded: <ul style="list-style-type: none"> <li>Less than 100 m from the CRL site boundary</li> </ul>                                               |
| 2           | <ul style="list-style-type: none"> <li>31 ha in size;</li> <li>Located at the north end of the CRL site;</li> <li>Several areas of exclusion (i.e., small ponds and archaeological sites) interspersed through the area;</li> <li>Hydro is available 0.4 km from the site;</li> <li>The site is located a long distance from Plant Road (5 km on Mattawa Road); and</li> <li>Located in the Maskinonge Lake / Balmer Bay drainage basins</li> </ul> | Excluded: <ul style="list-style-type: none"> <li>Located adjacent to recorded archaeological sites</li> </ul>                                        |
| 3           | <ul style="list-style-type: none"> <li>24 ha in size;</li> <li>Located at the south west boundary of the CRL site; and</li> <li>Located in the Chalk Lake West drainage basin.</li> </ul>                                                                                                                                                                                                                                                           | Excluded: <ul style="list-style-type: none"> <li>Less than 100 m from the CRL site boundary.</li> </ul>                                              |
| 4           | <ul style="list-style-type: none"> <li>17 ha in size;</li> <li>Located at the south west boundary; and</li> <li>Located in the Chalk Lake West drainage basin.</li> </ul>                                                                                                                                                                                                                                                                           | Excluded: <ul style="list-style-type: none"> <li>Less than 100 m from the CRL site boundary.</li> </ul>                                              |
| 5           | <ul style="list-style-type: none"> <li>12 ha in size;</li> <li>Area is interrupted by a small stream;</li> <li>No access road from within the 300 m distance;</li> <li>Approximately 4.3 km from Plant Road;</li> <li>The area is generally flat or gently sloping;</li> <li>Number of woodland pools throughout; and</li> <li>Located in the Maskinonge Lake / Balmer Bay drainage basin.</li> </ul>                                               | Excluded: <ul style="list-style-type: none"> <li>Area is less than 14 ha and not considered large enough to accommodate the NSDF Project.</li> </ul> |
| 6           | <ul style="list-style-type: none"> <li>12 ha in size;</li> <li>Located at the north end of the CRL site; and</li> <li>Located in the Ottawa River watershed.</li> </ul>                                                                                                                                                                                                                                                                             | Excluded: <ul style="list-style-type: none"> <li>Area is less than 14 ha and not considered large enough to accommodate the NSDF Project.</li> </ul> |
| 7           | <ul style="list-style-type: none"> <li>11 ha in size;</li> <li>Located adjacent to the Mattawa Road and close to Plant Road;</li> <li>Large areas of exclusion (wetland areas) along the north-east edge;</li> <li>Hydro is available at the site; and</li> <li>Located in the Perch Creek and Perch Lake Watershed.</li> </ul>                                                                                                                     | Excluded: <ul style="list-style-type: none"> <li>Area is less than 14 ha and not considered large enough to accommodate the NSDF Project.</li> </ul> |
| 8           | <ul style="list-style-type: none"> <li>10 ha in size;</li> <li>Access to the site is poor (an old logging road which is not maintained is the only existing access);</li> <li>The closest road is approximately 500 m (Bass Lakes Road);</li> <li>The site is surrounded by wetlands and surface ponds, which interrupt the usable areas; and</li> <li>Located in the Maskinonge Lake drainage basin.</li> </ul>                                    | Excluded: <ul style="list-style-type: none"> <li>Area is less than 14 ha and not considered large enough to accommodate the NSDF Project.</li> </ul> |

| Site Number                               | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Rationale for Exclusion or Inclusion                                                                                                                                                                                       |
|-------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 9                                         | <ul style="list-style-type: none"> <li>10 ha in size;</li> <li>Site is interrupted by areas of wetlands and much of the site is covered by wetlands;</li> <li>Adjacent areas are not considerably above the wetland elevation; therefore, the site is prone to flooding;</li> <li>Hydro is available within 1 km of the site; and</li> <li>Located in the Perch Lake / Maskinonge Lake drainage basins.</li> </ul>                                                                                                                                                                | <p>Excluded:</p> <ul style="list-style-type: none"> <li>Area is less than 14 ha and not considered large enough to accommodate the NSDF Project.</li> </ul>                                                                |
| 10                                        | <ul style="list-style-type: none"> <li>The site is 10 ha in size;</li> <li>Located at the north end of the CRL site; and</li> <li>Located in the Balmer Bay drainage basin.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                            | <p>Excluded:</p> <ul style="list-style-type: none"> <li>Area is less than 14 ha and not considered large enough to accommodate the NSDF Project.</li> </ul>                                                                |
| 11                                        | <ul style="list-style-type: none"> <li>The site is 8 ha in size;</li> <li>There is hydro available approximately 1.2 km from the site;</li> <li>The site is 2.2 km from the Plant Road and 3.4 km from WMA B; and</li> <li>Located in the Chalk Lake East drainage boundary.</li> </ul>                                                                                                                                                                                                                                                                                           | <p>Excluded:</p> <ul style="list-style-type: none"> <li>Area is less than 14 ha and not considered large enough to accommodate the NSDF Project.</li> </ul>                                                                |
| 11A (Alternate Site)                      | <ul style="list-style-type: none"> <li>The site is 40 ha in size;</li> <li>Slope is greater than 10% in some areas of the site;</li> <li>There is a small pond at the north end of the site;</li> <li>Several woodland pools are present on the site;</li> <li>There is hydro available approximately 2.2 km from the site at the Plant Road;</li> <li>The site is 3.4 km from WMA B;</li> <li>Portion of the site is partially located in Blanding's turtle potential candidate critical habitat zone; and</li> <li>Located in the Chalk Lake East drainage boundary.</li> </ul> | <ul style="list-style-type: none"> <li>Carried forward for further analysis.</li> </ul>                                                                                                                                    |
| 12                                        | <ul style="list-style-type: none"> <li>The site is 8 ha in size;</li> <li>Access to the site is poor (an old logging road which is not maintained is the only existing access);</li> <li>The site is surrounded by areas of bog (organic material) and surface water (ponds, marshes, etc.) which interrupt the usable areas; and</li> <li>Located in the Maskinonge Lake drainage boundary.</li> </ul>                                                                                                                                                                           | <p>Excluded:</p> <ul style="list-style-type: none"> <li>Area is less than 14 ha and not considered large enough to accommodate the NSDF Project.</li> </ul>                                                                |
| Sand Trench Disposal Facility (STDF) Site | <ul style="list-style-type: none"> <li>Centrally located within the CRL site;</li> <li>The site is bounded by wetland (bog), Twin Lakes, 233 Lake, and the Nitrate Plant and associated plume;</li> <li>The site overlaps critical Blanding's turtle habitat and is adjacent to a Great Blue Heron colony, a protected species under the Migratory Birds Convention Act;</li> <li>Located in the Maskinonge Lake drainage boundary.</li> </ul>                                                                                                                                    | <p>Excluded:</p> <ul style="list-style-type: none"> <li>This area contains habitat of significant wildlife species (Blanding's Turtles);</li> <li>The site is not large enough to accommodate the NSDF Project.</li> </ul> |
| East Mattawa Road (EMR) Site              | <ul style="list-style-type: none"> <li>The site has a capacity of &gt;30 ha in size;</li> <li>Close proximity to the CRL main campus;</li> <li>Water service, natural gas and power sources are available in close proximity;</li> <li>Located in the Perch Creek and Perch Lake Watershed.</li> <li>Located in close proximity to the Perch Lake Swamp wetlands;</li> </ul>                                                                                                                                                                                                      | <ul style="list-style-type: none"> <li>Carried forward for further analysis</li> </ul>                                                                                                                                     |

### **5.1.6.1 East Mattawa Road**

In general terms the EMR site is located on a ridge that slopes away from the Ottawa River and towards the Perch Lake Basin, approximately 1.1 km from the Ottawa River and 500 m from the CRL main campus and is approximately 34 ha in size (Figure 5-1). The northern boundary abuts Power Line Road and the southern boundary is just short of ER-3 Road and the Perch Lake Ring Road. On the western side, a 30 m setback from the Perch Lake Swamp wetlands forms the site boundary and to the east a local ridge line of the Ottawa Valley forms the boundary. The site boundary to the north is forested land between the hydro corridor and Plant Road. To the west and south is a low lying marsh area, with the existing WMA A and B further northwest. The South East Mattawa Road leads to ER-3 Road and the Perch Lake Ring Road. To the east is forested land, which drops down to the main CRL site on the opposite side of the ridge.

#### **Technical Feasibility**

East Mattawa Road is one of three existing designated emergency evacuation routes from the CRL main campus. Access to the site is provided by both the Plant Road and the Emergency Route #3 (ER-3 Road). Both access routes are regularly travelled and subject to routine maintenance. Emergency Route #3 has been re-routed as part of a previously planned upgrade to this road. Overall, access to the EMR site is well established and upgrades required for heavy equipment and truck traffic to the NSDF would be minimal.

Mandatory services (i.e., Class IV power, water for sanitary and process requirements, gas or other heating sources) can be readily accessed for the EMR site. The EMR site is approximately 500 m from the CRL main campus, which is the source of CRL's decommissioning work that will generate much of the waste. Overall, the services required to support the NSDF Project are all located much more proximate to the EMR site. A potential water source could be taken from 500 m from the EMR site, and a natural gas pipeline is installed along Plant Road at the juncture of EMR site. The EMR site is located within the Perch Creek and Perch Lake Watershed, which has been impacted by plumes emanating from the WMA A and the Liquid Dispersal Areas (LDA). As such, extensive environmental studies of contaminant hydrogeology have been completed in the last 60 years and continue to be ongoing as part of CNL's existing Environmental Management Plan thus, a robust understanding of the Perch Creek and Perch Lake Watershed exists, and CNL has confidence in predictions of how radiological releases would behave. The Environmental Management Plan for the CRL site can easily be expanded to include monitoring and sampling locations for the NSDF Project.

#### **Economic Feasibility**

Both site areas' overburden is adequate and site clearing costs will be comparable between the sites as tree growth density characteristics are similar. Overall, the services required to support the NSDF are all located much more proximate to the EMR site. A potential water source could be taken from 500 m from the EMR site, and a natural gas pipeline is installed along Plant Road at the juncture of EMR.

### **5.1.6.2 Alternate Site**

The Alternate site is located within the Chalk Lake Basin, southeast of WMA F (Figure 5-1) and is approximately 37 ha in size. Access to the Alternate site is via the existing Port Hope Road, a narrow gravel road adjacent to the western border of the site. The existing access road to the site from the Plant Road is 2.2 km long and will require considerable upgrades to provide safe passage of heavy equipment and truck traffic.

### **Technical Feasibility**

Electricity is available from along the Plant Road, as well as natural gas from the pipeline recently installed on the CRL site, but are approximately 2.2 km from the Alternate site. Water service is available at the CRL main campus, but a new feed will be needed. The proposed tie-in to the water supply will be approximately 5 km from the Alternate site and a pipeline and pumping station would be needed to deliver water uphill to the Facility. Additional space is available to the area to the north of WMA F for use as lay down areas (currently used to store marine containers) or future facility expansion. Space is also available south of the Alternate site, close to the border with Garrison Petawawa.

The Alternate site is located in a greenfield area. As such, extensive modifications to CNL's existing Environmental Management Plan are needed to include monitoring and sampling locations for the NSDF Project, as there is a lesser understanding of site characteristics for the alternate site.

### **Economic Feasibility**

Both site areas' overburden is adequate and site clearing costs will be comparable between the sites as tree growth density characteristics are similar. The Alternate site will require considerable road upgrades for the 2.2 km route from the Plant Road to provide safe passage of heavy equipment and truck traffic. Electricity, natural gas and water supply would need to be brought in from a further away source. Overall, infrastructure costs are higher for the Alternate site as compared to the EMR site.

#### **5.1.6.3 Impacts**

The EMR site is located within the Perch Creek and Perch Lake Watershed, which has been impacted by groundwater plumes emanating from the WMA A and the LDAs. Extensive environmental studies have been completed in the Perch Lake Swamp wetland complex, located to the west of the EMR site, to characterize the existing radiological contamination in the soil and vegetation. Of particular interest are the adjacent legacy LDAs and WMA A, which discharge contaminated groundwater into the Perch Lake Swamp wetlands creating an environmentally impacted site. The EMR site is in close proximity to existing brownfield waste sites, and as such, consolidates land uses. The Chalk Lake Basin, within which the Alternative site is located, contains no operating facilities, WMAs, or any known contamination, and is therefore unaffected by CRL activities. The WMA F is the nearest WMA located approximately 1.5 km the north of the Alternate site, in the Maskinonge Lake basin. The Alternate site is in a greenfield area. There are no pre-existing plumes or contamination from WMAs in the vicinity of the Alternate site, thus introducing a new waste disposal area which is not contiguous with current CRL brownfield areas or impacted areas.

The EMR site is close to the CRL main campus, which is where the vast majority of waste from building decommissioning will be generated. The EMR site is approximately 4 km closer to the CRL main campus as compared to the Alternate site; trucks will travel approximately 6 to 7 km for delivering waste to the Alternate site from the CRL main campus. The increased transportation distance of wastes to the Alternate site would result in increased air emissions, and therefore greenhouse gases. Any dust created from the NSDF construction and operation on either site would be abated as per environmental protocols. Noise transmission to the CRL main campus will be mitigated by the topography as the EMR site is situated on the lower side of the hill facing inland. The Alternate site would not be visible to traffic on Plant Road or at the CRL main campus; noise is not anticipated to be an issue as the area is isolated.

In 2016, geotechnical surveys were completed at the EMR site [5-30]. Ground surface elevations range at the EMR site from a low of approximately 160 mASL within the low lying and relatively flat terrain bordering the



north side of Perch Lake, to a high of 196 mASL along the crest of the ridge to the east of Emergency Road #3 that separates the Perch Creek and Perch Lake Watershed and the Ottawa River watershed. The overburden thickness at the site typically ranges from approximately 0 to 10 m, depending on bedrock topography. The surficial geology consists primarily of sands, underlain by dense sandy silt till which contains some cobbles and occasional boulders. Organic soils (e.g., peat) have been deposited in the low lying and wetland areas.

Precipitation in the EMR site area recharges a shallow groundwater system that includes the overburden and the upper few metres of fractured bedrock. Groundwater levels range from about 0.5 m to more than 11.4 m depth, corresponding to elevations of between approximately 173 and 158 mASL. Groundwater flow directions reflect the site topography with the overall direction being southwesterly from the ridge bounding the east side of the site and semi radial from elevated lands within the bedrock bench. Within the low saturated lands to the west of the siting block, groundwater flow parallels the Perch Lake surface drainage. The crest of the ridge along the eastern side of the siting block is interpreted to roughly coincide with a groundwater (and surface water) divide between the Perch Creek and Perch Lake Watershed and the Ottawa River.

In 2014, geotechnical surveys were completed at the Alternate site ([5-30] [referred to as Block 11 in the report]). The Alternate site is reflective of the CRL site as a whole. The overburden thickness ranges from approximately 0 to 20 m depending on the bedrock topography. Generally, the overburden contains a thin layer of organic topsoil at the surface with a layer of loose sand, then compacted sand. The site is characterized by an undulating ground surface ranging from approximately 172 mASL in the east and northeast to a low of approximately 115 mASL in the wetland areas bordering Chalk (Sturgeon) Lake, which is located roughly 600 m to the southwest. Overall, the ground surface slopes to the west.

Precipitation falling on topographically high areas results in the recharge of the shallow scale groundwater system that includes the overburden and the upper few metres of fractured bedrock. Groundwater levels beneath the Alternate site range from about 0.5 m to more than 9 m depth, corresponding to elevations of between roughly 164 and 150 mASL. The southwestern part of the Alternate site is well drained, but much of the central portion of the area is low lying terrain resulting in with seasonal accumulations of surface water and saturated ground.

The proposed EMR site is 1.1 km from the main channel of the Ottawa River, but groundwater passing below it, discharges to Perch Creek before draining to the Ottawa River, providing a flowpath distance of about 2.6 km. It is the transit time through the groundwater portion of the flowpath however, that represents almost all of the average 7 year water residence time. By contrast, the Alternate site is about 3.5 km from the main channel of the Ottawa River, but about 850 m from Chalk Lake. Chalk Lake is a long narrow bay in the Ottawa River, and for the site evaluation it has been considered to be a part of the river. The groundwater residence time from the Alternate site to the location where the groundwater discharges to surface is about 2 years. Overland flow from the Alternate site's groundwater discharge area passes through a small lake (Toussaint) before discharging to Chalk Lake, but this only adds a few months of mean residence time. The predictions above are based on both measured and calculated data. The information for the EMR site is founded on observation of contaminant movement from the Reactor Pit #2 to Perch Lake and Perch Creek, (just west of the EMR site) over several decades, as well as calculations using groundwater gradients and soil characteristics arising from extensive study and site assessment. The predictions from the Alternate site are calculated based on gradient and soil characteristic data collected for the assessment of that site. In summary, the EMR site has a longer groundwater flow path and slower groundwater flow velocities over most of the flow path, compared to the Alternate site.

The EMR site is similar to the majority of the undisturbed forested areas of the CRL site in terms of terrestrial biodiversity. In the spring and summer of 2016, a biodiversity study was completed at both the EMR site and Alternate site. No butternut trees were found within the EMR site or in the surrounding area during the biodiversity surveys. Several bird species, including eastern whip-poor-will, eastern wood-pewee, wood thrush, golden winged warbler and the Canada warbler were observed in the vicinity of the EMR site. Four bat species were also detected including the little brown myotis, northern myotis, the tri-coloured bat and eastern small-footed myotis.

Extensive environmental studies have been completed in the Perch Lake Swamp wetland complex (located to the west of the EMR site) to characterize the existing radiological contamination in the soil and vegetation. These wetlands are home to Blanding's and snapping turtles. Biodiversity studies to date by CNL do not indicate that Blanding's turtles are making extensive overland movement in this area during their migration as no individuals have been sighted on the road in this location. Although the EMR site does not appear to fragment the Blanding's turtle habitat, development at the EMR site may encroach on some portion of the species terrestrial habitat. The EMR site is located immediately adjacent to the Perch Lake Swamp wetland and, therefore, has an increased potential for indirect effects on terrestrial species that use this habitat.

The Alternate site is similar to the majority of the undisturbed portion of CRL site in terms of terrestrial biodiversity. Several songbirds were observed during the 2016 biodiversity surveys including Canada warbler, eastern wood-pewee and eastern whip-poor-will. Bat surveys confirmed the presence of little brown myotis, northern myotis, and the tri-coloured bat and eastern small-footed myotis. Blanding's turtles have been observed using the adjacent wetlands habitat and crossing Port Hope Road during their spring migration. The Alternate site encroaches on the Blanding's turtles travelling corridor within the CRL site, which would potentially cause a slight fragmentation between habitats and may increase the potential for road mortality. No Butternut trees were observed during the biodiversity surveys.

Similar mitigation for both site locations would be required to limit effects to terrestrial biodiversity. Mitigation includes the protection of migration pathways for Blanding's turtles, installation of bat boxes, tree removal before and after the migratory bird nesting period and environmental awareness training for Contractor personnel. In addition, erosion and sediment control practices (e.g., silt fences, run-off management) already in place at the CNL property will be used during construction around disturbed areas, and existing programs such as CNL's Management of Land and Habitat Procedure will be implemented. As well, all work on the site would be subject to a Species At Risk Act permit.

There are six archaeological sites previously recorded within 1 km of EMR site, but none are located directly within the proposed footprint. An archaeological assessment was completed at the EMR Site in 2016 to identify cultural resources, determine their significance and identify any mitigation that may be required. Test pits were excavated during Stage 2 and 3 archaeological assessment. As a result of these archaeological assessment, modifications to the NSDF Project footprint were made to avoid a homestead. Following Stage 2 and Stage 3 excavations, two locations were identified for management of artefacts (i.e., Stage 4 assessment). An archaeological assessment was completed for the Alternate site in 2013 and 2014 and results indicate that there are no significant cultural resources within the areas surveyed [5-31].

In 2008, CNL developed an Archaeological Master Plan that resulted in a formal Cultural Resource Management (CRM) program at CNL. If during site preparation or construction activities, cultural material is identified, activities will be stopped and the CNL CRM specialist will be contacted.

Both alternatives would implement mitigation that provides for worker and public health and safety during all phases of the NSDF Project. In addition, mitigation implemented to protect the surface water environment, aquatic biodiversity and ecological health would be similar for both sites. Employment and business opportunities, and community well-being would also be similar for both site locations.

#### **5.1.6.4                    Rationale**

The comparative evaluation between facility location alternatives within the CRL site is provided in Table 5-8. As shown in the table, the EMR site is preferable for both economic and environmental reasons. In summary, the EMR site is adjacent to a Legacy WMA and in closer proximity to the existing waste operational areas. This represents a tighter consolidation of land uses and less effects on undeveloped areas. Extensive environmental studies have been completed in the Perch Creek and Perch Lake Watershed where the EMR site is located over the past decades, which adds additional confidence in how the Facility will react with the natural environment. In addition, the Perch Creek and Perch Lake Watershed has been impacted by plumes emanating from the WMA A and the LDAs. There may be perceived increased risks of the EMR site as it is located closer to the Ottawa River; however, the groundwater transit time from the EMR site to nearest surface waterbody is estimated to be 5 to 15 years with an average transit time of approximately seven years compared to approximately two years for the Alternate site.

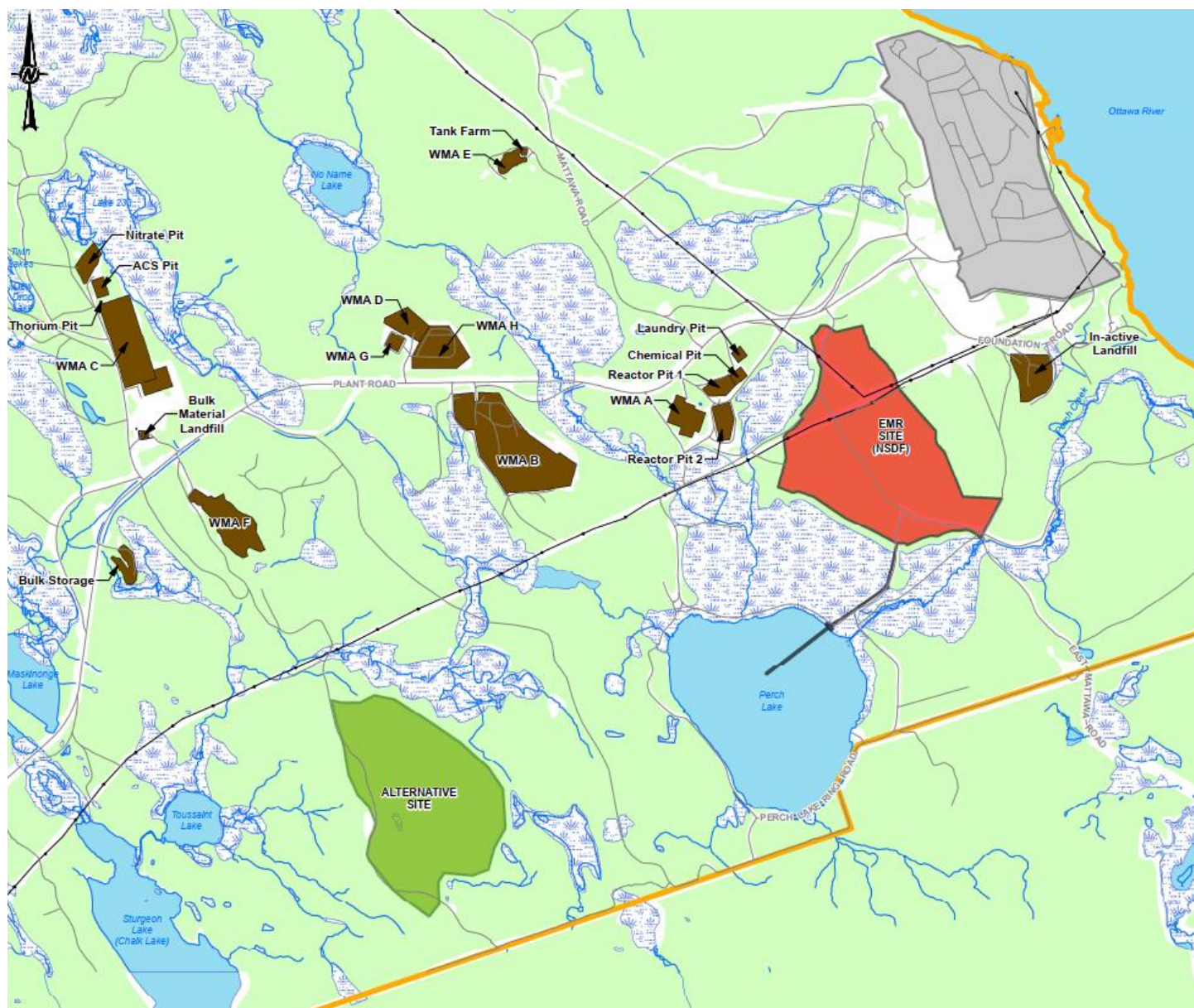


Figure 5-1 Alternative Site and East Mattawa Road (EMR) Site Locations

**Table 5-8**  
**Evaluation of Alternatives – Site Selection**

| Criteria                                   | Alternative 1 – EMR Site                                                                                                                                                                                                                      |                                                                                     | Alternative 2 – Alternate Site                                                                                                                                                                                                   |                                                                                       |
|--------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Technical Feasibility                      |                                                                                                                                                                                                                                               |                                                                                     |                                                                                                                                                                                                                                  |                                                                                       |
| Project Purpose                            | Both sites are technically feasible.                                                                                                                                                                                                          |                                                                                     |                                                                                                                                                                                                                                  |                                                                                       |
| Storage Capacity                           | The EMR site has sufficient area available to develop a facility with a storage capacity of 1,000,000 m³.                                                                                                                                     |    | The Alternate site has sufficient area available to develop a facility with a storage capacity of 1,000,000 m³                                                                                                                   |    |
| Monitoring Complexity                      | Extensive monitoring programs already exist in the vicinity of the EMR site; therefore, the existing Environmental Monitoring Plan for the CRL site can easily be expanded to include monitoring and sampling locations for the NSDF Project. |    | Limited monitoring is place at the Alternate Site. Significant expansion of CNL’s existing Environmental Monitoring Plan would be required to include monitoring and sampling locations for the NSDF Project.                    |    |
| Economic Feasibility                       |                                                                                                                                                                                                                                               |                                                                                     |                                                                                                                                                                                                                                  |                                                                                       |
| Life Cycle Costs                           | The site is close to existing services and has the lowest costs to provide project site services and access routes.                                                                                                                           |    | There would be increased costs in extending services, including new roads, at the Alternate site.                                                                                                                                |    |
| Environmental Effects                      |                                                                                                                                                                                                                                               |                                                                                     |                                                                                                                                                                                                                                  |                                                                                       |
| Biophysical                                |                                                                                                                                                                                                                                               |                                                                                     |                                                                                                                                                                                                                                  |                                                                                       |
| Environmental Setting                      | The EMR site is located in the Perch Creek and Perch Lake Watershed, which has been impacted by plumes emanating from the WMA A and the LDAs (i.e., brownfield site) and as such, consolidates waste land uses.                               |  | The Alternate site is located in the Chalk Lake basin, which is an undisturbed area with no previous contamination (i.e., Greenfield site).                                                                                      |  |
| Atmospheric Environment                    | The EMR is approximately 4 km closer to the CRL main campus as compared to the Alternate site.                                                                                                                                                |  | The increased transportation distance of wastes to the Alternate site would result in slightly increased air emissions, and therefore greenhouse gases.                                                                          |  |
| Geological and Hydrogeological Environment | The groundwater transit time from the EMR site to nearest surface waterbody is calculated to be 5 to 15 years with an average transit time of approximately 7 years.                                                                          |  | The groundwater transit time from the Alternate site to nearest surface waterbody is calculated to be 2 years.                                                                                                                   |  |
| Surface Water Environment                  | No anticipated difference between alternatives.                                                                                                                                                                                               |                                                                                     |                                                                                                                                                                                                                                  |                                                                                       |
| Aquatic Biodiversity                       | No anticipated difference between alternatives.                                                                                                                                                                                               |                                                                                     |                                                                                                                                                                                                                                  |                                                                                       |
| Terrestrial Biodiversity                   | The EMR site is located immediately adjacent to the Perch Lake Swamp, and therefore has an increased potential for indirect effects on terrestrial species that use this habitat.                                                             |  | The Alternate site encroaches on the Blanding’s turtles travelling corridor within the CRL site, which would potentially cause a slight fragmentation between habitats and increases the potential for increased road mortality. |  |
| Ecological Health                          | No anticipated difference between alternatives.                                                                                                                                                                                               |                                                                                     |                                                                                                                                                                                                                                  |                                                                                       |

| Criteria                                             | Alternative 1 – EMR Site                                                                                                           |                                                                                   | Alternative 2 – Alternate Site                                                                                                                         |                                                                                     |
|------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Social                                               |                                                                                                                                    |                                                                                   |                                                                                                                                                        |                                                                                     |
| Socio-economics                                      | No anticipated difference between alternatives.                                                                                    |                                                                                   |                                                                                                                                                        |                                                                                     |
| Land and Resource Use                                | An archaeological assessment was completed for the NSDF site. The site boundaries were adjusted to mitigate any potential impacts. |  | An archaeological assessment was previously completed and results indicate that there are no significant cultural resources within the areas surveyed. |  |
| Social Acceptability                                 | There may be perceived increased risks of the EMR site as it is located closer to the Ottawa River                                 |  | Located further from the Ottawa River and may be perceived more favourably.                                                                            |  |
| Human Health and Safety                              |                                                                                                                                    |                                                                                   |                                                                                                                                                        |                                                                                     |
| Public Health & Safety (construction and operations) | Both alternatives can be developed in a manner that protects public health and safety during construction and operations.          |                                                                                   |                                                                                                                                                        |                                                                                     |
| Public Health & Safety (long-term)                   | Both alternatives can be developed in a manner that protects public health and safety in the long-term.                            |                                                                                   |                                                                                                                                                        |                                                                                     |
| Worker Health & Safety                               | Both alternatives can be developed in a manner that protects worker health and safety.                                             |                                                                                   |                                                                                                                                                        |                                                                                     |

### 5.1.7 Leachate Management

Leachate is generated as water infiltrates through the ECM during operations (and to a much lesser extent during the post-closure phase). The operating period of the NSDF is 2024 to 2070, and wastewater treatment is required for the full duration of operations and plus several years following closure of the ECM and installation of the final cover. The average annual wastewater volume to be produced during operations is predicted to be approximately 11 000 m<sup>3</sup>/y. Another important hydraulic consideration is the maximum wastewater flow rate that must be received and processed by the WWTP. Leachate and decontamination water are produced at relatively low rates compared to contact stormwater, especially during major storm events. The maximum hydraulic flow rate was determined by back-to-back 100-year, 24-hour storm events (4 710 m<sup>3</sup>) and was selected as a worst-case design condition for determining the required volume of wastewater to be treated.

A comparison of projected leachate concentrations and discharge targets show that several radionuclides and non-radionuclides may be present at concentrations in the wastewater that exceed discharge targets, and treatment for these designated COPC will be required. The WWTP must therefore be designed for removal of radionuclides and selected non-radiological constituents (e.g., metals).

Three alternative means of leachate management were considered for meeting the above-mentioned design requirements for the NSDF Project:

1. Use of an existing wastewater treatment facility
2. Construction of a new WWTP.
3. No discharge through the use of a leachate evaporation pond.



### **5.1.7.1 Existing Waste Treatment Centre**

This alternative considers sending the wastewater discharge to the existing Waste Treatment Center (WTC) at CRL.

#### **Technical Feasibility**

The existing WTC at CRL was built more than 40 years ago to treat low level radioactive liquid waste originating from reactor and site operations. The WTC is expected to reach its end life in the next decade and will not be available for the operating life of the NSDF Project (i.e., 2024 to 2070). In addition, although WTC has the capacity to treat the volume of leachate predicted to be generated, this kind of throughput would pose a reliability risk to NSDF Project operations even if there were reinvestment in WTC. An underground pipeline to bridge the 2 km distance between facilities would be required. The 2 km pipeline distance is longer than the distance to discharge points for the WWTP; and therefore, more costly. It is also not certain that WTC decontamination performance is sufficient to meet treated leachate discharge/infiltration requirements, and therefore WTC may not be fit for purpose. The WTC operations are labour and energy intensive (\$7 million annually for the required throughput, exclusive of capital reinvestment). The WTC depends on powerhouse support (steam, steam condensate return in particular), and the powerhouse is slated for shutdown prior to 2025. For these reasons, the existing waste treatment facility is not a technically feasible option and is not further evaluated.

### **5.1.7.2 Wastewater Treatment Plant (New)**

This alternative considers a new WWTP that would treat wastewater sources at the NSDF Project site, including contact stormwater and leachate generated from the ECM, equipment and personnel decontamination water, and laboratory wastewater.

#### **Technical Feasibility**

The proposal to build a new, standalone treatment plant would meet the Project purpose and would use the best demonstrated available technology that is economically achievable for removal of the COPC from the NSDF wastewater. Further, this alternative would have the capacity to treat the volume of leachate predicted to be generated over the operating life of the NSDF Project (i.e., 2024 to 2070) and not limit the ECM's storage capacity over the long term. This alternative would have a design life of 50 years, after which the ECM would be sealed with the final cover and the volume of leachate would significantly decrease. Effluent monitoring will be required at the WWTP to ensure treated water meets effluent discharge targets.

### **5.1.7.3 No Discharge Option - Leachate Evaporation Pond**

Evaporation ponds are artificial ponds with very large surface areas that are designed to efficiently evaporate water by sunlight and exposure to the ambient temperatures.

## **Technical Feasibility**

Leachate evaporation ponds are used in hot dry climates and are not effective in the mid continental climate of central Canada with no distinct dry season. Therefore, a leachate evaporation pond is not considered to be a technically feasible alternative and is not further evaluated.

### **5.1.7.4 Rationale**

The new WWTP is the only technically feasible option available to treat the leachate to be generated from the NSDF. The WTC is expected to reach its end life by end of the next decade and will not be available for the operating life of the NSDF Project (i.e., 2024 to 2070). Leachate evaporation ponds are used in hot dry climates and are not effective in the mid continental climate of central Canada with no distinct dry season. As there is only one technical feasible alternative, potential environmental effects on VCs are not presented in this section; rather the potential environmental effects of the new WWTP are evaluated in the EIS [5-7].

### **5.1.8 Effluent Discharge Options**

Following treatment in the WWTP, the treated effluent will need to be managed on-site or be discharged to the natural receiving environment. The estimated annual volume of the treated effluent to be discharged is approximately 11 000 m<sup>3</sup>. Options for discharge of the treated effluent are:

- Discharge to ground.
- Discharge to surface water (i.e., Perch Creek, Perch Lake or the Ottawa River).
- Co-discharge to the NSDF Stormwater System and to ground.
- Discharge to ground and discharge to surface water.
- No liquid discharge (i.e., thermal evaporator).

#### **5.1.8.1 Discharge to Ground**

Discharge of treated effluent to ground would entail the construction of an exfiltration gallery which would promote the exfiltration of treated water into the local groundwater regime. Discharge to ground utilizes the ground for retention capabilities allowing for radionuclide decay. The exfiltration gallery would be located within the NSDF site up-gradient of the East Swamp Wetland. The treated effluent, once discharged to ground, would be returned to the adjacent wetlands and eventually discharge to Perch Lake and the Ottawa River. Discharge to ground provides the added benefit of enabling control of recharging water to the wetlands. Further, an exfiltration gallery provides additional retention time for radioactive decay for tritium that will be present in the effluent before discharge to the Perch Lake and Perch Creek receiving systems.

The exfiltration gallery would be designed to operate all year round. Winter conditions would be accounted for by doubling the calculated required design area of the gallery in line with the Ministry of Environment, Conservation and Parks Guidelines for Stormwater Management and Design [5-32].

In the event that the gallery overflow pipe is activated, an overflow relief pipe is provided from the exfiltration gallery to route flows that exceed the exfiltration capacity of the gallery to the East Swamp. A rip rap stone dispersion pad is provided at the outlet point of the overflow culvert to dissipate the energy effluent discharged and reduce erosion. Further erosion protection is provided at the culvert outlet to mitigate the ponding of water on the east side of EMR, thereby, mitigating erosion potential of both the roadway and



disruption of surface and subsurface infrastructure located downgradient of the exfiltration gallery and upstream of the East Swamp.

### **Technical Feasibility**

Exfiltration galleries have been used as a low impact approach to water management and serve to replenish and maintain surface and groundwater levels. They have been used at several Ontario sites in various commercial and industrial applications.

The initial design consisted of an exfiltration gallery located within the NSDF site, located downhill from the WWTP. However, hydrogeological conditions at this location are such that the local soils and groundwater regime do not have capacity to accept peak flows from the WWTP at all times. The average WWTP discharge rate is higher than the infiltration capacity of the hosting soils, and the problem is amplified during storm events. Therefore, the current design of the exfiltration gallery cannot support the required flow from the WWTP and is not technically feasible. To address this, additional engineering options were considered including:

- Alternative exfiltration locations on the NSDF site;
- Alternative exfiltration location outside of the NSDF site; and
- Discharge to an existing legacy LDA adjacent to the NSDF site.

#### ***Alternative Locations on the NSDF Site***

Space for additional groundwater exfiltration infrastructure on the NSDF site is limited due to the size and hydrogeological characteristics of soils at the NSDF site as well as wetland areas with environmentally sensitive natural features. Therefore, two additional locations within the NSDF site were evaluated. Hydrogeological modelling performed for these two sites indicates that both suffer from inundation challenges similar to that of the original location and will fall short of the required infiltration capacity, and therefore both these options were ruled out.

#### ***Alternative Locations off the NSDF Site***

Canadian Nuclear Laboratories also evaluated two locations outside the NSDF site, located to the northeast of the WWTP. The surrounding area for these locations is across the watershed line which drains to the Ottawa River, unlike the current site location which drains to the Perch Creek and Perch Lake Watershed. The watershed along the Ottawa River is less affected by CRL operations compared to the Perch Creek and Perch Lake Watershed which has been impacted by legacy WMA's and it is desirable to manage all treated effluent within the Perch Creek and Perch Lake Watershed. For this reason, the option was ruled out.

#### ***Discharge to Existing Legacy Liquid Dispersal Area***

Canadian Nuclear Laboratories also evaluated the option of discharging the treated effluent to an existing LDA located adjacent to the NSDF site. This area was used from the 1950's to 2000 to manage untreated low level liquid waste from CRL operations prior to the expansion of the CRL Waste Treatment Centre. The LDA managed up to approximately 100 000 m<sup>3</sup> of low level liquid waste annually.

Discharge to the existing LDA would meet the project purpose and could manage the volume of leachate generated from the ECM. However, the discharge of NSDF treated effluent to this dispersal area would generate additional radiologically contaminated groundwater. Due to the existing contamination within the LDA, this alternative is not technically feasible.

In summary, based on all the options evaluated above, the sole use of the exfiltration gallery is not sufficient to manage the peak flows from the WWTP at all times. Therefore, the exfiltration gallery on its own is not considered technically feasible. An exfiltration gallery may however be combined with other design options. These combination options are discussed in Section 5.1.8.2.4 (Co-discharge with NSDF Stormwater System and Discharge to Ground), and Section 5.1.8.2.5 (Discharge to Ground and Direct Discharge to Surface Water).

Combination options were examined for multiple reasons including:

- The use of an exfiltration gallery is consistent with the design approach communicated to stakeholders and Indigenous peoples.
- The exfiltration gallery will have sufficient capacity during post-closure to handle reduced flows from the WWTP after the ECM is capped.
- The use of the exfiltration gallery as a primary discharge location is beneficial because it provides additional retention time for radioactive decay (e.g., tritium) and returns water to local wetlands.

### **5.1.8.2 Discharge to Surface Water (Perch Creek, Perch Lake or the Ottawa River)**

The direct discharge of the treated effluent to surface water would require the construction of a transfer line from the proposed new WWTP to a suitable waterbody. Canadian Nuclear Laboratories investigated the feasibility of discharging directly to multiple waterbodies including Perch Creek, Perch Lake and the Ottawa River. Each of these discharge locations are discussed further in the sections below.

#### **5.1.8.2.1 Discharge to Perch Creek**

A discharge to Perch Creek was considered. However, the average effluent flow rate is approximately 10% of the low summer flow rate for Perch Creek and the maximum effluent flow rate is approximately 100% of the low summer flow rate for Perch Creek. Direct discharge to Perch Creek would not be expected to be assimilated (i.e., mixed) to the same extent as a larger body of water (e.g., Perch Lake) which could extend the mixing distance down to the Ottawa River depending of flow conditions. Therefore, this alternative was not considered technically feasible and is not evaluated further.

#### **5.1.8.2.2 Discharge to Perch Lake**

Constructing a transfer line from the proposed new WWTP to Perch Lake requires the consideration of routing a transfer line through potentially contaminated areas and potential disturbance of wetlands that support critical habitat for designated species at risk. Canadian Nuclear Laboratories considered two route options:

- 1) Transfer line Route 1 – Transfer line Route 1 would run 1.6 km around the east side of the ECM along the Perch Lake Ring Road to Perch Lake. Pumping would be needed to a high point east of the ECM, from where the water will flow by gravity. This option would require the construction of a small pumping station.
- 2) Transfer line Route 2 – This route option would run 1.3 km around the north and west side of the ECM to Perch Lake. A gravity flow transfer line partly installed by horizontal directional drilling would be required to cross the East Swamp. Unlike Transfer line Route 1, pumping would not be needed.

Both options would be designed to convey the full flow when both treatment trains of the WWTP are operational and can be operated all year.

### **Technical Feasibility**

The use of a transfer line to discharge treated effluent is widely used and effective, and standard mitigation are available to limit adverse effects and provide adequate provisions to protect the environment. Further, CNL currently monitors water quality within Perch Lake and any additional monitoring requirements would be incorporated into the existing monitoring program. Therefore, both route options are considered technically feasible.

### **Economic Feasibility**

The capital and operation cost for the discharge of treated effluent to Perch Lake is expected to represent less than 1% of the costs for the overall project.

#### **5.1.8.2.3 Discharge to Ottawa River**

Canadian Nuclear Laboratories currently discharges treated effluent and surface water via a number of outfalls and streams on the Ottawa River. This alternative considers sending the treated effluent from the WWTP to one of these existing discharge points along the Ottawa River. Any options would require the construction of a transfer line to transport the treated effluent from the WWTP to the ultimate discharge point to the Ottawa River. The transfer line to Ottawa River would be gravity-fed.

### **Technical Feasibility**

There are existing discharge points along the Ottawa River that could handle the proposed discharge volume from the WWTP. The transfer line for some of the discharge points would require construction along the perimeter of the developed CRL site. Although existing underground infrastructure along the perimeter of the developed site adds complexity to construction; construction of a transfer line to the Ottawa River is technically feasible.

### **Economic Feasibility**

The capital and operation cost for the discharge of treated effluent to Ottawa River is expected to represent less than 1% of the costs for the overall project.

#### **5.1.8.2.4 Co-discharge with the NSDF Stormwater System and Discharge to Ground**

If an exfiltration gallery is used, it must be complemented with other measures. One option considered is to use one or more of the three existing surface water management ponds on-site jointly with the exfiltration gallery. These ponds manage all non-contaminated surface water within the NSDF site and discharge to adjacent wetlands and will be dispersed by level spreaders to achieve even flow distribution to the wetland and control erosion.

### **Technical Feasibility**

The surface water management ponds do not have the capacity to accommodate additional flows from back to back storm events given they were only designed for run-off volumes. The viability of enlarging the existing ponds or adding new ponds was assessed. However, there is insufficient space on the NSDF site to accommodate a new pond or enlarging the existing ponds. Therefore, this option was not considered technically feasible.

#### **5.1.8.2.5 Discharge to Ground and Discharge to Surface Water**

This alternative involves the combination of the discharge to ground (Section 5.1.8.1) with the direct discharge to either the Ottawa River (Section 5.1.8.2.3) or Perch Lake (Section 5.1.8.2.2) via a pipeline. For the discharge to Perch Lake, the two pipeline route options discussed in Section 5.1.8.2.3 were investigated as part of this alternative.

##### **Technical Feasibility**

The combination of discharge to ground with a direct discharge to surface water provides an additional discharge option when there is insufficient infiltration capacity at the exfiltration gallery. During post-closure, the ECM will be capped resulting in reduced flows from the WWTP and the exfiltration gallery will have sufficient capacity to manage all flows from the WWTP. As discussed in Sections 5.1.8.2.2 and 5.1.8.2.3, the discharge to either Perch Lake or Ottawa River are considered technically feasible. Further, both transfer line options for the discharge to Perch Lake are considered technically feasible. Therefore, discharge to ground combined with discharge to surface water (i.e., Perch Lake or the Ottawa River) is technically feasible.

##### **Economic Feasibility**

The capital and operation cost for the exfiltration gallery and the discharge of treated effluent to either Perch Lake or Ottawa River are expected to represent less than 1% of the costs for the overall project.

#### **5.1.8.2.6 No Liquid Discharge (Thermal Evaporator)**

Because of public concerns about liquid emissions, options to reduce or eliminate liquid emissions were considered. A thermal evaporator could be installed in the WWTP to evaporate the treated effluent and release it to atmosphere.

##### **Technical Feasibility**

The evaporator would be technically feasible for normal flow conditions but would not have the capacity to manage the flow from back-to-back storm events. It is also noted that this option would not eliminate the need for infrastructure to allow for liquid discharges of treated effluent during storm events. Therefore, this option was not considered technically feasible.

#### **5.1.8.3 Impacts**

Based on the review above, three effluent discharge options were considered technically and economically feasible:

- Discharge to Perch Lake (Section 5.1.8.2.2).
- Discharge to Ottawa River (Section 5.1.8.2.3).
- Discharge to ground and to surface water (Section 5.1.8.2.5).

The discharge to Perch Lake would require the construction of a new discharge to a waterbody; however, the discharge to the Ottawa River could use an existing outfall where the treated effluent could be combined with an existing discharge to the Ottawa River.

Potential effects to the atmospheric environment considered for all alternatives are related to nuisance noise from construction activities, and increased air and greenhouse gas emissions. Greenhouse gas emissions are expected to be of the same order of magnitude for all alternatives.

Potential effects to groundwater are limited to the option for combined discharge to ground and surface water. The exfiltration gallery would release the treated effluent to ground which would then infiltrate into the groundwater and migrate towards East Swamp Stream and ultimately Perch Lake.

The key pathways related to surface water and aquatic biodiversity include the construction of a new discharge point in a surface waterbody and the release of treated effluent directly to a surface waterbody or via groundwater. The discharge to the Ottawa River alternative includes options to discharge to an existing outfall which limits the construction related effects for the construction of the transfer line. The discharge to Perch Lake would require the construction of a new discharge point within Perch Lake. Design options would need to be considered to limit the resuspension of sediment during operations in Perch Lake due to a thick layer of fine, semi-liquid, highly organic mud lining the bottom of Perch Lake which is susceptible to re-suspension if disturbed. Appropriate mitigation would also be required during construction of the infrastructure to limit adverse disturbances to the Perch Lake shoreline, lakebed, and surrounding watershed.

If only an exfiltration gallery were used (Section 5.1.8.1) an overflow pipe would be required when there is insufficient infiltration capacity at the exfiltration gallery which could result in overland flow of treated effluent. The combination of the exfiltration gallery and discharge to Perch Lake would allow excess flow to be diverted to Perch Lake and eliminate the risk of overland flow at the exfiltration gallery.

All alternatives would result in small changes to surface water quality, which are not expected to result in adverse effects on aquatic biodiversity. The treated effluent will meet effluent discharge targets for protection of the environment and human health.

Discharge to surface water (Perch Lake or the Ottawa River), will require construction of a transfer line from the WWTP to the discharge location. Transfer lines are widely used and standard mitigation measures are available to limit adverse effects on the environment from construction.

A comparison of the environmental effects for the options of direct discharge to surface water compared to the option of discharge to ground combined with discharge to surface water is provided in Table 5-9.

A comparison of the environmental effects for the options of direct discharge to Perch Lake to the option of direct discharge to the Ottawa River is provided in Table 5-10.

#### **5.1.8.3.1 Effluent Strategy Focus Group**

The NSDF Project team hosted a Focus Group on the effluent discharge alternatives in late 2019 May. As a result of feedback on the draft EIS with respect to the effluent management strategy, the NSDF Project chose to further evaluate solutions to manage effluent discharge from the NSDF Project. As a result of the expressed public interest in the protection of the Ottawa River, the NSDF Project decided that a focus group session would be beneficial to the options analysis process and serve as a good forum for members of the public to express their opinions.

Public participation within projects which trigger environmental assessments is critical and CNL considers all input received to ensure good decisions are made with respect to environmental stewardship. At the NSDF Effluent Strategy Focus Group, there was representation from a number of special interest groups including members of the public, local municipalities and non-government organizations. The approach implemented for the Focus Group session included:

- Targeted invite to representatives (or individuals) that expressed an interest in the measures the NSDF Project will take to protect the Ottawa River, as well as the environment in general. To ensure an effective and meaningful discussion, the NSDF Project requested for organizations to identify individual to participate who ideally had a background in environmental sciences, familiarity with effluent management practices and a general awareness of the proposed project.
- Provision of relevant background information including general project information, a description of the WWTP, and sharing of the NSDF Project effluent discharge targets, as well as several related project links.
- A tour of the proposed NSDF Project site to ensure participants were familiar with the setting and environmental baseline conditions.
- Presentations during the focus group session included an overview of leachate treatment alternatives, calculated wastewater quantities, effluent discharge targets and a brief introduction to the alternative means assessment process within CEAA.
- Discussions by the participants were solicited by facilitating two exercises within the focus group session. The first exercise had the participants develop the evaluation criteria through identification of environmental components that were of importance to them followed by a multi-voting process to refine the criteria list as a group. The second exercise had the participants perform a relative evaluation of the effluent discharge options using focus group developed criteria. Participants were broken into two working groups for these exercises and then presented their findings for a round-table discussion.
- Individual survey forms were provided to the participants to provide reflection on their thoughts prior to and following group exercises.

The NSDF Project's intent of the focus group session was to take discussions into consideration for potential improvements to the facility design and incorporation into the final EIS. Although the NSDF Project described and presented the effluent discharge options, the NSDF Project's updated alternative means assessment was not shared with focus group participant so not to influence the discussion. General observations of the discussions included:

- The evaluation criteria developed by the focus group were similar to the NSDF Project developed criteria (presented within Section 5.1.1) thus, indicating the NSDF Project's assessment criteria is representative of the public's environmental values. The evaluation criteria developed by the focus group included protection of aquatic life, quantity and quality of effluent discharge, changes in the physical environment as a result of the NSDF Project and public concern.
- During evaluation of the effluent discharge options, both focus groups unanimously rejected the option to discharge to the Ottawa River and scored the discharge to Perch Creek quite low. Additionally there was no interest in further consideration of the discharge to air option. The preferred option was discharge to groundwater although there was recognition this option needed to be in combination with a surface water discharge to Perch Lake due to reduced capacity of the exfiltration gallery under high groundwater elevation conditions during spring.

- Interestingly each focus group suggested additional options which are discussed below:
  - Reduce quantity of leachate and contact-water that requires treatment. A number of design optimizations were suggested to achieve this target including the potential to include a weather cover structure cover over the operating face of the disposal cell.
  - Combination of groundwater exfiltration and an artificial wetland as a receiving environment for the treated effluent.

The discussions from the focus group session are being considered by the NSDF Project team as potential mitigation measures of the NSDF Project's potential effects on the environment. Specifically, the NSDF Project is exploring an artificial wetland as a supplemental component of the treatment system, which would further mitigate residual effects predicted on surface water quality as discussed in Section 5.4.2. An artificial wetland would enhance removal of constituents from the treated effluent prior to release to the natural environment. The artificial wetland also provides enhanced retention time for radioactive decay of treated effluent compared to discharge to Perch Lake.

Additionally, weather cover structure designs are being evaluated for compatibility with the NSDF Project configuration and if feasible, could be implemented as a mitigation measure and operational optimization.

Three effluent discharge options were considered technically and economically feasible and each have comparable potential environmental effects including:

- Discharge to Perch Lake (Section 5.1.8.2.2);
- Discharge to Ottawa River (Section 5.1.8.2.3); and
- Discharge to ground and discharge to surface water (Section 5.1.8.2.5).

Combined discharge to ground and surface water is beneficial because the exfiltration gallery provides additional retention time for radioactive decay (e.g., tritium) and replenishes water to the local wetlands. For this combined option, the water collected in the ECM as leachate would be treated and returned to the Perch Creek and Perch Lake Watershed (via the exfiltration gallery) consistent with existing conditions. In addition, the exfiltration gallery will have sufficient capacity as a standalone option during post-closure to manage the reduced flows from the WWTP after the ECM is capped.

For both the surface water discharge options (i.e., Perch Lake or Ottawa River), a transfer line would need to be constructed. For the Ottawa River option, the transfer line could connect to an existing outfall where the treated effluent could be combined with an existing discharge to the Ottawa River. Transfer lines are widely used and standard mitigation measures are available to limit adverse effects on the environment from construction.

The treated effluent will meet effluent discharge targets protective of the environment and human health. While both surface water options are protective of environment and human health, direct discharge to the Ottawa River is expected to be perceived unfavourably by the public and Indigenous peoples. Discharge to Perch Lake is, therefore, the preferred of the two options.

A comparative evaluation of the discharge to surface water versus the discharge to ground combined with a discharge to surface water is provided in Table 5-9. A comparative evaluation of a discharge to Perch Lake versus Ottawa River is provided in Table 5-10.

**Table 5-9**

**Evaluation of Alternatives – Effluent Discharge Options (Discharge to Surface Water vs. Discharge to Ground and Discharge to Surface Water)**

| Criteria                                             | Discharge to Surface Water                                                                                                                                                            |                                                                                     | Discharge to Ground and Discharge to Surface Water                                                                                                                                                                                                |                                                                                       |
|------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Technical Feasibility                                |                                                                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Project Purpose                                      | Both alternatives meet the technical requirements.                                                                                                                                    |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Storage Capacity                                     | Neither of the alternatives will limit the storage capacity of the NSDF                                                                                                               |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| An Example of Best Available Technology              | A pipeline and discharge to a surface waterbody is an example of a best available technology and widely used.                                                                         |    | A pipeline and discharge to a surface waterbody is an example of a best available technology and widely used. An exfiltration gallery has been used previously but less extensively than a pipeline                                               |    |
| Design Robustness                                    | Pipelines are widely used and standard and effective mitigation and controls are available to limit adverse effects on the environment.                                               |    | Pipelines are widely used and standard and effective mitigation and controls are available to limit adverse effects on the environment. The exfiltration gallery will also provide additional retention time for radioactive decay (e.g. tritium) |    |
| Monitoring Complexity                                | Both alternatives may require monitoring requirements; however, these monitoring programs are relatively straightforward and similar programs are currently in place at the CRL site. |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Economic Feasibility                                 |                                                                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Life Cycle Cost                                      | Less than 1% of capital and operating costs of the overall project                                                                                                                    |   | Less than 1% of capital and operating costs of the overall project                                                                                                                                                                                |   |
| Environmental Effects                                |                                                                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Biophysical                                          |                                                                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Environmental Setting                                | Construction of a new outfall structure in Perch Lake.                                                                                                                                |  | Construction of a new outfall structure in Perch Lake.                                                                                                                                                                                            |  |
| Atmospheric Environment                              | Limited air emissions related to construction                                                                                                                                         |  | Limited air emissions related to construction                                                                                                                                                                                                     |  |
| Geological and Hydrogeological Environment           | No discharges to groundwater and hence no impacts.                                                                                                                                    |  | Discharge to ground replenishes local groundwater and the wetlands.                                                                                                                                                                               |  |
| Surface Water Environment                            | No radionuclide decay (e.g., tritium) through groundwater.                                                                                                                            |  | Tritium discharges to surface water are reduced due to decay of tritium during groundwater transit.                                                                                                                                               |  |
| Aquatic Biodiversity                                 | Small changes to water quality which will not result in adverse effects on aquatic biodiversity.                                                                                      |  | Small changes to water quality which will not result in adverse effects on aquatic biodiversity.                                                                                                                                                  |  |
| Terrestrial Biodiversity                             | No anticipated difference between alternatives.                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Ecological Health                                    | No anticipated difference between alternatives.                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Social                                               |                                                                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Socio-economic                                       | No anticipated difference between alternatives.                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Land and Resource Use                                | No anticipated difference between alternatives.                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Social Acceptability                                 | Direct discharge to Perch Lake may be a concern.                                                                                                                                      |  | Discharge to ground provides additional retention time for radioactive decay (e.g., tritium) and replenishes local groundwater and the wetlands.                                                                                                  |  |
| Human Health and Safety                              |                                                                                                                                                                                       |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |
| Public Health & Safety (construction and operations) | All alternatives can be developed in a manner that protects public health and safety during construction and operations.                                                              |                                                                                     |                                                                                                                                                                                                                                                   |                                                                                       |



| Criteria                           | Discharge to Surface Water                                                                             | Discharge to Ground and Discharge to Surface Water |
|------------------------------------|--------------------------------------------------------------------------------------------------------|----------------------------------------------------|
| Public Health & Safety (long-term) | All alternatives can be developed in a manner that protects public health and safety in the long-term. |                                                    |
| Worker Health & Safety             | All alternatives can be developed in a manner that protects worker health and safety.                  |                                                    |

**Table 5-10**

**Evaluation of Alternatives – Effluent Discharge Options (Discharge to Perch Lake vs. Discharge to Ottawa River)**

| Criteria                                   | Alternative 1 – Discharge to Perch Lake                                                                                                                                                               |                                                                                     | Alternative 2 – Discharge to Ottawa River                                                                                                    |                                                                                       |
|--------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| Technical Feasibility                      |                                                                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |
| Project Purpose                            | Both alternatives meet the technical requirements.                                                                                                                                                    |                                                                                     |                                                                                                                                              |                                                                                       |
| Storage Capacity                           | Neither of the alternatives will limit the storage capacity of the NSDF                                                                                                                               |                                                                                     |                                                                                                                                              |                                                                                       |
| An Example of a Best Available Technology  | A transfer line and discharge to a surface waterbody is an example of a best available technology and widely used.                                                                                    |    | A transfer line and discharge to a surface waterbody is an example of a best available technology and widely used.                           |    |
| Design Robustness                          | Transfer lines are widely used and standard and effective mitigation and controls are available to limit adverse effects on the environment.                                                          |   | Transfer lines are widely used and standard and effective mitigation and controls are available to limit adverse effects on the environment. |   |
| Monitoring Complexity                      | Both alternatives may necessitate additional monitoring requirements; however, these monitoring programs are relatively straight-forward and similar programs are currently in place at the CRL site. |                                                                                     |                                                                                                                                              |                                                                                       |
| Economic Feasibility                       |                                                                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |
| Life Cycle Cost                            | Less than 1% of capital and operating costs of the overall project                                                                                                                                    |  | Less than 1% of capital and operating costs of the overall project                                                                           |  |
| Environmental Effects                      |                                                                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |
| Biophysical                                |                                                                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |
| Environmental Setting                      | Construction of a new outfall structure in Perch Lake.                                                                                                                                                |  | An existing outfall structure on the Ottawa River could be used                                                                              |  |
| Atmospheric Environment                    | Limited air emissions related to construction                                                                                                                                                         |  | Limited air emissions related to construction                                                                                                |  |
| Geological and Hydrogeological Environment | No discharges to groundwater and hence no impacts.                                                                                                                                                    |  | No discharges to groundwater and hence no impacts.                                                                                           |  |
| Surface Water Environment                  | No radionuclide decay (e.g., tritium) through groundwater.                                                                                                                                            |  | No radionuclide decay (e.g., tritium) through groundwater.                                                                                   |  |
| Aquatic Biodiversity                       | Small changes to water quality which will not result in adverse effects on aquatic biodiversity.                                                                                                      |  | Small changes to water quality which will not result in adverse effects on aquatic biodiversity.                                             |  |
| Terrestrial Biodiversity                   | No anticipated difference between alternatives.                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |
| Ecological Health                          | No anticipated difference between alternatives.                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |
| Social                                     |                                                                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |
| Socio-economic                             | No anticipated difference between alternatives.                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |
| Land and Resource Use                      | No anticipated difference between alternatives.                                                                                                                                                       |                                                                                     |                                                                                                                                              |                                                                                       |

| Criteria                                             | Alternative 1 –<br>Discharge to Perch Lake                                                                               |                                                                                   | Alternative 2 –<br>Discharge to Ottawa River                                                                                                                                       |                                                                                     |
|------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Social Acceptability                                 | Direct discharge to Perch Lake may be less of a concern                                                                  |  | Protection of the Ottawa River is a high priority for the public. Discharge directly to Ottawa river is expected to be perceived unfavourably by the public and Indigenous peoples |  |
| <b>Human Health and Safety</b>                       |                                                                                                                          |                                                                                   |                                                                                                                                                                                    |                                                                                     |
| Public Health & Safety (construction and operations) | All alternatives can be developed in a manner that protects public health and safety during construction and operations. |                                                                                   |                                                                                                                                                                                    |                                                                                     |
| Public Health & Safety (long-term)                   | All alternatives can be developed in a manner that protects public health and safety in the long-term.                   |                                                                                   |                                                                                                                                                                                    |                                                                                     |
| Worker Health & Safety                               | All alternatives can be developed in a manner that protects worker health and safety.                                    |                                                                                   |                                                                                                                                                                                    |                                                                                     |

### 5.1.9 Discharge Type

The total annual volume of contact surface water to be treated and discharged to the Perch Creek and Perch Lake Watershed is approximately 11 000 m<sup>3</sup>. This represents less than 1 percent (%) of the annual average total outflow from Perch Lake of approximately 1 700 000 m<sup>3</sup>. The current design for the planned discharge, is for treated effluent to be primarily discharged to the proposed exfiltration gallery, with excess volume to be directly discharged to Perch Lake, as necessary. Due to the conditions within the lake, an effective and reliable discharge system is required to distribute treated effluent into Perch Lake. Additionally, mitigation would be put in place for infrastructure associated with the direct discharge to Perch Lake to limit adverse disturbances to the shoreline, lakebed, and surrounding watershed.

To address the need for an effective and reliable discharge system, multiple engineering options were considered including:

- Discharge by Surface Spray onto Perch Lake.
- Piped Outfall to Perch Lake (Submerged Outlet in Perch Lake).
- Piped Outfall to Perch Lake (Above Water Discharge).
- Submerged Diffuser in Perch Lake (Alignment along Lakebed).
- Submerged Diffuser in Perch Lake (Diffuser Suspended in Water Column).

#### 5.1.9.1 Discharge by Surface Spray onto Perch Lake

A discharge by surface spray alternative would involve spraying treated effluent over the lake surface through a series of above-water on-lake or lake periphery discharge units. As such, this discharge option would only be possible in open water conditions (i.e., year-round operation is not possible). The associated infrastructure for this discharge would likely consist of a series of pipes that would extend some distance into the lake.

#### Technical Feasibility

The Project is designed to dispose of up to 1 000 000 m<sup>3</sup> of waste which will generate approximately 11 000 m<sup>3</sup> of treated effluent per year. As noted above, surface spray discharge onto Perch Lake would be viable only in open water conditions. However, there is insufficient capacity on the NSDF Project site to temporarily store treated effluent during the winter months. Therefore, the selected design option must be able to operate year-round to ensure that the planned storage capacity of the ECM can be met. As a result, this alternative is not technically feasible and is not carried forward for further analysis.

**5.1.9.2 Piped Outfall to Perch Lake (Submerged Outlet in Perch Lake)**

Treated effluent would be discharged into the lake below the water line through a single piped outlet. This system could therefore be expected to operate year-round. The pipe would extend some distance along the lakebed to a deeper zone of the lake and would be buried to maintain discharge depth below winter ice and to prevent pipe freezing. A stable lakebed or consolidated sediment would be required below the discharge point and around the pipeline where it extends into the lake below the shoreline and shallow sediment on the lake periphery. As long as the submerged discharge occurs at a suitable depth and treated effluent quality remains within appropriate water quality guidelines and/or site-specific benchmarks, this type of discharge may be undertaken under gravity flow discharge conditions.

**Technical Feasibility**

Discharge into Perch Lake through a piped outfall would be operationally simple. However, the installation would be dependent on finding a location in Perch Lake that would support the pipe (i.e., a suitable natural or engineered foundation) and would probably require a winter installation. This would require burial of the discharge pipe below the ice-cover depth at the shoreline and along the lakebed to prevent freezing. Depending on the outlet depth below the lake surface, year-round operation is feasible. Annual inspection and maintenance by divers would be required each spring to check and clear the piped outlet. This option could discharge the required annual volume and meet the discharge rates under gravity flow conditions. Based on the above, this alternative is technically feasible.

**Economic Feasibility**

The capital and operation cost for the discharge of treated effluent to Perch Lake via a submerged piped outfall is expected to represent less than 1% of the costs for the overall NSDF Project.

**5.1.9.3 Piped Outfall to Perch Lake (Above Water Discharge)**

Treated effluent would be discharged onto the lake surface through a pipe outfall, limiting the discharge to open water conditions (i.e., year-round operation is not possible). In this case, the outfall would extend over the lake and be located at or above the water line. Erosion of the shoreline and adjacent lakebed would be mitigated as necessary, depending on the configuration of the outfall structure and its location. The infrastructure to support the piped extension onto the lake may require anchoring within the shoreline and lake periphery (i.e., littoral zone). Anchoring would also require strong bed foundations, which may be limited within the littoral zone of the lake. This type of outfall could be undertaken under gravity flow discharge conditions if the outfall structure was stable and designed to reduce potential erosion risk.

**Technical Feasibility**

Similar to the surface spray alternative, this alternative cannot operate year-round. Therefore, this proposed alternative is not technically feasible and is not further evaluated.

**5.1.9.4 Submerged Diffuser in Perch Lake (Alignment along Lakebed)**

A submerged diffuser would be located along the lakebed and anchored to the bed at various points along the submerged pipeline in a well-consolidated zone. This would prevent settlement of the outlet into the sediment layer and limit erosion of the lakebed. Treated effluent would be dispersed into the lake by a series of small-nozzle ports attached to the diffuser pipe by extension pipes. The length of the extension pipes would be determined by the target depth for discharge in the water column to optimize dispersion and reduce

the risk of lakebed disturbance by the discharge. A relatively constant discharge is required for this option to actively disperse the discharge through the small discharge ports so as to avoid localized effluent concentrations around the diffuser; therefore, this option requires a pumped discharge condition to provide an appropriate mixing zone. This type of design would be installed within the lake at a depth below the ice cover in winter, allowing for year-round operation. The diffuser would need to be stable to optimize dispersion efficiency, so bed anchoring is critical to limit the potential for sediment mobilization during discharge. Anchors could potentially be placed in the clay layer below the soft sediment substrate.

#### **Technical Feasibility**

This option allows for year-round discharge, as the diffuser would be located in a zone within Perch Lake that is deep enough for the diffuser ports to be below ice and with sufficient water column height to allow maximized mixing within Perch Lake. Installation is considered challenging due to reported soft foundation conditions. This option requires discharge to be pumped to maintain discharge velocity. Annual inspection and maintenance by divers would be required each spring to check and clear the piped outlet, and to verify stability of the lakebed and anchors.

Procedures would be required that include monitoring to confirm the effectiveness of the diffuser and to confirm that the effluent quality remains within criteria bounds so that discharge does not present risk to aquatic biota in the receiving environment. Appropriate mitigation will be required to reduce the risk of excessive discharge variability (i.e., contingencies for the consideration of pumped discharge conditions), and water quality outside of acceptable guidelines and/or site-specific benchmarks.

#### **Economic Feasibility**

The capital and operation cost for the discharge of treated effluent to Perch Lake via a submerged diffuser is expected to represent less than 1% of the costs for the overall NSDF Project.

#### **5.1.9.5 Submerged Diffuser in Perch Lake (Diffuser Suspended in Water Column)**

Instead of lying along the lakebed as described for Option 3a, this diffuser option extends into the lake with buoyancy support and is suspended in the water column. The buoyancy support for the pipeline extension would limit the application for this option to open water conditions. This diffuser option would also need to be located in a consolidated lakebed zone of Perch Lake, as stable anchoring is necessary along the pipeline and at the diffuser end of the pipe line to keep the diffuser at a constant depth. Anchors could potentially be placed in the clay layer below the sediment substrate.

#### **Technical Feasibility**

The selected design option must be able to operate year-round to ensure that the planned storage capacity of the ECM can be met. However, this alternative will be limited to open water conditions; therefore, this alternative is not technically feasible and is not carried forward for further analysis.

#### **5.1.9.6 Impacts**

Based on the review above, two effluent discharge options were considered technically and economically feasible including:

- Piped outfall to Perch Lake with a submerged outlet.
- Submerged diffuser in Perch Lake along the lakebed.

Both alternatives are expected to have similar potential environmental effects, with the exception of pathways to surface water and aquatic biota. Within Perch Lake, the construction of either alternative will result in the disturbance of the lakebed sediment during the construction and operations phases. Mitigation will be required to limit resuspension of sediment during the construction and operations phases. The submerged diffuser is expected to result in less resuspension of sediment compared to a submerged piped outlet. Further, the submerged diffuser is expected to provide a more efficient mixing zone compared to a submerged piped outlet.

#### 5.1.9.7 Rationale

Two alternatives were considered technically and economically feasible for the discharge of treated effluent to Perch Lake. The comparative evaluation between these alternatives is provided in Table 5-11. Both alternatives will result in disturbance of the lakebed sediment during construction and operation which will require mitigation. However, the submerged diffuser is expected to limit these effects during operation. The piped outfall will also require regular maintenance to ensure that the outfall stays clear of sediment.

The submerged diffuser will provide a maximized mixing zone at the point of discharge. Based on the above, the submerged diffuser alternative is considered more favourable than the submerged piped outfall.

**Table 5-11**  
**Evaluation of Alternatives – Discharge Type**

| Criteria                                   | Alternative 1 – Piped Outfall to Perch Lake<br>(Submerged Outlet in Perch Lake)                                                                                                                                               | Alternative 2 –<br>Submerged Diffuser in Perch Lake<br>(Alignment along Lakebed)     |                                                                                                                                       |                                                                                       |
|--------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------|
| <b>Technical Feasibility</b>               |                                                                                                                                                                                                                               |                                                                                      |                                                                                                                                       |                                                                                       |
| Project Purpose                            | Both alternatives are technically feasible.                                                                                                                                                                                   |                                                                                      |                                                                                                                                       |                                                                                       |
| Schedule                                   | Both alternatives could be constructed to meet the NSDF Project start date.                                                                                                                                                   |                                                                                      |                                                                                                                                       |                                                                                       |
| Storage Capacity                           | Neither alternative will limit the storage capacity of the NSDF                                                                                                                                                               |                                                                                      |                                                                                                                                       |                                                                                       |
| Monitoring Complexity                      | The alternative will require monitoring to confirm that the treated effluent will meet effluent discharge targets. Monitoring and maintenance of the submerged outfall will be required to ensure it remains free of sediment |  | The alternative will require monitoring to confirm that the treated effluent will meet effluent discharge targets                     |  |
| <b>Economic Feasibility</b>                |                                                                                                                                                                                                                               |                                                                                      |                                                                                                                                       |                                                                                       |
| Life Cycle Costs                           | Both alternatives are expected to be less than 1% of capital and operating costs of the overall NSDF Project                                                                                                                  |                                                                                      |                                                                                                                                       |                                                                                       |
| <b>Environmental Effects</b>               |                                                                                                                                                                                                                               |                                                                                      |                                                                                                                                       |                                                                                       |
| <b>Biophysical</b>                         |                                                                                                                                                                                                                               |                                                                                      |                                                                                                                                       |                                                                                       |
| Environmental Setting                      | Both alternatives will require construction within Perch Lake                                                                                                                                                                 |                                                                                      |                                                                                                                                       |                                                                                       |
| Atmospheric Environment                    | No anticipated difference between alternatives.                                                                                                                                                                               |                                                                                      |                                                                                                                                       |                                                                                       |
| Geological and Hydrogeological Environment | No anticipated difference between alternatives.                                                                                                                                                                               |                                                                                      |                                                                                                                                       |                                                                                       |
| Surface Water Environment                  | Alternative 2 will result in less resuspension of sediment and will provide a more efficient mixing zone                                                                                                                      |  | The alternative will result in less resuspension of sediment and will provide a more efficient mixing zone compared to Alternative 1. |  |
| Aquatic Biodiversity                       | Alternative 2 will result in less resuspension of sediment and will provide a more efficient mixing zone                                                                                                                      |  | The alternative will result in less resuspension of sediment and will provide a more efficient mixing zone compared to Alternative 1. |  |

| Criteria                                                | Alternative 1 – Piped Outfall to Perch Lake<br>(Submerged Outlet in Perch Lake)                                           | Alternative 2 –<br>Submerged Diffuser in Perch Lake<br>(Alignment along Lakebed) |
|---------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| Terrestrial Biodiversity                                | No anticipated difference between alternatives.                                                                           |                                                                                  |
| Ecological Health                                       | No anticipated difference between alternatives.                                                                           |                                                                                  |
| Social                                                  |                                                                                                                           |                                                                                  |
| Socio-economics                                         | No anticipated difference between alternatives.                                                                           |                                                                                  |
| Land and Resource Use                                   | No anticipated difference between alternatives.                                                                           |                                                                                  |
| Social Acceptability                                    | No anticipated difference between alternatives.                                                                           |                                                                                  |
| Human Health and Safety                                 |                                                                                                                           |                                                                                  |
| Public Health & Safety<br>(construction and operations) | Both alternatives can be developed in a manner that protects public health and safety during construction and operations. |                                                                                  |
| Public Health & Safety<br>(long-term)                   | Both alternatives can be developed in a manner that protects public health and safety in the long-term.                   |                                                                                  |
| Worker Health & Safety                                  | Both alternatives can be developed in a manner that protects worker health and safety.                                    |                                                                                  |

#### 5.1.10 Summary and Alternative Means discussion

The NSDF Project has explored alternative means of carrying out the project, as per the guidance of IAEA SSG-29 [5-12]. Each alternative presented included a discussion of the impacts of the alternative, usually with a focus on potential environmental impacts. Advantages and disadvantages of each alternative were presented, as per IAEA SSG-23 Section 4.68 through 4.71 [5-4].

The examination of alternative means of carrying out the Project indicates the proposed near surface disposal facility is the preferable option in terms of both technical and economic feasibility. Impacts due to the construction and operation of the NSDF are either comparable or more favourable to most of the alternatives studied. As per IAEA SSG-23 [5-4], Section 4.66 and 4.67, the optimization for the Facility applied a judgemental and qualitative process to the development of the facility design, which is further expanded on in subsequent sections of the Safety Case (Sections 5.3 and 5.4).

Alternatives for facility type were examined. These included:

- No facility – on-going storage.
- Very Low Level Waste (VLLW) disposal facility.
- Near Surface Disposal Facility.
- Geologic Waste Management Facility (GWMF).

Not building a facility would involve the continued use of ongoing or interim storage, which is not in alignment with Canada's Radioactive Waste Policy Framework [5-1]. The fraction of the total LLW that could be segregated as VLLW is disproportionate to the time, effort and storage requirements that would be expended to realize any net benefit from the work. In addition, the LLW with higher activity that is segregated from the VLLW will still require a separate LLW disposal facility. A GWMF would meet the project requirements, but it is an over-engineered solution for LLW that would cost at least 10 times more than the NSDF. Therefore, a near surface facility is shown to be CNL's preferred option for the disposal of CNL's LLW.

Alternatives to the design of a near-surface facility were considered. These included:

- Engineered containment mound.
- Above ground concrete vaults.
- Shallow caverns.

Above ground concrete vaults (AGCV) are technically feasible, but are subject to deterioration from wind, rain and freeze/thaw cycles and are vulnerable to cracking as a result. The AGCV option is estimated to cost 4.5 times the ECM option. Shallow caverns were not considered feasible for the 1 000 000 m<sup>3</sup> of LLW, as this would require multiple caverns. More importantly, the average groundwater level on the CRL site means that there is a high likelihood that the hydrogeological characteristics of a shallow cavern would not meet IAEA requirements with respect to groundwater flow paths and the migration of radionuclides. The ECM design meets the requirements for the LLW, and has been demonstrated to be an effective technology at other LLW disposal sites around the world.

Alternatives to the facility location were considered. Canadian Nuclear Laboratories examined the differences between siting the facility on the CRL property and siting off-site on CNL-owned property, such as WL and the NPD site. The physical location of both WL and NPD meet most technical requirements for the siting of the NSDF. However, both WL and NPD are subject to closure, and will therefore lose many services in the next decade (i.e., Class IV power, water for sanitary and process requirements, gas or other heating sources, or other nuclear operating infrastructure). This would make the operations of a new facility difficult. Furthermore, most of the waste already exists, or will be generated, at CRL. Shipping nearly 1,000,000 m<sup>3</sup> of waste from CRL to WL or the NPD site, at an average of 20 m<sup>3</sup> of waste per truck, would result in 50 000 shipments. The potential environmental effects of transporting such large volumes by truck will be greater than disposal in an on-site facility at CRL. The off-site transport of large amounts of radioactive waste on public roads (i.e., 50 000 shipments travelling roughly 1 900 km from CRL to WL or 35 km from CRL to NPD), may raise perceived safety concerns amongst the public.

The site selection process for the proposed NSDF on CRL property was described. Of the 15 potential sites identified, only two met the mandatory criteria for the NSDF: the EMR site, and the Alternate Site (site 11A). The EMR site is the preferred site for the following reasons:

- The EMR site borders previously radiologically impacted lands, whereas the Alternate Site is considered greenfield area.
- Due to the previous radiological impacts to the Perch Lake Basin, the characteristics of the site have been studied for many decades, and is perhaps one of the best characterized plots of land in Canada from an environmental radiological transport perspective.
- The EMR site has a longer transit time for groundwater to reach the Ottawa River due to the topography and features of the Perch Lake drainage basin, as compared to those of the Alternate Site.
- The EMR site is closer to the existing LLW waste on site and also the decommissioning and demolition waste that will be generated on the CRL main campus. This also reduces the transport time, greenhouse gas emissions, and cost.

Alternatives for leachate management were considered. These included:

- Use of the existing Waste Treatment Center (WTC).
- Building a new and dedicated WWTP.
- No discharge option through the use of evaporators.

The existing WTC is over 40 years old, and there are significant uncertainties in its ability to treat the additional volume and content from the NSDF. In addition, this option would require 2 km of pipeline to be constructed on the CRL site, along with significant re-investment and upgrades to existing infrastructure. For these reasons, use of the existing WTC was deemed not technically or economically feasible. Leachate evaporation ponds were also deemed not technically feasible because the climate has no distinct dry season. As a result, the preferable leachate management strategy is the construction of a dedicated WWTP on the NSDF footprint.

Several effluent discharge alternatives were discussed. These included:

- Discharge to ground;
- Discharge to surface water, which includes discharge to:
  - Perch Creek
  - Perch Lake
  - the Ottawa River
  - the NSDF stormwater system and to ground (co-discharge)
  - to ground and surface water
- No liquid discharge.

Perch Creek does not have sufficient flow rate to accept the discharge, and was deemed to be not technical feasible. Discharging to the NSDF stormwater management ponds was also found to not be technically feasible due to the lack of space required.

Many combinations of the above alternatives are feasible for the NSDF Project, specifically discharges to Perch Lake, Ottawa River, and a combination of ground and surface water. A combination of discharge to ground and surface water is beneficial because the exfiltration gallery provides additional retention time for radioactive decay, and replenishes water to the local wetlands. The remainder of the discharge is proposed to be sent to Perch Lake, where the transit time to the Ottawa River is also beneficial for radioactive decay. Direct or combination discharge directly to the Ottawa River is also technically feasible, given that the treated effluent will meet effluent discharge targets protective of the environment and human health. However, direct discharge to the Ottawa River is expected to be perceived unfavorably by the public; therefore, discharge to Perch Lake is preferable.

The alternatives for the type of discharge to surface water (Perch Lake) were evaluated:

- Discharge by surface spray.
- Piped outfall (submerged outlet).
- Piped outfall (above water).
- Submerged diffuser (aligned along lakebed).
- Submerged diffuser (suspended in water).

The surface of Perch Creek is frozen during the winter season. The WWTP is expected to be able to operate 12 months a year. As a result, discharge by surface spray and piped outfall above water are eliminated on technical feasibility. Freezing also present complications for the diffuser suspended in water due to buoyancy being an important design factor. As a result, only two of the options are technically feasible, the submerged outlet and submerged diffuser. The diffuser has the additional bonus of provided the maximum mixing zone at the point of discharge, and is considered the preferred option.



Alternatives to carrying out the Project were evaluated. A near-surface type of facility on the CRL site has been demonstrated to be CRL's preferred option. An ECM type of near-surface facility is demonstrated to be the most appropriate for LLW. The selected site meets all project requirements. Leachate and discharge management options were identified. A mix of groundwater discharge to an exfiltration gallery combined with submerged discharge to Perch Lake is the current design basis of the facility. However, conceptual plans for a weather cover structure placed over the waste are being developed, and have the potential to reduce leachate quantities if implemented. In addition, conceptual work is being performed to evaluate the feasibility of an artificial wetland as an effluent discharge option.

## 5.2 Site Characterization

Site characterization contributes to the safety of the system by reducing uncertainties associated with site characteristics or potential hazards associated with the site. Site-specific characterization enables the NSDF Project to:

- Provide site environmental baseline and site specific information.
- Make informed-decisions during site selection and design.
- Develop detailed design using site-specific data and inputs.
- Develop numerical models representative of the site.
- Develop environmental monitoring.

The scope of site characterization has been optimized during site selection and detailed design phases. Table 5-12 provides key references corresponding to NSDF Project site characterization. The scope of site characterization included interdisciplinary surveys to understand the characteristics of soil, rock, surface water, groundwater quality and quantity, biodiversity and the archeological characteristics of the EMR site (i.e., NSDF site) and the Alternative Site. The level of site characterization detail increased as the NSDF Project developed. Figure 5-2, Figure 5-3 and Figure 5-4, illustrate the testing, depth of boreholes, and survey locations at the NSDF site, respectively.

During the site selection phase, site characterization was performed on both the EMR site and the Alternative Site to provide data. Existing CRL data on the site locations was used at the beginning of the NSDF Project. LIDAR data was used to define the topography and GPR was used to define the overburden thickness. A multidisciplinary survey (Phase 0), characterized the soil, groundwater, biodiversity and any archeological sites at the NSDF site and the Alternative Site.

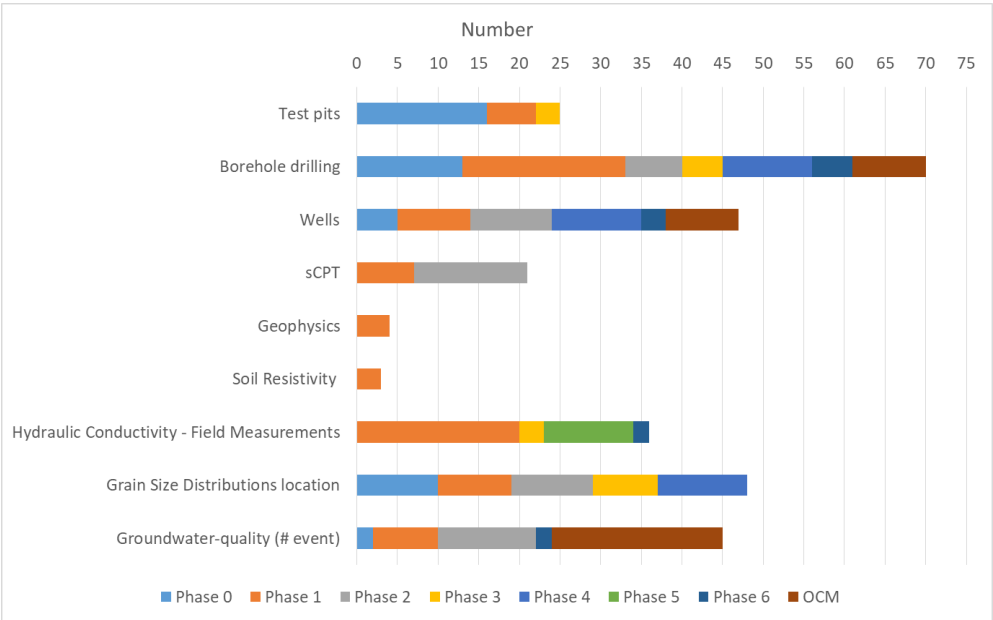
During the detailed design phase, site characterizations focused on the EMR site to provide site-specific data to develop detailed design, to enable the construction phase and future monitoring, and to develop models and analyses to support license application documents. An extensive multidisciplinary site characterization survey was completed at the NSDF site (i.e., Phase 1 to 6 and OCM (Operational Control Monitoring)). Depths of borehole investigation were extended from soil to bedrock. The site characterizations included 123 survey locations with maximum depth of approximately 32.9 m. In total, approximately 582 m of soil samples and 367 m of rock core were used for site characterization.

The current hydrogeology models have been calibrated using on-site measurements of rock properties and groundwater profile, making the model representative of the EMR site. Radiological surveys of the soil and vegetation samples from the EMR site were taken to support the construction phase. Groundwater monitoring wells and air monitoring systems have been installed at the EMR site to provide a baseline for the development of the future monitoring program.

**Table 5-12**  
**Site Characterization for the NSDF Project**

|                                                  |                                                                                  |                                        | Site Selection                          | Detail Design                     |                           |                                      |           |
|--------------------------------------------------|----------------------------------------------------------------------------------|----------------------------------------|-----------------------------------------|-----------------------------------|---------------------------|--------------------------------------|-----------|
| Topics                                           | Documents                                                                        | References                             | Select site & develop conceptual design | Provide input for detailed design | Enable construction phase | Enable future monitoring and testing | Licensing |
| <b>Geotechnical</b>                              |                                                                                  |                                        |                                         |                                   |                           |                                      |           |
|                                                  | Subsurface investigation at NSDF site (Phase-0)                                  | [5-30], [5-33]                         | x                                       |                                   |                           |                                      |           |
|                                                  | Pre-existing information from CRL Site & site investigation at alternative sites | [5-34], [5-35], [5-36]                 | x                                       |                                   |                           |                                      |           |
|                                                  | Multidisciplinary subsurface investigations Phase 1                              | [5-37]                                 |                                         | x                                 |                           |                                      |           |
|                                                  | Multidisciplinary subsurface investigations Phase 2                              | [5-38]                                 |                                         | x                                 |                           |                                      |           |
|                                                  | Multidisciplinary subsurface investigations Phase 3                              | [5-39]                                 |                                         | x                                 |                           |                                      |           |
|                                                  | Multidisciplinary subsurface investigations Phase 4                              | [5-40]                                 |                                         | x                                 |                           |                                      |           |
|                                                  | Multidisciplinary subsurface investigations Phase 5                              | [5-41]                                 |                                         | x                                 |                           |                                      |           |
|                                                  | Multidisciplinary subsurface investigations Phase 6                              | [5-42]                                 |                                         | x                                 |                           |                                      |           |
|                                                  | Groundwater elevation and quality                                                |                                        |                                         |                                   |                           |                                      |           |
|                                                  | Groundwater quality                                                              | [5-43], [5-44], [5-45]                 |                                         | x                                 | x                         | x                                    |           |
|                                                  | Groundwater elevation and quality at NSDF Site                                   | [5-46], [5-47], [5-48]                 |                                         | x                                 | x                         | x                                    |           |
|                                                  | Groundwater elevation and quality at CRL site                                    | [5-49], [5-50]                         |                                         |                                   | x                         | x                                    |           |
|                                                  | Hydrogeology models                                                              | [5-7]                                  |                                         |                                   |                           |                                      | x         |
|                                                  | Physical Characteristic of Perch Lake                                            | [5-51]                                 |                                         |                                   |                           | x                                    | x         |
|                                                  | Air quality monitoring                                                           | [5-52]                                 |                                         |                                   |                           | x                                    |           |
| <b>Radiological and chemical characteristics</b> |                                                                                  |                                        |                                         |                                   |                           |                                      |           |
|                                                  | Soil sampling                                                                    | [5-53], [5-54], [5-55], [5-56], [5-57] |                                         |                                   | x                         |                                      |           |
|                                                  | Vegetation sampling                                                              | [5-58], [5-59]                         |                                         |                                   | x                         |                                      |           |
| <b>Biodiversity and archeology</b>               |                                                                                  |                                        |                                         |                                   |                           |                                      |           |
|                                                  | Biodiversity at NSDF site                                                        | [5-60]                                 | x                                       | x                                 | x                         | x                                    |           |

|        |                                                     |            | Site Selection                          | Detail Design                     |                           |                                      |           |
|--------|-----------------------------------------------------|------------|-----------------------------------------|-----------------------------------|---------------------------|--------------------------------------|-----------|
| Topics | Documents                                           | References | Select site & develop conceptual design | Provide input for detailed design | Enable construction phase | Enable future monitoring and testing | Licensing |
|        | Stage 1, 2, 3 Archeological                         | [5-61]     | x                                       |                                   |                           |                                      |           |
|        | Stage 4 Archeological                               | [5-62]     | x                                       |                                   |                           |                                      |           |
| Design |                                                     |            |                                         |                                   |                           |                                      |           |
|        | Conceptual Design                                   | [5-63]     | x                                       |                                   |                           |                                      |           |
|        | Scope of characterization for detailed design phase | [5-64]     |                                         | x                                 |                           |                                      |           |
|        | Geotechnical synthesis report                       | [5-65]     |                                         | x                                 | x                         | x                                    |           |



Note:  
Phase 0 was done during site selection phase.  
Phase 1, 2, 3, 4, 5, 6, and OCM (Operation Control Monitoring) were done during detailed design phase.

Figure 5-2 Site Characterization Survey for NSDF Project

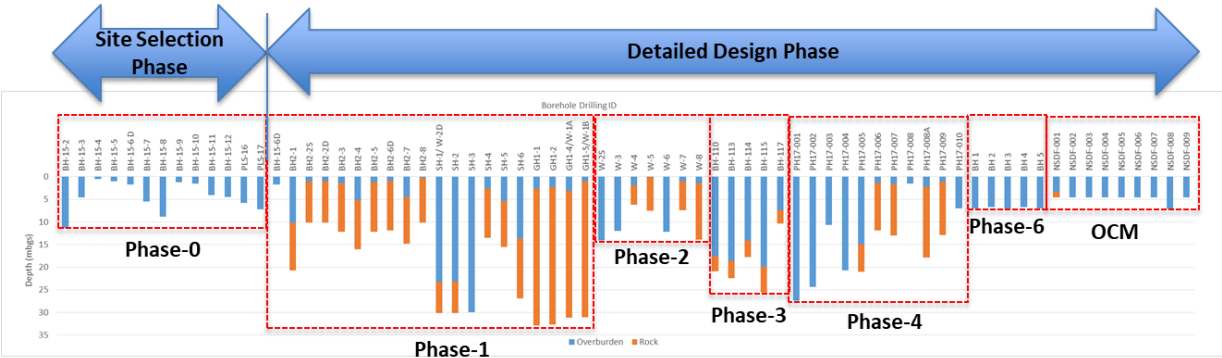
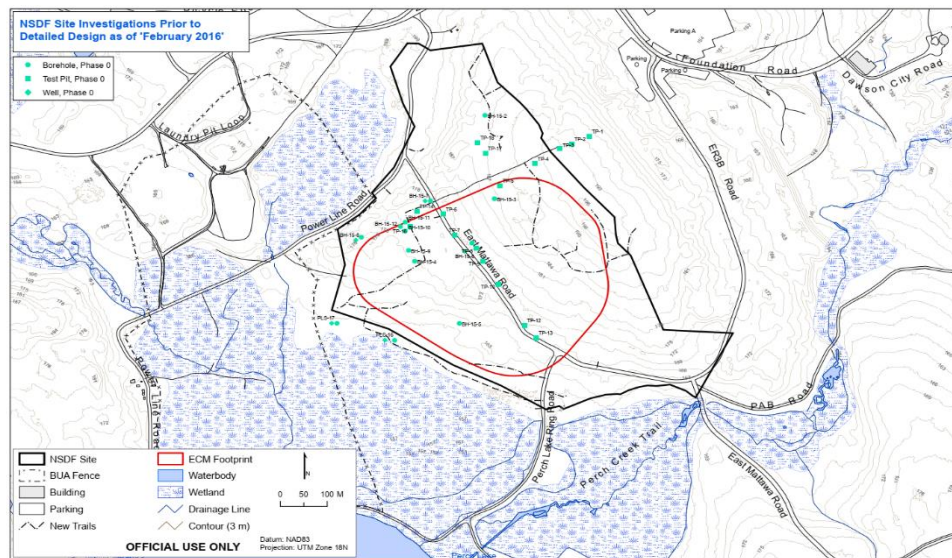
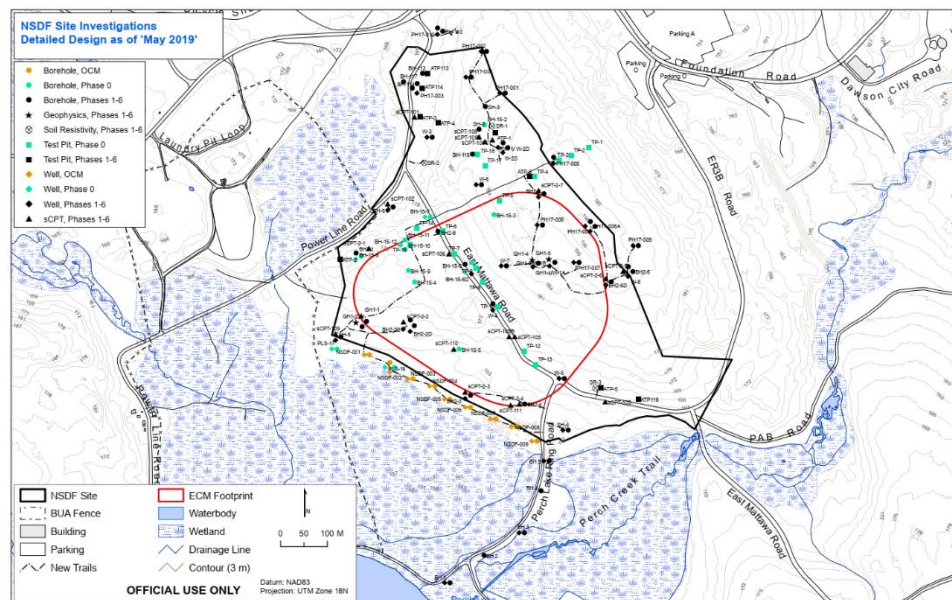


Figure 5-3 Depths of Boreholes



(a) Site Selection Phase



(b) Detailed Design Phase

**Figure 5-4 Geotechnical Survey Locations at the NSDF Site**

### 5.2.1 Site Characterization Optimization

As a result of site characterization, optimization was made to the following aspects: site boundary; protection of species at risk; design and numerical models; and monitoring systems.

#### 1. Site Boundary

Figure 5-5 illustrates changes to the NSDF Project site boundary in response to archeological assessments. The NSDF Project included four stages of archeological assessment that were conducted during the site selection

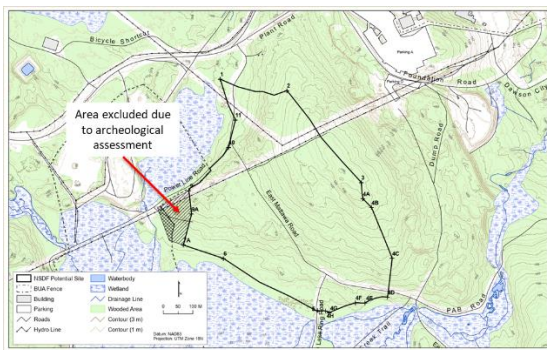
and detail design phases, in parallel with site selection process. Final site selection was deferred until the results of the archeological assessment were available.

Based on the findings during Stages 1- 3 archeological assessment, the site boundary was modified to exclude an unsuitable area from archeological aspects and to include additional area to meet the NSDF Project requirement. Current archeological assessment (i.e., Stage 4), concluded that no further archaeological assessment is required to start NSDF construction.

In response to the recommendations provided in the biodiversity and habitat review, bat houses, turtle fence, and turtle culverts have been installed at the NSDF site to protect the species at risk that will potentially be affected by the Project.

During the detailed design phase, field characterizations were extended to the bedrock and groundwater monitoring wells were added at the NSDF site. The results reduced uncertainty in the design and hydrogeology numerical models.

Monitoring systems have been initiated and strategically placed at the NSDF site to enable construction and future phases. The monitoring system includes: groundwater monitoring wells to monitor groundwater quality and quantity, and dust monitoring stations.



(a) Initial Site Boundary



(b) Current Site Boundary

**Figure 5-5 Change of site Boundary in Response to Archeological Assessment**

### 5.3 Engineered Containment Mound Design Optimization

The NSDF Project selected an ECM design life of 550 years. The NSDF analysis and testing program indicated that the HDPE GMB, the main component of base liner and final cover systems, could have a service life significantly longer than the design requirement of 550 years.

The ECM has been designed in accordance with CNL's Design Authority and Design Engineering program [5-66]. This section describes the evolutions and results of ECM design iteration and optimization. The ECM design iteration included conceptual design, followed by 30%, 60%, 90%, 100%, and post 100% detailed design.

The ECM detailed design has used accepted methodologies, codes, standards, and available information. The safety case and detailed design documentation will be updated in the future to incorporate the as-built ECM configurations and material properties.

#### 5.3.1 Optioneering

As part of 30% design development an Optioneering study was conducted to select options for the ECM design components. The options evaluated were: (1) ECM Floor Elevation; (2) LCS and Leak Detection System (LDS); (3) Types of Base Liner Systems; and (4) Geometry and Configuration of Final Cover System.

##### 5.3.1.1 Engineered Containment Mound Floor Elevation

Three options were considered for the ECM floor elevation: Lower Floor Elevation (Option 1), Higher Floor Elevation (Option 2); and Mid-Level Floor Elevation (Option 3) (Figure 5-6). The Mid-level floor elevation (Option 3) was selected, because this configuration reduces the impact to the groundwater level table and eliminates the risk associated with installing an underdrain system.

##### 5.3.1.2 Leachate Collection System and Leak Detection System

Figure 5-7 illustrates two options considered in the Optioneering study of the LCS and LDS design [5-67]: the use of sump/pumps (Option 1); or Gravity (Option 2). Option 1 using the sump and pump system for the LCS was recommended and selected.

Following the option evaluation study, each component of the ECM base layer system was evaluated individually for the suitability of the LCS and LDS design [5-68]. The evaluation confirmed the design specifications for the LCS and LDS were optimized with respect to:

- Hydraulic conductivity of the drainage layer (i.e., grain size of the granular layer), based on the average annual infiltration rate.
- Maintaining the leachate head level above the primary liner below the design criteria. This is achieved by a combination of the hydraulic conductivity of the granular layer and the maximum spacing between LCS collection pipes.
- Clogging prevention, based on the three major anticipated clogging mechanisms: growth of biomass, precipitation of minerals, and deposition of suspended solids. While the system is not expected to experience extensive chemical/biological clogging or fouling during operations, the design includes provisional cleanout ports.
- Long-term structural seismic stability of the LCS and LDS components.

- Collection pipe size and material.
- Pump capacity.
- Leachate storage.
- Frost protection.

#### **5.3.1.3 Base Liner System**

Figure 5-8 illustrates three design options considered for the Optioneering study]: single CCL (Option 1); Single Composite Liner (Option 2); or Double Composite Liner (Option 3). The Double Composite Liner (Option 3) was selected for the base liner system.

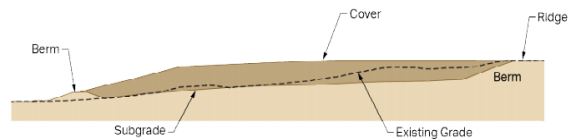
#### **5.3.1.4 Final Cover System**

The geometry of the final cover system affects the long-term maintainability and stability of the ECM. Figure 5-9 illustrates three design options considered in the Optioneering study [5-69]: gabel (Option [a]), mansard (Option [b]) or ridges and valleys (Option [c]). The ridges and valleys (Option [c]) configuration was selected to control storm water events, to prevent erosion, and to achieve long-term performance.

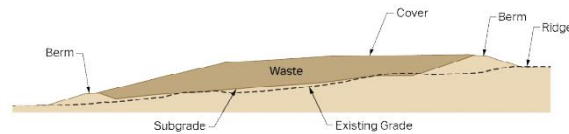
#### **5.3.1.5 Cell Configuration and Waste Placement**

Figure 5-11 illustrates the changes to the ECM cell configuration and waste placement throughout the design process. The conceptual design was comprised of four cells and did not specify any development phases [5-63]. The 60% design introduced two phases of development and 10 cells. Increasing the number of cells can potentially reduce the quantity of contact water and contribute to safety during the operation phase. The final design simplified the cell configuration and waste placement to avoid potential errors during the operations phase [5-70].

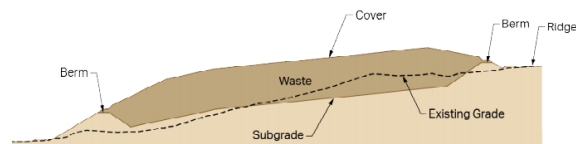




**Option 1 – ECM Profile Based upon Excavation**

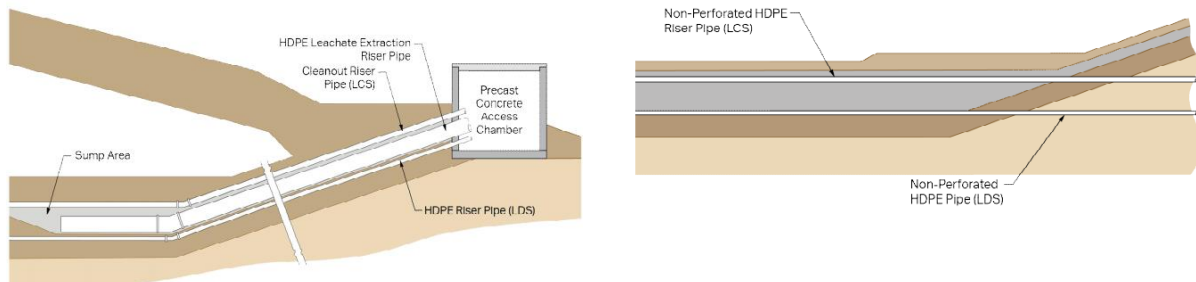


**Option 2 – Higher Floor Elevation**



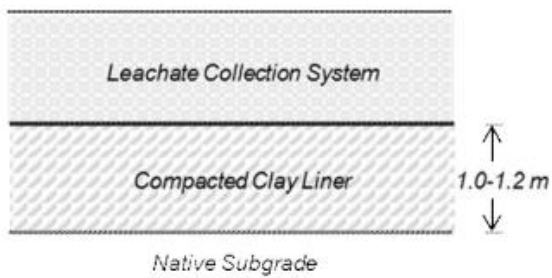
**Option 3 – Mid-level Floor Elevation (Selected)**

**Figure 5-6 Options for Engineered Containment Mound Floor Elevations**

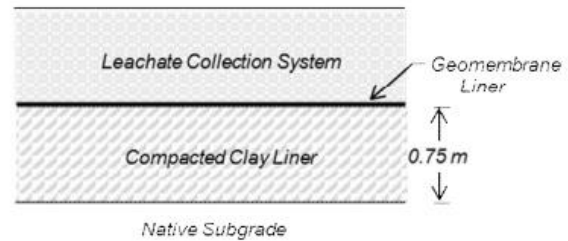


**Option 1 - LCS on Top of Base Liner (Selected)    Option 2 - Gravity LCS through the Base Liner System**

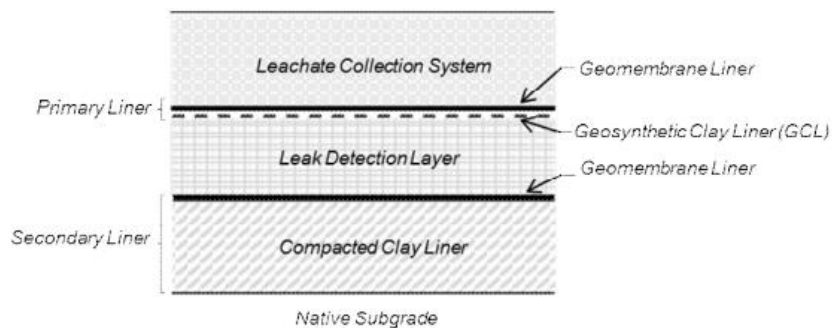
**Figure 5-7 Options for Leachate Collection Removal System**



Option 1 – Single Compacted Clay Liner



Option 2 – Single Composite Liner



Option 3 – Double Composite Liner (Selected)

Figure 5-8 Options for Base Liner System

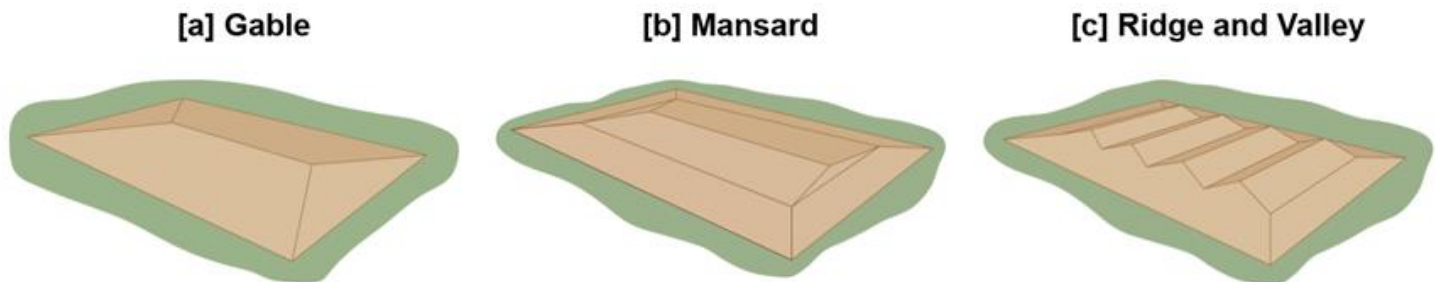
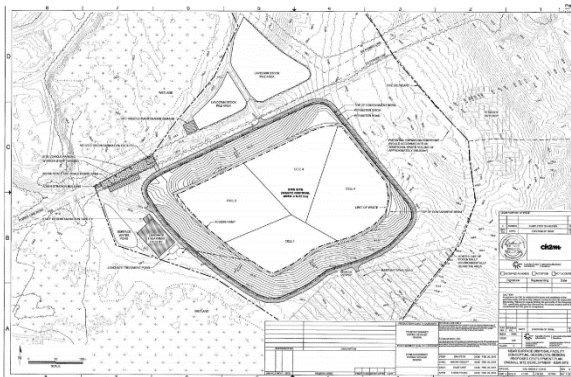
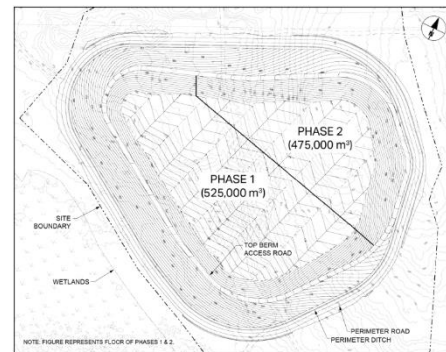


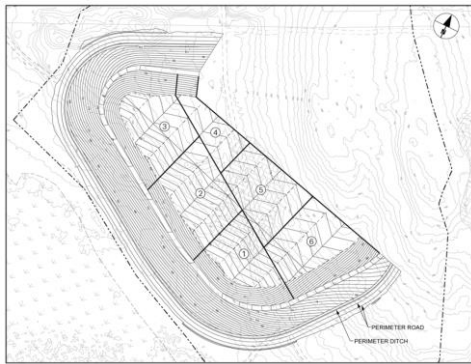
Figure 5-9 Options for Cover System



(a) Conceptual Design with 4 Cells



(b) Detailed Design 2 Phases, 10 Cells



(c) Initial Detailed Design, Phase 1



(d) Initial Detailed Design, Phase 2



(e) Current Detailed Design, Phase 1



(f) Current Detailed Design, Phase 2

**Figure 5-10 Changes on the Configurations of the ECM Cells and Waste Placement**

### 5.3.2 Seismic Design

Seismicity is considered in the ECM design. Figure 5-11 illustrates the process to conduct seismic design:

- (1) Definition of design criteria, seismic hazards for the site, design configuration and material properties;
- (2) Conducting analyses to assess the performance of the ECM design in response to the site-specific seismic

hazard; and (3) Evaluating whether the ECM design can meet the criteria. If the criteria are met, then the ECM seismic design is considered adequate, otherwise the ECM design was modified to mitigate seismicity issues.

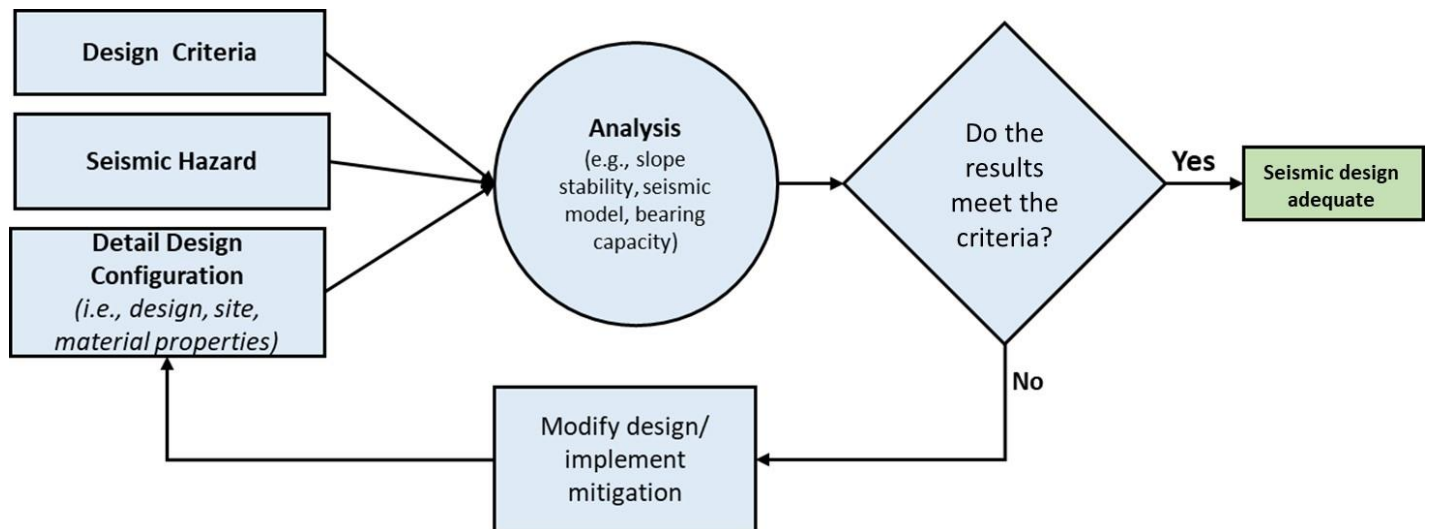


**Figure 5-11 Process for NSDF Seismic Design**

### 5.3.2.1 Site-Specific Seismic Hazard and Criteria

A site-specific PSHA was performed to determine the seismic level corresponding to the NSDF site for the ECM design [5-71]. The analysis considered: past seismic data in the vicinity of the NSDF site; assessment of geologic site conditions; regional seismo-tectonic conditions; development of a seismic source model; and calculation of earthquake ground motions [5-71]. The analysis utilized the current methodology developed by the Geological Survey of Canada and complied with 2015 NBCC [5-72]. An ITPR by a SME from an academic institution, confirmed the suitability of the PSHA results to develop the ECM detailed design at the NSDF site in Chalk River, Ontario [5-73].

Table 5-13 summarizes the seismic performance criteria used to design the ECM, which include: PGA, maximum strain and displacement, and minimum Factor of Safety (FS). The ECM seismic performance criteria were defined according to CSA N289.4-12 [5-74]. The ECM must be able to withstand a 1-in-10 000 year seismic event, while maintaining containment of waste and leachate. Seismic deformations due to the 1-in-2 500 year seismic event, must not result in damage that requires an emergency response, or impedes operation of the ECM. Containment of waste and leachate must be maintained.

Maximum strain and displacement, and minimum FS, were determined based on case histories of the existing disposal facilities comparable to the NSDF including: Environmental Management Waste Management Facility (EMWMF) in Oak Ridge, Tennessee (USA), and Fernald On-site Disposal Facility in Ohio (USA) [5-75].

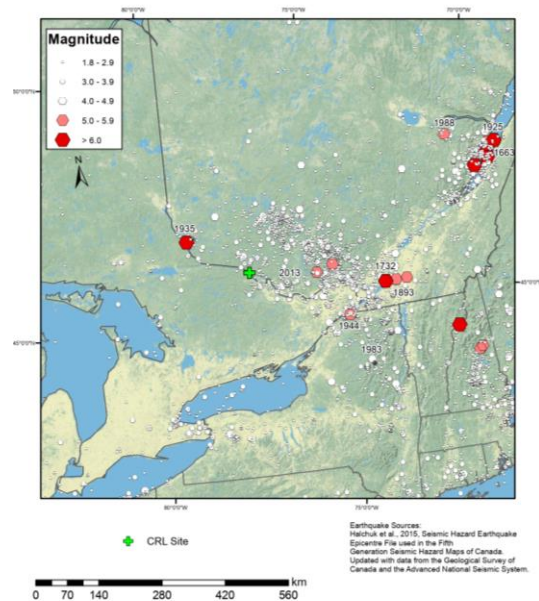


**Figure 5-12 Historical Seismicity of Northeastern United States and Southeastern Canada (1627-2017) [5-71]**

**Table 5-13**  
**Seismic Performance Criteria for the NSDF ECM [5-71]**

| Seismic Loading Criteria                             | Design Analysis or Parameter                                  | Performance Criteria |
|------------------------------------------------------|---------------------------------------------------------------|----------------------|
| Design Basis Earthquake (DBE)<br>(10 000 year event) | Design PGA <sup>1</sup>                                       | 0.55 g               |
|                                                      | Maximum Permanent Displacement of Base Liner GMB <sup>2</sup> | < 30 cm              |
|                                                      | Maximum tensile strain on GMB components <sup>3</sup>         | < 3%                 |
|                                                      | Post-Earthquake FS                                            | > 1.20               |
|                                                      | Other: No slope reversal for both cover and liner system      |                      |
| Operating Basis Earthquake (OBE) (2 500 year event)  | Design PGA <sup>1</sup>                                       | 0.25 g               |
|                                                      | Maximum Permanent Displacement of Base Liner GMB <sup>2</sup> | < 15 cm              |
|                                                      | Cover displacement                                            | < 30 cm              |
|                                                      | Seismic (Pseudostatic) FS                                     | > 1.0                |

<sup>1</sup> PGA – Peak Ground Acceleration

<sup>2</sup> The maximum deformation criteria for the LCS and leak detection system piping are the same as those presented for the base liner GMB. The piping is anticipated to see the same deformations and is anticipated to be no more deformation-sensitive than the GMB.

<sup>3</sup> Strain includes both locked-in static strains due to vertical settlement, and strains induced by seismic deformation.

### 5.3.2.2 Ground Improvement

The ECM design considers potential liquefaction, due to the level of seismic hazards at the NSDF site. Liquefaction is defined as the loss of soil shear strength under monotonic or cyclic loading, such as due to seismic events. Liquefaction only occurs in saturated soils and its susceptibility depends on soil and rock characteristics at the site. Liquefaction is mitigated by implementing sufficient ground improvement or design features as part of the ECM design. The ECM seismic design included: liquefaction analysis, deformation analyses, and slope stability analyses.

The objectives of the liquefaction analysis were to assess:

1. Whether ground improvement is required, and
2. The extent of required ground improvement to mitigate potential liquefaction due to seismic hazards at the site [5-76].

Liquefaction analysis used the results of PSHA and the site characterizations at the NSDF site (i.e., seismic Cone Penetration Test). The analysis followed the methodology defined in [5-77]. The analysis used several computer codes (i.e., CLIQ, FLAC 2D, FLAC 3D, and SHAKE). The results of finite difference models (i.e., FLAC 2D, FLAC 3D and SHAKE) defined the ground surface as input to the liquefaction analyses. A computer code (i.e., CLIQ), was used to perform the liquefaction analysis. The analysis concluded that a ground improvement is required to mitigate potential liquefaction associated with the ECM design and site.

Ground improvement options considered were: in situ soil cement mixed panels, vibro-replacement (stone columns), vibro piers, excavation and replacement, and dynamic compaction. Initially, the stone column option was selected, however this option was not considered to be adequate in preventing liquefaction based on the PSHA results. The “Excavate and Replace” method was selected as the optimal liquefaction mitigation method [5-76] and [5-78]. Figure 5-13 illustrates typical berm section with “excavate and replace” ground improvement.

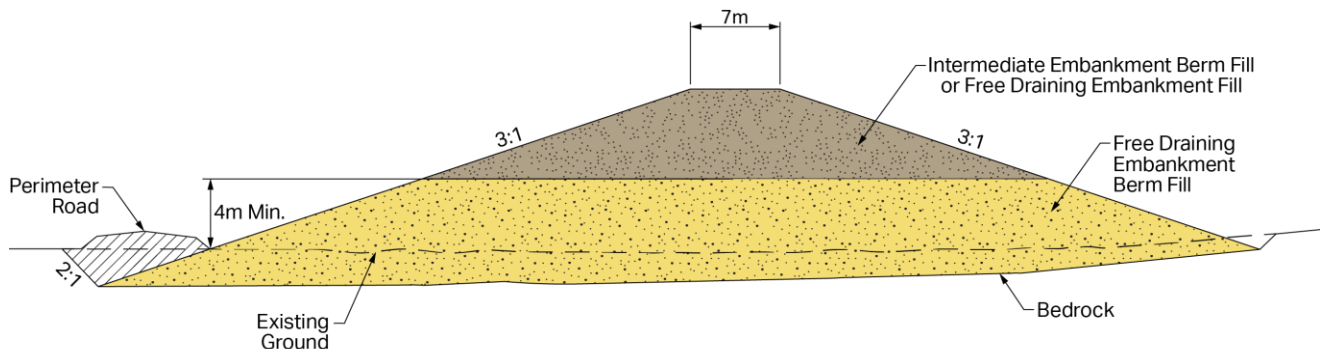


Figure 5-13 Typical Berm Section

### 5.3.2.3 Deformation Analyses

Deformation analyses were performed to assess the magnitude of seismically-induced ECM deformation and strains [5-76]. The analyses used numerical models and analytical methods. The results were compared to the corresponding criteria (see Table 5-14).

FLAC 3D Version 5.01, a finite difference code, was used to perform non-linear time-history analyses on the ECM during operation and post-closure phases due to seismic events. The analyses utilized 2D and 3D

geometries and included selected cases before application of ground improvement and after application of ground improvement. Figure 5-14 shows an example of results from time history analyses. The results confirmed: (1) the need for ground improvement to mitigate a potential liquefaction and (2) effectiveness of ground improvement to eliminate potential liquefaction due to seismic hazards at the NSDF site.

The criteria for maximum seismically induced deformations under the OBE and DBE seismic events were 15 cm and 30 cm, respectively. The results of analyses, with ground improvement, demonstrated that the maximum shear displacements due to seismic loads were less than 2 cm and 5 cm along the base and cover liner systems, respectively. These displacements were well below the criteria of 30 cm. The maximum seismically induced axial strains in the base and cover liners were less than 0.9% and 0.2%, respectively, which were significantly less than criteria of < 3%.

In addition to numerical models, analytical methods were used to calculate seismically induced slope displacements [5-79], using the methods developed by Makdisi and Seed [5-80], Bray and Travasarou [5-81]; and Swaisgood [5-82]. The results confirmed, that the displacement due to seismic events, were well below the criteria. In conclusion, the ECM is not anticipated to experience loss of containment due to seismic event after application of ground improvement. No further optimization is required to the seismic design of the ECM.

**Table 5-14**  
**Calculated Maximum Deformation Analysis and Criteria**

|                                                                                      | Due to OBE event |            | Due to DBE event |                                                        |
|--------------------------------------------------------------------------------------|------------------|------------|------------------|--------------------------------------------------------|
| Results of the analysis                                                              | Results**        | Criteria** | Results**        | Criteria**                                             |
| FLAC Models                                                                          |                  |            |                  |                                                        |
| 2D and 3D FLAC Models<br>Maximum Shear Displacements<br>along the base liner systems | 2 cm             | 15 cm      | 2 cm             | 30 cm                                                  |
| Final Cover system                                                                   | 5 cm             |            | 5 cm             | 30 cm                                                  |
| Maximum axial strain – base                                                          | NA*              | NA*        | 0.9%             | Maximum tensile<br>strain on GMB<br>components<br>< 3% |
| Maximum axial strain at the final<br>cover system                                    | NA*              | NA*        | 0.2%             |                                                        |
| Analytical Calculation                                                               |                  |            |                  |                                                        |
| Makdisi and Seed [5-80]                                                              | <1 cm            | 15 cm      | 3.06 cm          | 30 cm                                                  |
| Bray and Travasarou [5-81]                                                           | <1 cm            |            | <1 cm            |                                                        |
| Swaigood [5-82]                                                                      | 2.6 cm           |            | 5.6 cm           |                                                        |

Note: \*NA: Not part of the assessment; \*\*The ECM design meets criteria when the displacement and strain results are less than criteria.



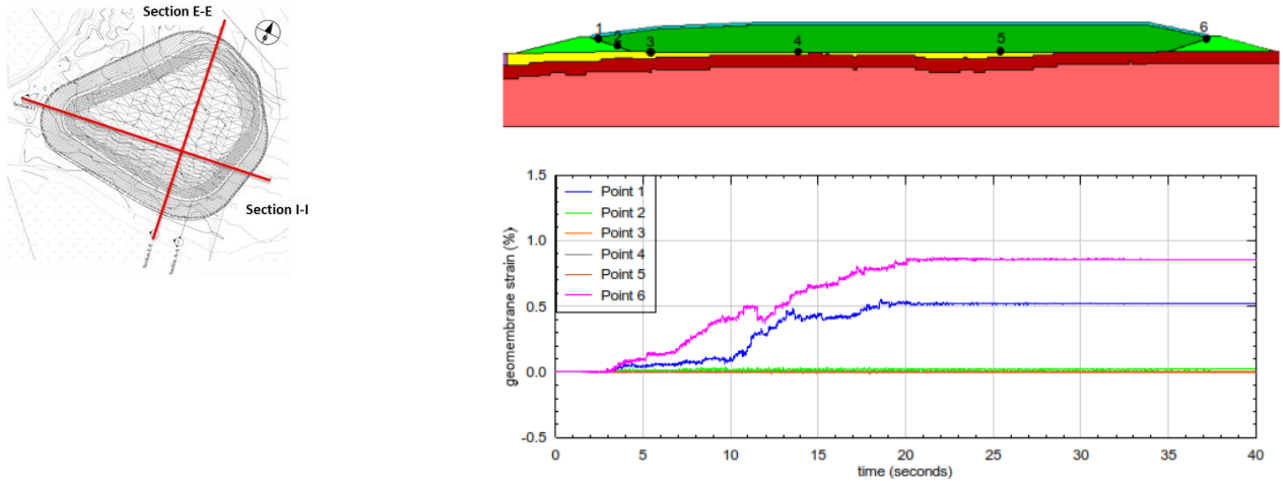


**Figure 5-14 Example of the Results of Time History Analyses  
 (Geomembrane Strains at the Base Liner Systems across Section I-I)**

#### 5.3.2.4 Slope Stability Analyses

Slope stability analysis was performed to assess the FS of selected ECM slope cases during pre-closure and post-closure phases [5-79] (see Table 5-15). A higher FS indicates a more stable slope.

A computer code, SLOPE/W 2016, was utilized to conduct limit equilibrium. The SLOPE/W code is commonly used in geotechnical engineering practice in Canada and internationally. The analysis utilized circular and block methods to determine failure surfaces. The inputs included the properties of soil and rock from site characterizations at the NSDF and properties of the berm, liner systems, and waste properties based on the design specifications.

Engineering properties of the ECM design components (e.g., base liner and final cover systems, berms, embankments, etc.) and waste and their spatial distribution have been defined in design specifications [5-83], landfill development and sequencing plan [5-84], waste placement and compaction plan [5-85], and waste acceptance criteria [5-86].

The results of the ECM slope stability analysis confirm that the stability of the ECM slopes have been optimized during operation and post-closure phases.



**Table 5-15**  
**Factor of Safety from Slope Stability Analyses**

|    |                                                                      | Short-Term<br>(pre-closure) | Long-term<br>(post-closure) | Minimum<br>FS** | FS from Slope Stability Analysis** |                     |              |
|----|----------------------------------------------------------------------|-----------------------------|-----------------------------|-----------------|------------------------------------|---------------------|--------------|
|    |                                                                      |                             |                             |                 | ECM/<br>Containment<br>Berm        | Containment<br>Berm | Working Face |
| 1. | Static Analysis<br>(Drained Case)                                    | Yes                         | -                           | 1.5             | 2.37 to 2.47                       | -                   | 1.89 to 1.92 |
|    |                                                                      | -                           | Yes                         |                 | 2.40 to 3.24                       | 2.23 to 2.78        | NA*          |
| 2. | Pseudostatic<br>Analysis (Seismic<br>Case) OBE<br>(2 500 year) event | Yes                         | No                          | 1.0             | 1.23 to 1.69                       | 1.28 to 1.74        | 1.00 to 1.14 |
| 3  | Residual Analysis                                                    | No                          | Yes                         | 1.2             | 1.73 to 1.83                       | 1.46 to 1.51        | NA*          |
| 4  | Post-Earthquake<br>Analysis                                          | -                           | Yes                         | 1.2             | 1.95 to 2.89                       | 1.98 to 2.45        | NA*          |

Note: \*NA = not part of the analysis; \*\*FS meets criteria, when FS from slope stability analysis is greater than criteria.

The bathtubbing effect in the post-closure phase seismic analysis did not include the effect of “bathtubbing”. Bathtubbing refers to a predicted state of the ECM at a point in time where the base liner system is functioning as designed and the final cover system has degraded, allowing water to build up inside the ECM waste layer. The slope stability analysis [5-87] had not accounted for the pressure and mass of the water, and the overall effect that this additional mass would impart during a seismic event. Further analysis was performed [5-87]. The results of the analyses show that:

- Saturated waste consideration has insignificant effect on the overall seismic performance of the ECM, and;
- The “bathtubbing” scenario passes both the static and post-earthquake scenarios.

The ECM will be constructed on a slope. This greatly limits the volume of water that can possibly accumulate inside the ECM before flowing over the perimeter berm. At peak bathtubbing the projected volume of saturation is 6 588 m<sup>3</sup>, meaning that less than 1% of the waste may be saturated with water. Figure 5-15 and Figure 5-16 demonstrates where water is calculated to accumulate based on the slope of the facility and height of the berm. Figure 5-15 shows the area impacted by bathtubbing, while Figure 5-16 illustrates the water level at the 2 cross sections “WW” and “EE” indicated on Figure 5-15, with respect to the berm and ECM height.

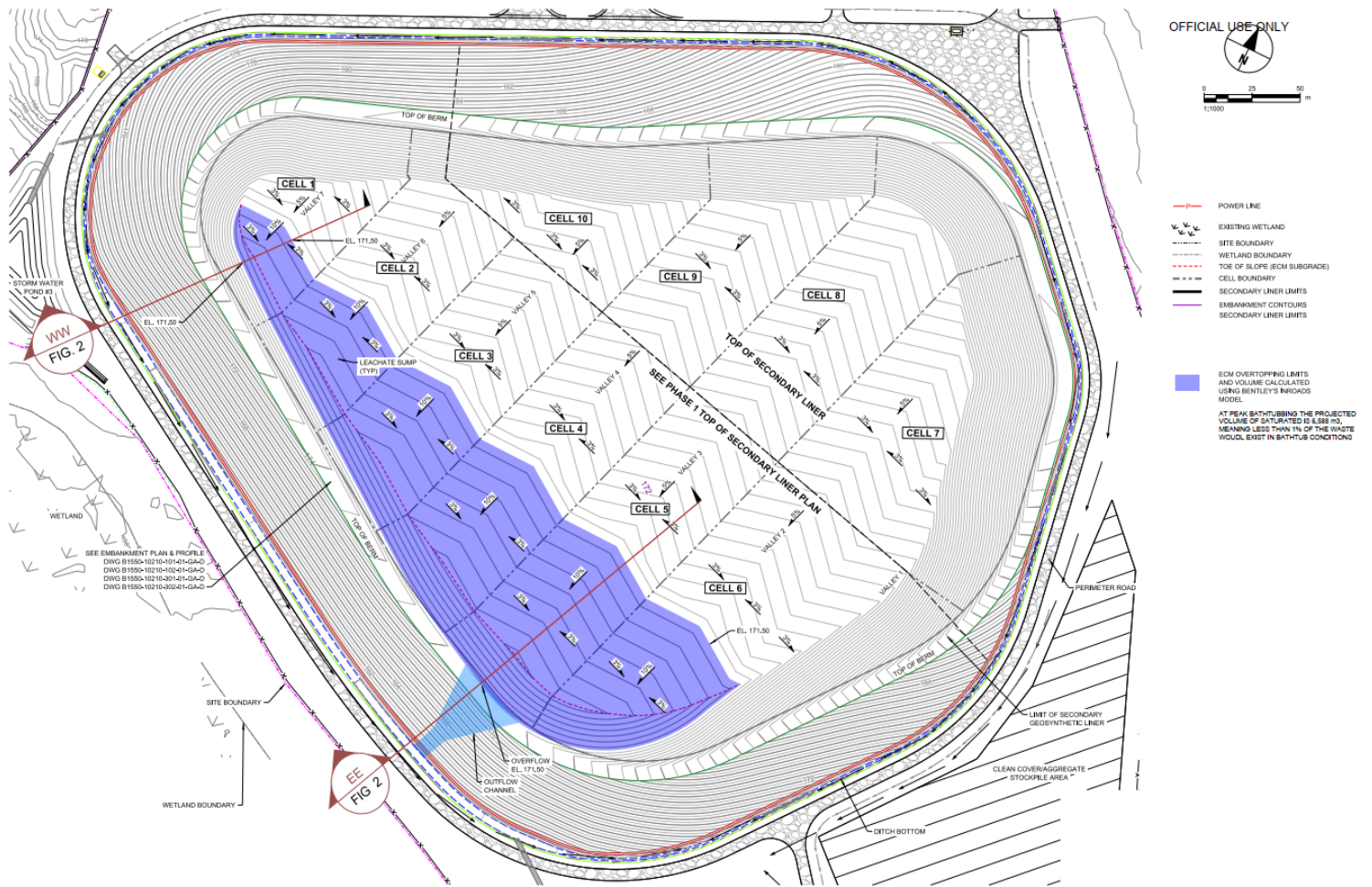
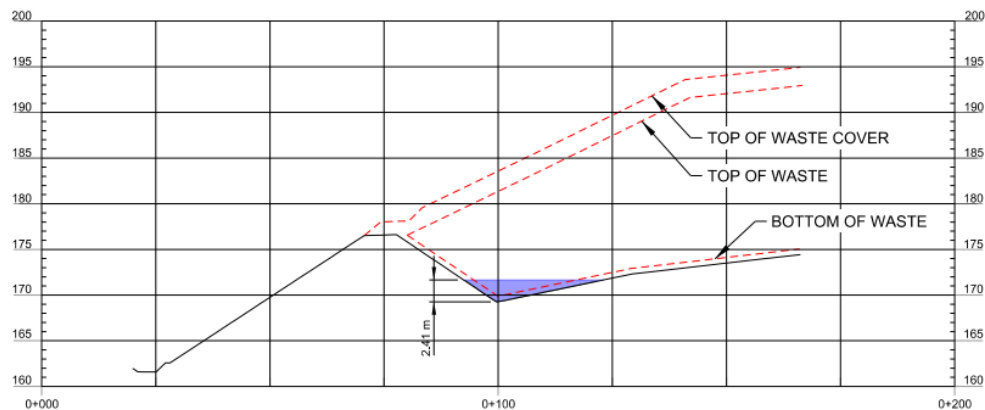


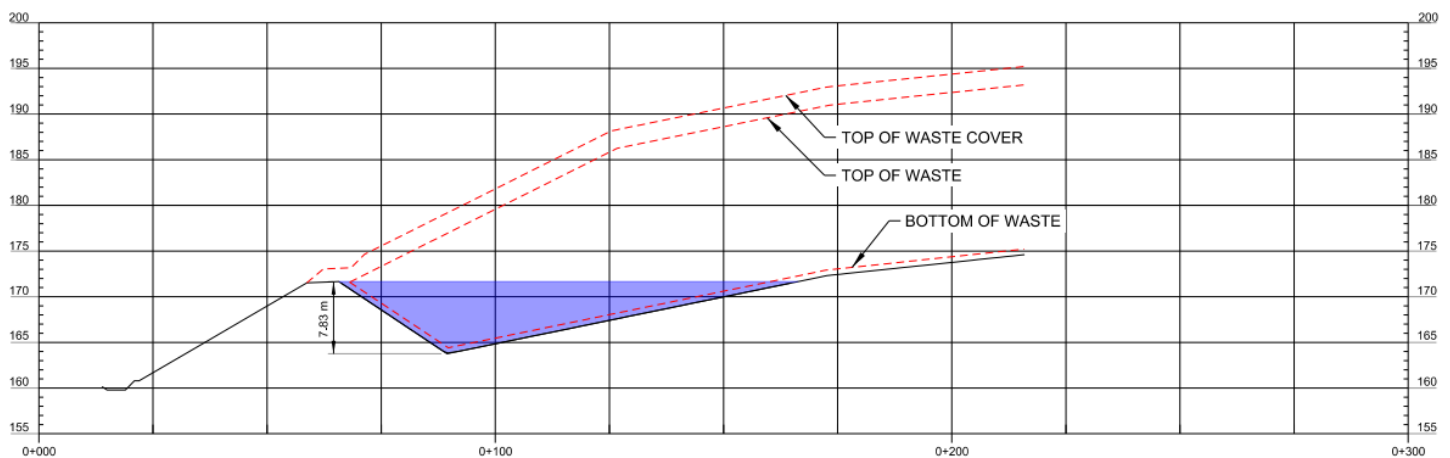
Figure 5-15 ECM Bathtubbing Scenario



### WW | WEST OVERTOPPING PROFILE

FIG. 1

Scale: 1:1 (H) 1:2 (V)



### EE | EAST OVERTOPPING PROFILE

**Figure 5-16 ECM sections WW and EE under saturated conditions**

#### 5.3.2.5 Saturated Waste Conditions

An additional seismic analysis [5-88] has been performed and demonstrates the capacity of the ECM perimeter berm to continue to provide its structural function, even when subjected to the scenario of a DBE event and saturated waste conditions, mounding of the water table inside the waste layer (i.e., bath tubing conditions). The saturated waste conditions has an insignificant effect on the overall seismic performance of the ECM [5-88]. This seismic analysis [5-88], along with the seismic analysis [5-76] show that the ECM perimeter berm has a large factor of safety. This factor of safety implies that the ECM perimeter berm would remain structurally stable even if there is some damage due to the PMP event.

The ECM has been designed to provide erosion resistance to a PMP event when the final cover has been installed. The erosion resistance stems from design features selected to resist Probable Maximum Flows generated from a PMP including:

- Rockfill on the sides of berm (installed prior to operations).
- Concrete down chutes on the sides of the berms for concentrated flows (installed prior to operations).
- Turf Reinforcement Mat in the valleys on the cap.
- Riprap in valleys on cap.
- Riprap in steeper sections of the cap.

The erosion from a PMP has been assessed and is documented in [5-89].

During operations, a sacrificial liner is installed over the entire ECM baseliner and inner 3:1 side-slope of the perimeter berm (excluding the active cell) to protect the top layer of the baseliner (hence the inner surface of the perimeter berm) against erosion. The rockfill and concrete down chutes will protect the outer surface of the perimeter berm during operations. Erosion in the active cell will be limited with the use of temporary covers, specific waste compaction and grading requirements and on-going inspections and maintenance.

### 5.3.3 Bearing Capacity and Settlement

The ECM design included analyses of bearing capacity, settlement and differential settlement to evaluate the ECM foundations [5-90] and [5-65]. Estimating differential settlement of the foundation soil beneath the ECM floor is important, since it can potentially increase hydraulic head acting on the liner system or tensile strains in the liner components [5-90]. Settlement analysis of the ECM was performed using the computer code Settle 3D (Version 3.0), which employs elastic theory and the Boussinesq stress distribution method [5-91].

The existing natural overburden deposit in the ECM area ranges from 0 to 6 m thick in most areas and consists primarily of compact to dense silty sand, with trace to some gravel. The remaining interior area will bear on a maximum of 3 m of dense native silty sand overlaying the bedrock. Analyses of settlement and bearing capacity were performed for the areas where the ECM bears on soil subgrade.

All overburden material beneath the ECM perimeter berm is to be removed and replaced with specified backfill materials as indicated in the previous section. The berm will be constructed on bedrock, which does not pose a bearing capacity concern [5-90] and [5-65]. The base liner system will be constructed directly on the finished base grade [5-90] and [5-65].

Conclusions from the bearing capacity and settlement analyses included:

- The portions of the ECM bearing on bedrock do not pose concerns for bearing capacity.
- A bearing capacity failure and lateral displacement of the silty sand foundation is considered negligible [5-90] and [5-65].
- Potential subgrade settlements have been accounted for in the design of the liner and LCS. Subgrade settlement varies from zero to 7 cm in areas where the ECM bears on bedrock to areas where it rests on 3 m of soil, respectively.
- Differential settlement for foundations was conservatively estimated to be less than 0.001 m/m and is in accordance with CAFEM [5-92] recommendations. Differential settlement of the ECM foundation liner is

not expected to significantly affect leachate drainage over the base of the ECM. The slope of the ECM floor will maintain positive drainage after experiencing maximum differential settlement.

- The tensile strain, due to differential settlement, is less than 0.01% and well below the CCL's tensile strain capacity of 0.1% to 0.4% [5-85]. Differential settlement of the ECM foundation is not expected to cause tensile cracking of the CCL of the base liner system.

No further ECM optimization is required with respect to differential settlement.

### **5.3.3.1 Differential Settlement due to Wood and Organics**

Quantitative settlement analysis and literature review was conducted to assess potential differential settlement within the ECM due to wood and other organic materials contained in the NSDF waste [5-93].

#### **5.3.3.1.1 Quantitative Analysis**

Quantitative settlement analysis was conducted to estimate the volume of potential voids that degradation could produce and to quantify the long-term potential for subsidence during the post-closure period. The numerical analysis was done using Settle3D Version 4.0 with an assumption that the wood and organics will completely decompose, such that 100% of their volume is lost. Compressible or degradable waste was assumed to be 8.9% of the total waste volume ( $\sim 1\,000\,000\text{ m}^3$ ) (i.e., 8.8% wood and 0.1% other organics). The analysis shows that the ECM can accept the anticipated volumes of wood and organic material and still achieve long-term stability with minimal settlement and no slope reversals on the final cover. The settlement calculations show that the maximum settlement will be no more than 8.31 cm at 550 years and no more than 12.3 cm at 5 000 years. The Waste Placement and Compaction Plan provides an adequate framework for ensuring uniformity of the waste and minimization of void spaces. The analyses support the conclusion that the ECM will remain stable and experience no significant differential settlement over its design life.

#### **5.3.3.1.2 Literature Review of ECM Type Facilities**

The literature review was conducted to examine the methods that can be used to minimize potential differential settlement. The review included existing LLW disposal facilities and other facilities with an ECM-type design, including:

- Maxey Flats LLRW Facility (1963-1977).
- Beatty LLRW Facility (1962-1992).
- Los Alamos County Airport Landfill (1940s).
- Barnwell LLRW Facility (1971).
- Debris & Hazardous Waste Landfills (reported 1985-87).
- Hanford Environmental Restoration Disposal Facility (ERDF) (start operation 1996).
- Oak Ridge Environmental Management Waste Management Facility (EMWMF) (start operation 2002).
- Idaho Subsurface Disposal Area (SDA) (operation: 1950s).
- Uranium Mill Tailings Remediation Action (UMTRA) Program Title I Disposal Site (data reported in 1996 to 2000).

Considering that some facilities included in the review were developed several decades ago, when the best-practice at the time of the development was different from the current best practice, several facilities have

experienced various degrees of differential settlement. However, at least one facility (e.g., UMTRA Program Site I) was able to successfully minimize settlement by applying waste placement and void filling methods. Similar methods will be applied in the NSDF.

#### **5.3.3.1.3 Conclusions About Differential Settlement in LLW Disposal Facilities**

The following conclusions can be drawn from the settlement analysis and literature review:

- The existing facilities that have demonstrated site stability and reduced or eliminated differential settlement have done so through strict adherence to various operational controls, plans, and standard operating procedures.
- Operational controls have proven effective in reducing or eliminating differential settlement. Such controls and techniques include, but are not limited to:
  - Waste acceptance criteria.
  - Waste placement plans.
  - Maximizing uniformity in the waste.
  - Filling voids.
  - Having a compaction requirement that minimizes differential settlement.
  - Allowing time for settlement between the completion of the waste fill and the final cover construction.
- Differential settlement in the ECM can be minimized through the implementation of operational practices and waste acceptance criteria. Most important among the operational practices is to place the waste in a manner that results in minimum void space.
- The operational practices at the NSDF are consistent with the current practices that will support long-term stability and minimal settlement.
- The analyses support the conclusion that the ECM will remain stable and experience no significant differential settlement over its design life.

#### **5.3.4 Design of Base Liner and Final Cover Systems**

The design of the base liner and final cover systems considered: optimization [5-94]; leachate compatibility evaluation [5-95]; freeze/thaw evaluation [5-96]; and performance and life cycle evaluation [5-97]. The results were configurations of the base liner and final cover systems (see Figure 5-17 (c)) and specifications of each component of the systems defined in [5-75]. The base liner and final cover systems have a ridge and valley design feature. Figure 5-18 illustrates grading of the base liner system with ridge and valley features. This feature is illustrated in Figure 5-9 for the final cover system.

The design identified potential material sources for the construction of the base liner and final cover systems [5-98]. Selection of the HDPE GMB was supported by the R&D project discussed in Section 5.3.4.5. The results of these analyses have been incorporated in the current design, and CQA for the base liner and final cover systems.

##### **5.3.4.1 Configuration of Base Liner and Final Cover Systems**

Figure 5-17 illustrates the development of configurations of the base liner and final cover systems from conceptual to detailed design. The ECM design involved a collaboration between SMEs from CNL, external contractors/consultants, and academic institutions to provide review on selected aspects of the design,

including the liner system design. The review provided unbiased perspective to the project. This collaboration provided benefits in the application of state-of-the-art technology and best practice, such as application of pre-existing R&D results and the initiation of a testing program to support the design of the ECM liner systems [5-99] discussed in Section 5.3.4.5. In response to the recommendation of the SME from academic institution, the NSDF liner systems included sand cushion layers overlaying the HDPE GMB to limit strain and enhance long-term performance of the HDPE GMB [5-99]. Further optimization involved testing programs to select a specific HDPE GMB product meeting the required long-term performance.

As part of 60% detail design development, a series of analyses [5-94] were performed to evaluate and optimize configurations of the base liner system, final cover system, and components of the systems: HDPE Geomembrane, GCL, CCL, geotextile protection layers, granular protection layers, intrusion barrier, sand cushion and cover soil layers.

The analyses were carried out using sets of equations published in the technical literature [5-94]. The results of these analyses have been implemented as part of the design of ECM base liner and final cover systems.

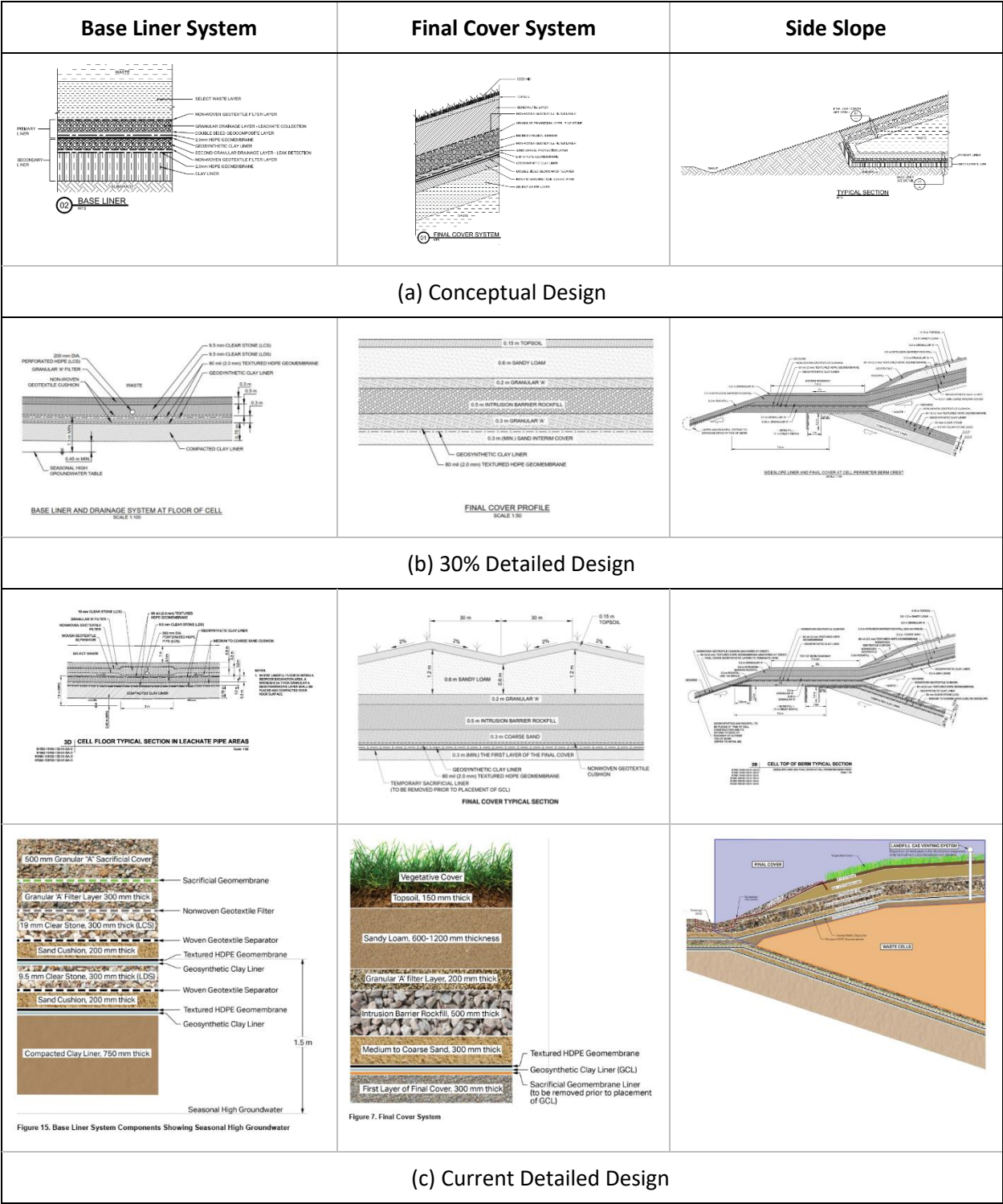


Figure 5-17 Changes of Base Liner, Final Cover and Side Slope Design



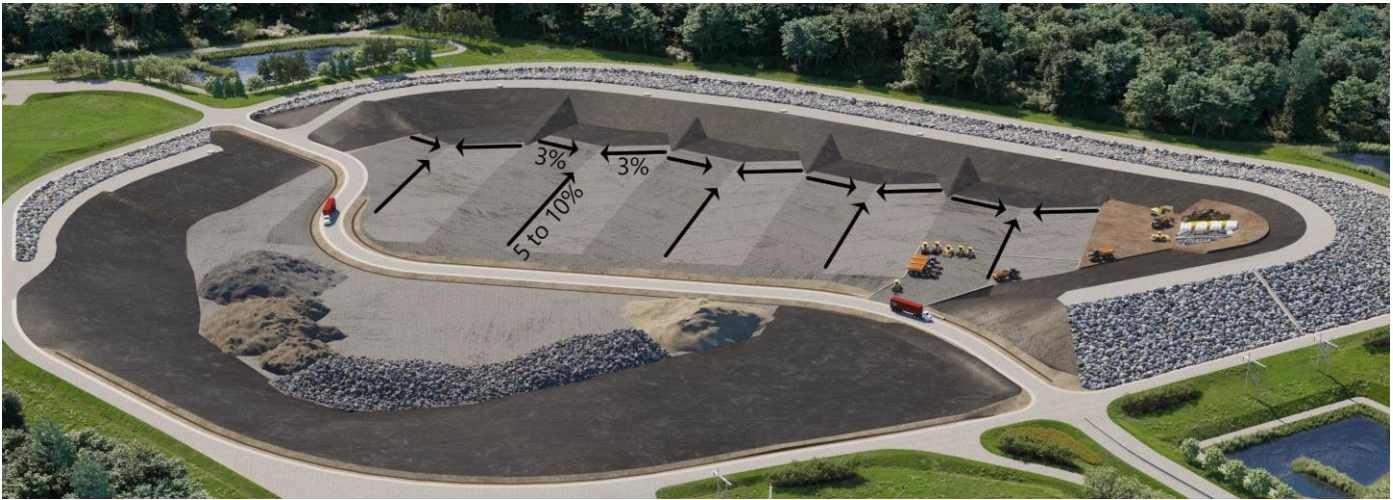


**Figure 5-18 Grading of the Base Liner System with Ridges and Valley Design**

#### **5.3.4.2 Leachate Compatibility Evaluation**

As part of 60% detail design development, a series of evaluations were performed to demonstrate that the proposed materials for the ECM base liner system are compatible with the expected characteristics of the leachate within the ECM throughout the operations and post-closure phases [5-95]. In addition to the NSDF waste inventory, radiological and non-radiological waste inventories from comparable disposal sites were considered to evaluate leachate compatibility of each component of the NSDF base liner and final cover systems.

The main conclusion was that due to their low permeability, CCL and a GCL are suitable as barrier system components in the base liner system for the NSDF. Radiological characteristics of the ECM leachate are not expected to accelerate the degradation of the liner system components [5-97].

#### **5.3.4.3 Performance and Life Cycle Evaluation**

As part of the 60% detail design development, the design of ECM base liner and final cover systems included evaluations of performance and the life cycle of the systems [5-97]. The evaluation assessed if each component of the base liner and final cover systems could meet life cycle requirements, and the ability for resisting surface water erosion.

The evaluation concluded that:

- HDPE GMB, GCL and CCL can function as designed throughout the design life.
- Although the design recognized that it is not critical for the geotextile cushion to meet the design life, the geotextile cushion can perform adequately over the design life.
- It is crucial that the liner system components are installed according to the construction specifications and QA.

#### **5.3.4.4 Freeze and Thaw Evaluation**

The design of the ECM included evaluation of the potential effects of freeze-thaw cycles for each component of the base liner and final cover systems [5-96]. Using the method outlined in the Canadian Foundations Manual [5-98], the potential frost penetration depth at the site is calculated as 1.75 m.

The HDPE GMB and GCL in the final cover system will be overlaid by at least a 1.75 m thick layer of natural materials (see Figure 5-19) and will be sufficient to prevent freezing of the cover liner components. In addition, the HDPE GMB is not adversely affected by freeze-thaw cycles [5-100].

Considering that the final cover will be installed progressively as the ECM cells reach their final waste contours, a temporary (interim) rock fill layer at least 0.3 m thick will be applied for temporary erosion protection rather than frost protection.

While the GCL on the perimeter side slope may undergo an increase in hydraulic conductivity due to the freeze-thaw cycles prior to waste placement on the slopes, consolidation of the GCL after placement of the waste fill against the slope will heal macro-voids caused by freezing; thus, there will not be any residual adverse effect on the GCL's hydraulic conductivity.

The CCL may be affected by freeze-thaw cycles during the operations phase. Using a minimum 0.5-m-thick layer of frost protection material (e.g., soil or soil-like waste) on the finished floor and a 1.2-m-thick layer on the finished side slopes is adequate to prevent freezing of the CCL.

#### **5.3.4.5 Research and Development for the Liner System Design**

As part of the development of the ECM detailed design, testing programs investigated the long-term performance of the candidate HDPE GMBs. The work was reported in [5-23] and published in [5-99] and [5-101].

The testing program provided technical-based evidence: to support the regulatory licensing application, to demonstrate 550 year design-life and to refine the HDPE GMB specifications.

The service life of GMB will depend on: the formulation to manufacture the GMB; and the exposure conditions (e.g., chemical composition of fluid in contact with GMB, temperature, and tensile strains in GMB). Factors affecting the design life of the HDPE GMB in a LLW disposal facility [5-101] have been considered in the NSDF design.

The testing program involved several SMEs from CNL, consultants from the industries and academic institutions, and the manufacturers.

The testing program included: a series of index property tests, long-term performance tests, and the relative performance analyses. Figure 5-19 illustrates the process to conduct long-term performance tests. Methods for testing and analysing the data have been performed in accordance with applicable standards and published technical literature [5-23]. The tests were conducted for five different HDPE GMB candidates and three leachate simulants. Radiation exposure to the GMB was calculated and determined to have a negligible effect on service life.

The leachate simulants included the ones comparable for the NSDF and typical Municipal Solid Waste (MSW) leachates. Testing using MSW leachate simulant, represents a more conservative case than testing using NSDF leachate simulants. The testing results indicated that two candidate GMBs have predicted service-lives well in excess of the required 550 year design-life (i.e., >2000 years).

Conservative assumptions used to develop the design and models included: leakage rate through base liner system were assumed approximately  $\leq 2$  mm/year [5-94]; and leakage rate through the final cover system of approximately 0.3 mm/year [5-97].

The construction trials (e.g., [5-102]), highlighted that the quality of as-built HDPE GMB is highly dependent on the level of CQA. Selection of the HDPE GMB will be followed by the application of a comprehensive CQA Program during the NSDF construction phase. Construction Quality Assurance addresses potential aspects that can affect the HDPE GMB performance during construction, e.g., tensile membrane strains/stresses induced by poor construction practice; wrinkles of HDPE GMB; and optimization of the welding locations and methodology. Construction Quality Assurance includes confirmatory tests on selected HDPE GMB prior to its acquisition and an inspection by qualified personnel during installation of the base liner and final cover systems [5-23], [5-99] and [5-101]. The descriptions of tests and personnel qualifications to conduct CQA was defined [5-103]. The selected HDPE GMB in the NSDF has been optimized via this process.

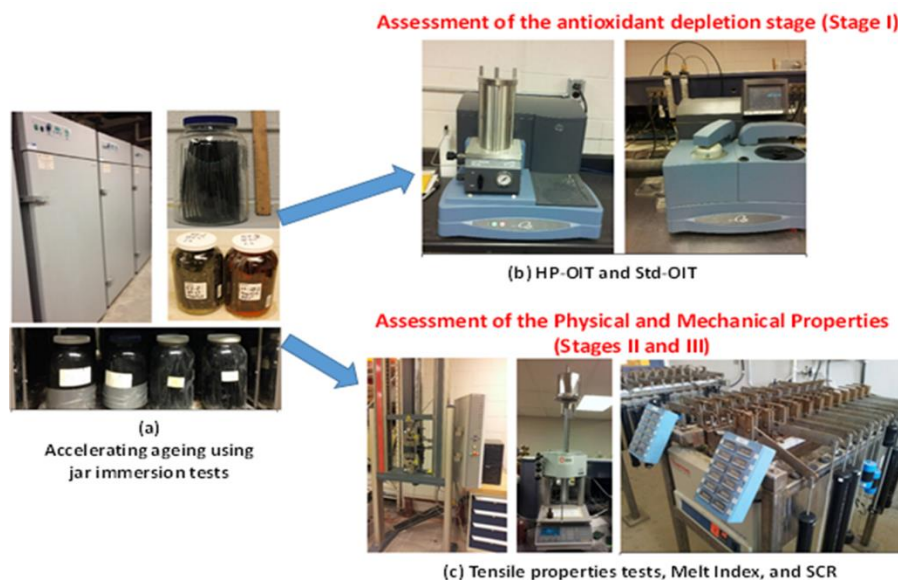


**Figure 5-19 Process of Long-term Performance Test**

#### **5.3.4.6 Application of Compacted Clay Liner**

Figure 5-17c illustrates the current configuration of the final cover system. The CCL is a components of the base liner system, and is not a component of the final cover system based on the following rationale.

On its own, the CCL is desirable because: it is a natural material and likely lasts longer than geosynthetics; and it provides protection from poor geosynthetics installation that can lead to increased leakage rates. It is important to evaluate the overall performance of cover systems, instead of the CCL on its own. In principle, the CCL can function effectively, when sufficient constraints are available to avoid desiccation and to maintain target density. The benefits of the CCL application were more obvious for the base liner system than for the

final cover system. The project evaluated the CCL use in the final cover system and concluded that the addition of a CCL in the NSDF cover system has no significant benefit.

Table 5-16 provides estimated leakage rates associated with each key parameters for various cover system configurations and key assumptions used to estimate these leakage rates. The evaluation discussed pros and cons of cover systems: (a) CCL only; (b) CCL/GMB; (c) GMB/GCL/CCL; and (d) GMB/GCL and sand foundation.

The following conditions for comparisons were used in Table 5-16: (1) precipitation in an area was 1000 mm/year, for comparison, precipitation in Chalk River, Ontario, averages 839 mm/ year; (2) an average hydraulic head was 0.14 m; and (3) CCL is 0.6 m thick.

**(a) Compacted Clay Liner only**

The CCL only cover system involves vegetative cover layers overlaying the CCL. This type of cover system has been used for MSW landfills in Ontario, when it is considered desirable to have sufficient leachate generation to stabilize the waste in a reasonable time. In this case, the CCL is expected to degrade with time due to desiccation caused by thermal, wet-dry and freeze-thaw cycles. Also vegetation roots will penetrate into the CCL and leave permeable conduits that may increase leakage with time. While a CCL can minimize leakage in the short-term, leakage through CCL-only cover system is expected to increase with time from 150 to 250 mm per annum or 4000 to 7000 lphd (litre per hectare per day), due to an increase in hydraulic conductivity from approximately  $4 \times 10^{-9}$  m/s to  $7 \times 10^{-9}$  m/s.

**(b) Geomembrane/Compacted Clay Liner**

The "GMB/CCL" composite cover system comprises: vegetative cover layer, a filter, a bio-barrier/drainage layer, and a composite liner with a protection layer, GMB and CCL. Some holes in the GMB are anticipated to occur during construction, and the leakage in a composite liner system will depend on the number and size of holes in the GMB, the hydraulic head, and the state of the CCL.

Studies have shown that the quantity of holes in a GMB depends on the level of CQA (e.g., Giroud 2016 [5-102]). With casual CQA involving expert inspectors only appearing occasionally, one can expect 20 or more holes per hectare in the GMB. With good CQA involving a full-time expert, inspectors on site, one can expect 5 to 6 holes per hectare (ha) and one 200 m-long-wrinkle per ha. No electrical leak location survey was applied in both cases [5-102]. The NSDF is applying full-time QA with electrical leak location survey, to further minimize potential holes in the GMB during construction.

In this configuration, the CCL can desiccate before or after it is covered by the GMB. If desiccation occurs, it will substantially increase leakage through any holes by distributing flow over a much larger area [5-104]. The CCL can be subjected to an increase in hydraulic conductivity with time due to wet-dry or freeze-thaw cycles, unless there is adequate cover soil to provide protection from the effects of weather.

Assuming good CQA and ideal conditions with no desiccation or degradation of the CCL, and a hydraulic conductivity of  $1 \times 10^{-9}$  m/s, the leakage is estimated to be 135 lphd. With desiccation of the top of the liner giving surface cracks 3 mm deep with a spacing of 250 mm and an opening of 0.5 mm (transmissivity of  $2.4 \times 10^{-6}$  m<sup>2</sup>/s; [5-104]), the leakage would be 1600 lphd.

**(c) GMB/GCL/CCL**

The GMB/GCL/CCL composite cover system has a vegetative layer, a filter, biobarrier/drainage layer, a protection layer, a GMB, a GCL, and CCL. This type of configuration was used in the Fernald facility [5-105]. The performance of this composite liner configuration depends on the desiccation that occurs to the CCL both

before and after the GMB is placed and before the drainage layer is placed, the extent of cation exchange for the GCL, and the needle punching of the GCL.

The Fernald liner with GMB/GCL/CCL is below about 2 m of cover soil, corresponding to a stress on the liner of 30 to 35 kPa (or higher). This soil thickness will help to protect the GCL and the CCL from thermal cycles. Whether it is sufficient to fully protect the CCL, will depend on the local climatic conditions.

The GCL in the system reduces the effect of desiccation of the CCL by providing a potentially low transmissive interface between the GMB and GCL to minimize leakage through the holes in the GMB. If there were no cation exchange at this stress and it was permeated by relatively clean water, one would expect a hydraulic conductivity of less than about  $5 \times 10^{-11}$  m/s. However, the GCL must hydrate from the CCL. The pore water in the CCL is likely to have significant divalent cations (e.g.,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  and possibly monovalent  $\text{K}^{+}$ ), which will induce cation exchange that will likely increase the hydraulic conductivity from  $5 \times 10^{-11}$  m/s to  $2 \times 10^{-10}$  to  $5 \times 10^{-10}$  under a very low head (< 7cm in the drainage layer) [5-106]. If there is needle punching in the GCL with a bundle size greater than about 0.8 mm in diameter, this could increase substantially to  $10^{-8}$  to  $10^{-7}$  m/s under a head of 0.07 to 0.14 m [5-106]. This is relatively easy to develop unless the drainage layer is uniform gravel. While there are some benefits to adding the CCL to the GMB/GCL/CCL system, there is also a degradation in cover performance.

At the Fernald Preserve Facility, the precipitation is about 580 mm/year, calculated from the  $208 \times 10^6$  liters of precipitation over 36 ha or 15,800 lphd reported by Powell [5-105]. The leachate collected is about 59 lphd, assuming 100% collection, which implies that the cover is quite effective at deflecting all but a very small proportion (0.37%) of the infiltration in the year for which data was given. While it was low compared to a GMB/CCL leakage of 135 lphd noted above, this number is still relatively large compared to a more effective GMB/GCL/CCL liner system. With the application of good CQA, one can expect leakage of 7 lphd. The observed leakage is 8-fold higher than expected with a good GMB/GCL/CCL composite liner. This suggests that there has been both some impact on GCL performance and that there is desiccation of the CCL below the GMB, both of which could be undetected with even with good CQA.

**(d) GMB/GCL on 0.3 m sand layer**

An alternative to the design described above is the design proposed for the NSDF. This design has vegetative layers, a filter, biobarrier, a drainage cushion of medium to coarse sand, and a composite liner with a GMB/GCL composite liner on a 0.3 m sand layer. The NSDF final cover system will have 1.75 to 2.35 m of soil over the liner to prevent impacts from wet-dry and freeze-thaw cycles on the GCL. The NSDF design specifies that the sand will be clean with no significant cations in the pore water. In addition, the GCL will be placed on the sand layer at an adequate water content to allow hydration of a scrim-reinforced needle punched GCL. The GCL fine grained bentonite will have 80% to 100% gravimetric water content before it can be hydrated by infiltration at the location of any undetected holes in the GMB. The NSDF will apply good CQA and electrical leak location survey to minimize holes in the GMB. Under benchmark conditions, the leakage through the NSDF cover systems would be between 4 to 12 lphd. This range depends on the grainsize distribution and initial gravimetric water content in the sand layer. In conclusion, the predicted NSDF leakage rate of 4-12 lphd is comparable or less than the theoretical leakage rate for a GMB/GCL/CCL cover system (e.g., Fernald cover system) of 7 lphd. The NSDF final cover system is more economical and expected to achieve the same level or better performance than the GMB/GCL/CCL cover system; thus, it is considered to be optimized.

**Table 5-16**  
**Comparison of Estimated Leakage Rates for Various Cover System Configuration**

| Cover System Configurations      | Leakage Rates (litres per hectare per day (lhpD))       | Note                                                     |
|----------------------------------|---------------------------------------------------------|----------------------------------------------------------|
| CCL only                         | 4000 to 7000 lhpD*                                      | Example application in MSW landfills in Ontario          |
| GMB/CCL                          | 135 to 1600 lhpD*                                       |                                                          |
| GMB/GCL/CCL                      | 59 lhpD**; 7 lhpD*                                      | Example application in Fernald Preserve Facility [5-105] |
| GMB/GCL on 0.3 m sand foundation | 4 to 12 lhpD*<br>(depending on grain size distribution) | Example application for the NSDF final cover system      |

\* Estimated leakage rate under benchmark conditions: average precipitation in the area = c. 1000 mm/year; CCL thickness = c. 0.6 m; annual average hydraulic head = c. 0.14 m; and a good Construction Quality Assurance (CQA) defined by Giroud 2016 [5-102].

\*\*Leakage rate reported in Fernald Preserve Facility with average precipitation in the area = 580 mm/year [5-105].

### 5.3.5 Gas Migration

The ECM design considered potential gas migration and included: modelling and evaluation of the radon and other landfill gas [5-107]; evaluation of gas migration in leachate [5-108]; and development of a landfill gas management plan [5-109].

Modelling and evaluation of the radon and other landfill gas [5-107], was performed to estimate the characteristics and quantity of radon and other gases that might be generated from wastes disposed of in the ECM over time. The study results were examined against applicable regulatory guidelines.

The results of the evaluation and modelling show that the emission of radon gas from the ECM, will comply with dose requirements for workers or members of the public during operations, after cover placement, and closure of the ECM. The LandGem® simulation results, show the time dependence of LFG generation over the operations phase and the ICP, which extends 300 years beyond closure of the ECM. After closure of the ECM and construction of the final cover, gas generation decreases, as there is reduced availability of moisture and oxygen in the waste.

The estimated radon dose to a worker in the NSDF is calculated to be 9.6E-04 mSv/y and is negligible compared to the worker action level for effective dose of 20 mSv/y. The dose is also negligible compared to the public dose limit of 1 mSv/y. The calculated peak doses to a worker during operations are 1.6E-05 mSv/y from tritium and 2.2E-06 mSv/y from C-14. The combined worker dose from radon, tritium, and C-14 is 9.8E-04 mSv/y, which is below the regulatory limit for worker dose and for any other person as specified in reference [5-110].

The study concluded that based on the predicted radon gas generation rates described above, no additional measures or controls are expected to be required to mitigate radon gas emissions from the ECM during the operational phase and after closure.

Results of the evaluation and literature reviews showed that the ECM will not generate sufficient LFG pressures or volumes to warrant either: use of active operational controls during ECM disposal operations to limit build-up of methane gas concentrations in active waste disposal working areas; or active collection and treatment of LFG.

During the period of ECM operations, LFGs generated in the ECM are anticipated to have low concentrations of methane and carbon dioxide. The LFG will have low flow rates and will largely dissipate through air flow across the working area, with a small portion of LFGs being retained in the waste. No additional measures or controls are expected to be required to mitigate LFG emissions from the ECM during the operations phase.

The LFGs generated in the ECM may contain small amounts of tritium or C-14. The generated gas volume that contains tritium or C-14 is expected to be six to seven orders of magnitude less than the volume of gas that contains stable isotopes of these elements.

To address the unlikely event that LFG generation rates in the ECM are higher than anticipated, the final cover system design includes specific components to mitigate against potential future build-up of gas pressures within the ECM after closure and final cover system installation. The passive LFG control system includes an array of passive LFG vents [5-109]. The Gas Management Plan [5-109] describes the specifications and activities for controlling and monitoring radon and non-radioactive LFG.

A study was performed to evaluate the migration of radon and gas into leachate within the ECM [5-107]. The analysis confirmed that the ECM design features will limit the production or accumulation of radon in leachate and air. Based on the predicted radon gas generation rates, no additional measures or controls are required to mitigate emissions from the ECM during the operations phase and after closure.

### **5.3.6 Precipitation Events**

The Ontario PMP event of 596 mm of precipitation in 24 hours is appropriate for the NSDF PMP event, however a more conservative PMP event of 570 mm of precipitation in 12 hours was selected for the NSDF site since this PMP produces a peak flow, which is 12% higher than the 24 hour distribution [5-111].

Based on Canadian safety guidelines relevant to the NSDF Project and the CRL site, all NSDF water collection and conveyance systems (including the final cover) are designed to resist erosion, safely convey flows, and maintain structural integrity during design scenarios up to a PMP storm event.

The features on the ECM, which includes the perimeter berm, will resist the dynamic force due to the PMP event. A hydraulic analysis [5-89] was completed to determine velocities experienced by the various hydraulic elements (final cover system, perimeter berm, channels) in the ECM drainage system under the PMP event and to identify if any commonly accepted erosion thresholds were exceeded. The hydraulic analysis results indicate that anticipated velocities for the various hydraulic elements, under PMP conditions, do not exceed allowable velocities thus erosion would not occur [5-89].

The duration of the PMP intensity, 291 mm over 1 hour, could cause the loss of the vegetative layer and soils associated with the final cover due to raindrop/splash erosion from direct rainfall impact. This could ultimately expose the 500 mm rock-filled intrusion barrier layer of the ECM final cover. However, the final cover intrusion barrier rockfill layer would respond in a similar fashion to the rip-rap outer layer of the perimeter berm; sheet flow would occur. The barrier would not erode and the underlying engineered barrier system (geomembrane and GCL) would protect and prohibit exposure of the waste.



There is no mechanism for ECM perimeter berm failure that will be caused by extreme precipitation. The ECM perimeter berm is constructed starting from the bedrock surface upwards, using free draining material. As part of the mitigation for liquefaction potential, all deleterious material has been removed from the construction and foundation of the perimeter berm. Therefore, there are minimal forces imposed on or within the ECM berm due to PMP surface flows impacting the berm laterally.

During the operations phase, the PMP event does not cause overtopping of the ECM perimeter berm. In the case that the PMP event occurred during operations, contact water run-off may overtop the temporary contact water pond but would be contained within the ECM [5-112].

The first day of ECM operations would provide the largest open capture area for precipitation during a PMP event, since all cells are open to collect precipitation and none of the cells have received a final cover to direct precipitation outside the ECM. Using the 12 hour 570 mm PMP event, a volume of 25 855 m<sup>3</sup> would be accumulated in the Phase 1 area. This volume corresponds to an elevation in the ECM just below the 170 m contour. The volume of the water pool would need to reach an elevation of 171.5 m to overtop the perimeter berm at the low point along the south edge of the ECM.

No environmental release from the ECM would result.

## **5.4 Waste Water Treatment Plant Design Optimization**

This section provides a summary of the WWTP design optimization.

### **5.4.1 Waste Water Treatment Plant Process Design**

The steps for WWTP processes design included:

- Assessing and selecting alternative treatment options for screening against a set of evaluation criteria to choose the preferred treatment methods that will advance to the testing phase.
- Iteratively refining input parameter values by adjusting overly conservative assumptions with more representative values based on up-to-date information.
- Conducting laboratory scale testing, pilot scale testing and computer modelling, with on-going refinement of input parameter values, and finally
- Defining the current WWTP design.

Figure 5-20 showing WWTP design evolution, represents an overview of the process. The far left represents “the end goal” for the WWTP design and everything to the right are the steps to achieve the goal. It illustrates a series of sequential steps, portraying the optimization process. Many of the activities were performed in parallel.



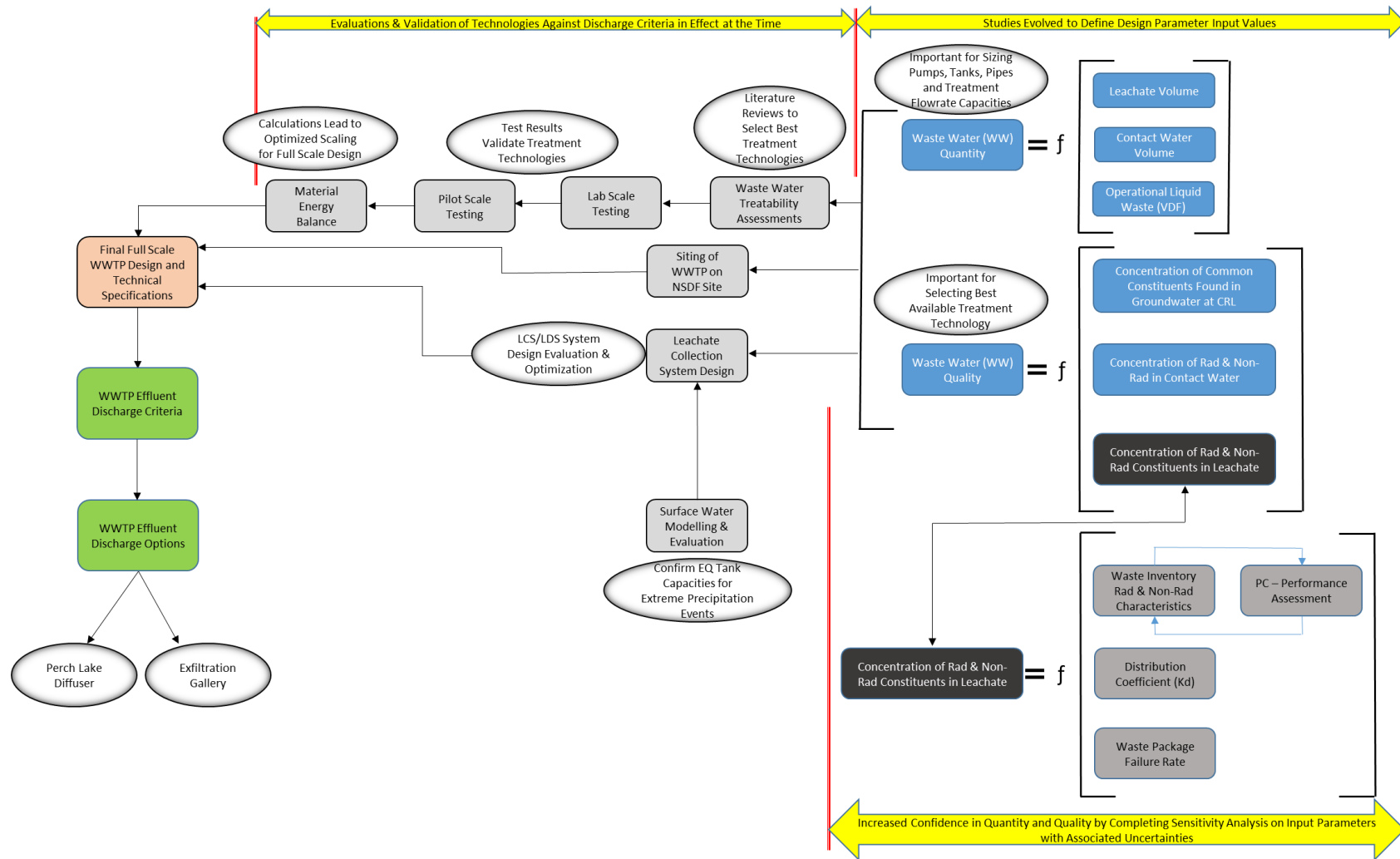


Figure 5-20 Waste Water Treatment Plant Design Iterations and Optimization

### 5.4.2 Wastewater Quantity

The total wastewater quantity is the sum of: Leachate; Contact Water; and Operational Liquid Waste. The wastewater volumes from each stream were calculated to determine the long-term average wastewater volumes needed to establish the flow-rate design capacity of the WWTP. Leachate quantities were determined using the HELP model (i.e., Hydrologic Evaluation of Landfill Performance 3.07), a water balance modelling program. The HELP model was run for a 100 year simulation. To calculate a reasonable upper value for the amount of potential infiltration, each cell was modelled using the area of the largest, uncovered cell. Results from that one cell were then applied to each additional cell in succession, to model the wastewater generation rate throughout the 50 year lifetime of the ECM [5-113]. In the first iteration, the model predicted 37 m<sup>3</sup>/day [5-114], slightly lower than the final iteration of 38 m<sup>3</sup>/day [5-114]. The difference was due to an increase of the largest open cell area from 12 000 m<sup>2</sup> to 15 000 m<sup>2</sup> in the final iteration. After the last waste cell is filled and final cover is constructed, contact water will be minimal.

Ways to optimize (i.e., minimize) wastewater quantity were considered. The NSDF radionuclide concentration limits apply a graded approach to control leachate radionuclide concentrations during placement of waste. There will be a small portion of waste which will be required to utilize robust packaging to prevent the spread of contamination. Specifically leachate controlled waste packages are intended to provide short-term barriers for wastes with higher radionuclides concentrations during the time the disposal cell is not covered with the final cover system (approximately 5-10 years). Thus more mobile radionuclides, such as tritium, are kept isolated from the environment to minimize liquid effluent releases during the operations phase.

During waste placement operations, all efforts are made to minimize the contact of precipitation with the contaminated waste thus limiting wastewater production. The operation of NSDF is limited to one cell at a time to limit the surface area of waste that is exposed to the environment (i.e., precipitation) at any given time. As a cell is developed, interim covers are placed over waste to limit infiltration of precipitation and promote surface water run-off. As each disposal cell is completed the final cover system is installed over the filled disposal cell. Other operational practices to limit contact with precipitation include grading and compaction of the waste fill to promote surface water run-off.

Furthermore, any water that makes contact with (or is suspect of contacting) the contaminated waste will be collected by the LCS and treated to remove contaminants in the WWTP prior to controlled release into the environment.

The design of the NSDF ECM is a large contiguous construct, in which active cells are located adjacent to closed cells. A movable roof system (weather cover structure) was considered for the open cell. To implement this, the roof base structure requires load-bearing support and anchorage, able to accommodate any potential dynamic loads such as design-basis tornado and earthquake. In designs where temporary roofs are utilized, between each adjacent cell there is an intermediate structural berm, which provides the necessary height and foundations for the moveable roof system. The NSDF ECM design does not have an intermediate "structural berm" between its cells. However, weather cover structure [5-115] conceptual designs are being evaluated for compatibility with the NSDF configuration and if feasible, could be implemented as a mitigation measure and operational optimization.

### 5.4.3 Wastewater Quality

The Leachate Contaminant Reduction Time and Contaminating Lifespan Evaluation study [5-113], was completed to define the wastewater contaminant concentrations for designing the treatment processes for the WWTP. The study predicted wastewater concentrations and volumes for the first 50 years of operation and for 300 years after closure. As shown in Figure 5-20, wastewater quality is a function of:

- Concentrations of common constituents found in groundwater at CRL that are not hazardous; however, they were considered in the WWTP design process to minimize their impact on processing systems [5-116]. Examples of common constituents include cadmium, iron, sulphate, and tannic acid.
- Concentrations of radiological and non-radiological COPC in the contact water and in the leachate.

The radiological and non-radiological COPC in the leachate are a function of:

- Waste inventory defining the radiological and non-radiological COPC.
- Distribution coefficient ( $K_d$ ) that is a derived variable used to calculate constituent-specific concentrations in leachate.
- Waste package failure rates that may increase the possibility for water to come into contact with waste.

The waste inventory specifies total constituent quantities and respective concentrations. The waste inventory was adjusted after each iteration of the PostSA. In the early WWTP design stages, information regarding the waste inventory was still in a preliminary stage. Radiological and non-radiological constituent concentrations measured in plumes at CRL, were used to prepare the simulant wastewater characteristics for the laboratory and pilot scale tests [5-117]. Simulant wastewater characteristics were adjusted when the waste inventory information became available.

The hazardous constituent concentrations in the leachate are calculated using a partitioning model that assumes a constant ratio of the contaminant concentration in the solid phase to the contaminant concentration in the liquid phase. The partitioning factor used is known as the distribution coefficient ( $K_d$ ). Partitioning models are commonly used in radiological assessments to determine leaching characteristics of radionuclides and metals in soil and soil-like wastes. The initial  $K_d$  values were based on one type of media (i.e., loam material), which were later substituted with values that reflected a weighted distribution of the various ECM material types [5-118]. Due to uncertainties associated with this parameter, sensitivity analysis considering a range of  $K_d$  values were used to estimate the effect on the leachate.

Due to the impracticality of treating the wastewater to remove tritium, CNL has incorporated stringent limits in the WAC [5-86] on the total amount of tritium that can be placed in the NSDF (see Table 13 of the WAC) and on the tritium concentration in individual waste shipments (see Table 4 of the WAC). These stringent controls on the amount of tritium being placed in the NSDF ensure that emissions from the WWTP will meet the tritium effluent discharge targets. The discharge target for tritium of 360 000 Bq/L is based on maintaining tritium concentrations in Perch Creek which discharges to the Ottawa River, below the drinking water guideline of 7 000 Bq/L. Furthermore, the use of the exfiltration gallery as a primary discharge location provides additional retention time for radioactive decay of tritium within the geosphere prior to reaching the biosphere and receptors. Tritium has a relatively short half-life of 12.3 years and therefore benefits from decay over the groundwater transit time from the exfiltration gallery to eventually Perch Lake, which is greater than 16 years. Thus, no treatment method is necessary to reduce the activity of tritium in the wastewater since it is instead controlled through means to isolate the source.

The OLC documented in the Section 15.3.2 Condition 10 of the SAR [5-119] is “The tritium activity concentration in the wastewater entering the WWTP for processing shall meet the tritium effluent discharge target of  $2.3\text{E}+05$  Bq/L.”, and this condition is included in Section 7.2.3, Limiting Conditions for Safe Operation.

#### 5.4.4 Wastewater Treatability Assessments

A review of treatment technologies was conducted to assess alternative methods for removal of various constituents expected to be present in the wastewater [5-116]. The potential effectiveness of the technologies was based on experience and information available in the literature, then validated by the results of the laboratory and pilot scale tests. Each technology was evaluated against a list of criteria which included:

- Effectiveness.
- Process flexibility.
- Secondary waste generation.
- Safety.
- Operational complexity.
- Space requirement.
- Utility requirements.
- Capital cost.
- Operating and maintenance cost.
- Best available technology economically achievable (BATEA).

The selected technologies were deemed optimal for the WWTP. The summary of the technologies evaluated and those selected for the full-scale WWTP as shown in Table 5-17.

**Table 5-17**  
**Summary of Technologies Evaluated and Selected for the WWTP**

| Technology                       | Selected for WWTP |
|----------------------------------|-------------------|
| Hydroxide Precipitation          | Yes               |
| Sulfide Precipitation            | Yes               |
| Co-Precipitation and Coagulation | Yes               |
| Flocculants                      | No                |
| Inclined-Plate Clarifiers        | No                |
| Solids-Contact Clarifiers        | No                |
| Ballasted Clarifiers             | No                |
| Gravity Filters                  | No                |
| Pressure Filters                 | No                |
| Membrane Separation              | Yes               |
| Ion Exchange                     | Yes               |
| Reverse Osmosis                  | No                |
| Activated Carbon                 | Yes               |
| Evaporation                      | No                |

| Technology                     | Selected for WWTP |
|--------------------------------|-------------------|
| Gravity Thickening             | Yes               |
| Recessed Chamber Filter Press  | Yes               |
| Spent Media Vacuum De-watering | Yes               |
| Belt Filter Press              | No                |

#### 5.4.5 Waste Water Treatment Plant Laboratory Scale Testing

The goal of the laboratory scale testing programs was to evaluate various treatment processes for removal of COPCs to meet expected discharge effluent limits for the WWTP, and determine the design input parameters for the WWTP. Laboratory scale tests were conducted following the test plan [5-120] in the early stages of design (30% design phase). The Laboratory Scale Test Report [5-121] results were subsequently used to guide the development of the Pilot Scale Test Plan [5-122].

A simulated wastewater composition was developed to replicate the expected leachate characteristics from the ECM, but without radionuclides [5-117]. The removal of non-radionuclide strontium was evaluated during the laboratory scale tests to simulate the removal of the radionuclide form.

The tests focused the evaluation on the following treatment technologies: Chemical precipitation; Aeration; Ultrafiltration; Reverse Osmosis; and IX. It was demonstrated that concentrations of heavy metals can be significantly reduced through chemical precipitation. Aeration was effective in precipitating low concentrations of several metals, including manganese and strontium. Ultrafiltration achieved complete removal of suspended solids to less than detectable concentrations in permeate.

Both IX and reverse osmosis were effective in reducing all target constituents to well below the expected discharge requirements [5-123]. Ion exchange did provide improved performance for removal of cesium.

The results of the laboratory scale tests led to the following recommendations for the pilot scale testing plan and full-scale WWTP design.

- The pilot scale testing was performed to confirm the laboratory scale results.
- Pilot equipment should include: Chemical precipitation with ferric chloride addition and pH adjustment; Membrane filtration; and IX.
- The focus of the pilot scale test was on the longer-term performance of the membrane filtration system, and further evaluation of IX resins and exhaustion rates.
- Although the laboratory scale tests illustrated that coagulant addition was not beneficial, the full-scale WWTP should include coagulant feed capability, in the event the wastewater does not contain high concentrations of iron at all times.

#### 5.4.6 Waste Water Treatment Plant Pilot Scale Testing

The primary objectives of the pilot scale tests were to simulate the proposed treatment processes of the full-scale WWTP in a continuous operation mode, to confirm that the final treated effluent meets or exceeds regulatory requirements for discharge to a surface water body, and to provide additional design information for incorporation into the WWTP design. The main processes of the WWTP pilot scale testing were selected based on the results of the laboratory scale tests [5-120], Leachate and Wastewater Treatability Assessment [5-116], and Design Concept Decision (Optioneering Study) for WWTP [5-124].

The pilot scale design basis was developed using the information available at the 60% design:

- Wastewater quantity was updated based on postulated storm events in conjunction with ECM operations, which impact the volume of precipitation that can come into contact with the waste. Quantity estimates also include the predicted volume of water requiring treatment as a result of other operational activities (e.g., vehicle decontamination water). The combined estimate was used to determine the design process flow rate minimum capacities [5-114].
- Wastewater quality and contaminant characteristics were updated based on a number of factors, such as the chemical and radionuclide contaminants in the waste [5-125], the water to waste contact time, and the leaching characteristics of chemicals, radionuclides and metals in the waste, which in turn, result in constituent specific concentrations in the wastewater [5-114].
- Effluent discharge requirements defined the maximum allowable concentrations in the discharge effluent stream for the predicted radionuclides and non-radioactive constituents [5-123].

The contaminant concentrations in the first few batches of wastewater simulant used in the pilot scale tests, matched those of the laboratory scale test study. Through further reviews of maximum expected leachate concentrations and expected discharge requirements, it was determined that non-radioactive heavy metals were the target constituents of concern, along with radionuclides. The simulated wastewater characteristics were adjusted to represent the expected leachate characteristics from the ECM, but without containing radionuclides. The removal of non-radioactive strontium was evaluated during the pilot scale test to simulate the removal of the radionuclide. The removal of other radionuclides was evaluated through process modelling. The simulant wastewater concentrations continued to be adjusted as testing progressed to reflect the most up-to-date waste inventory information.

The Leachate and Wastewater Treatability Assessment [5-116], assessed available treatment technologies and recommended those that required further evaluations as part of the pilot scale study. Details of the testing approaches and evaluation methods are described in [5-122]. The pilot scale tests focussed on:

- Chemical precipitation of heavy metals.
- Low-pressure membrane filtration (microfiltration) for removal of precipitated heavy metals.
- Granular activated carbon for adsorption of low concentrations of organic constituents.
- Ion exchange for removal of strontium, cesium, and low concentrations of heavy metals.
- Dewaterability of residuals produced from the chemical precipitation process and separated by the membrane filtration process that was to be evaluated during small-scale testing of recessed chamber filter press and centrifuge technologies.
- Two-stage reverse osmosis polishing of microfiltration permeate that was also to be evaluated during the second half of the pilot scale tests.

The effectiveness of each process stage was measured to determine if additional improvements were needed. The chemical precipitation removal efficiencies of cations were optimized by adding iron and aluminum salts as co-precipitation and coagulation agents, and by increasing the pH of the solution in the second precipitation reaction tank.

Evaluations of the GAC did not result in increased removal efficiencies of organic constituents however, this feature was recommended in the full-scale WWTP design as an option, in the event the organic constituents in the actual wastewater differ from those in the simulant wastewater.

Ion exchange was employed primarily for the removal of radionuclide surrogates (i.e., strontium and cesium). Testing identified the two best IX media to be used for each constituent and the order in which they should be operated. The combined process removal efficiencies following IX, were proven to be 99.7% for cesium and 99.5% to 99.9% for strontium. Testing also identified that pre-treated resins commonly used in the microelectronics industry, will need to be used in the WWTP otherwise, the concentrations of some metals in the effluent could exceed the influent concentrations.

Reverse osmosis provided comparable, and in some cases, higher removal efficiencies for heavy metals, but removal of cesium was lower, 72.1% to 92.1% compared to 99.7% for IX.

The pilot scale test optimized the technologies to be used in the WWTP, by demonstrating the effluent discharge requirements could be achieved using chemical precipitation, microfiltration, and IX (zeolite resin followed by strong acid cation resin) [5-126]. Data and observations generated by the pilot scale test were used to confirm the design requirements for the full-scale WWTP.

#### **5.4.7 Surface Water Modelling and Evaluation**

A study [5-112], was conducted to confirm if the capacity of three Equalization Tanks would be sufficient to store the additional contact water volume generated, as a result of a back-to-back 100 year, 24 hour storm events, superimposed with peak monthly precipitation and snowmelt during the operational period. The study used the HELP model to calculate the contact water volumes for this DBA precipitation event and the PMP event for Ontario being 596 mm in 24 hours. The Ontario PMP event is appropriate for the NSDF event, however a more conservative PMP event of 570 mm in 12 hours was selected for the NSDF site since this PMP produces a peak flow, which is 12% higher than the 24 hour distribution [5-111].

In the first iteration, the modelling input parameters for the development of appropriate Intensity-Duration-Frequency (IDF) relationships for the site, initially considered the results from the Ontario Ministry of Transportation's (MTO) web-based application (i.e., the "IDF CURVE LOOKUP that is used for drainage management in MTO projects). The MTO results relevant to the CRL site are based on the nearby EC Petawawa Forestry Gauge, which has 33 years of records from 1961–1994. This duration was later considered non-representative because of the lack of an additional 20 years of data from 1996–2015.

The closest long-term and current EC gauges are located at North Bay (1964–2015) and Ottawa (1967–2015) that are approximately 150 km from the CRL site. A recent study for the Town of Arnprior, which is approximately 100 km from the site, developed a representative IDF relationship for the Town, based on review and analysis of adjacent EC IDF data. The second iteration chose the latter as being the best representation for the CNL Site. The hydrologic calculations for sizing the Equalization Tanks were repeated based on this new data and based on a revised ECM cell configuration.

The study concluded the contact water run-off collection and conveyance system had been designed to adequately store and convey the wastewater generated from the largest operational cell during the back-to-back 100 year, 24 hour storm events. The storm event requires a water storage capacity of 4 710 m<sup>3</sup>, which equates to filling two and a half Equalization Tanks.

The study also estimated soil loss of the ECM final cover in the event the PMP occurred post-closure. As a result, turf reinforcement mat conveyance channels, riprap-lined down-drains and concrete chutes were added to the design.

#### 5.4.8 Treated Effluent Discharge Locations

Initially, the preferred effluent discharge location was an exfiltration gallery adjacent to the WWTP and upstream of East Swamp. Refinements of the ground and surface water modelling performed in support of the Project, identified that the exfiltration gallery alone was not sufficient to accept the total estimated volume of treated effluent. The solution was to design an effluent transfer system from the WWTP to Perch Lake.

In the spring of 2019, CNL held a Treated Effluent Management Workshop. Canadian Nuclear Laboratories invited specialists in water treatment and representatives from special interest groups who had expressed interest in the NSDF Project. Canadian Nuclear Laboratories presented the facts to the group, and the group assessed effluent management solutions and alternatives.

The outcome of the workshop was that the effluent discharge to Perch Lake was the preferred solution, ranked against metrics such as public perception, quantity and quality of treated effluent, and effects on the environment and biota.

An alternative strategy was identified at the workshop: the construction of an artificial wetland, which could receive the treated effluent and provide habitat for wetland-dwelling biota. Canadian Nuclear Laboratories is assessing this option by performing preliminary scoping and feasibility studies. The main challenge with this option is siting and effluent transport.

As of 2020 August, CNL has partnered with Ducks Unlimited Canada, a registered charity and not-for-profit organization, to further study the feasibility of the artificial wetland (as previously discussed in 5.1.8.3.1). At this time, the Project is in the conceptual stage, where several design options are being presented and considered:

1. Opportunity 1 – adding an artificial wetland feature to work with the existing WWTP exfiltration gallery. It would be set up as an either/or configuration (i.e., the WWTP could discharge to the wetland prior to exfiltration or direct to exfiltration. This would reduce the frequency of direct discharges via the diffuser system, and also provide additional hydraulic retention.
2. Opportunity 2 – naturalization of the current surface water management ponds (SWMP). This option improves total suspended solids (TSS) performance of the current systems. This is independent of the other options, but could be used in conjunction with them too.
3. Opportunity 3 – connection of the current SWMPs together. This would improve TSS performance of the current systems and also adds significant hydraulic retention in the system. There would still be the same outflows during significant storm events as currently proposed, but the system would perform better during routine operations. This option may be difficult given the site topography.
4. Opportunity 4 – addition of a “polishing pond” near the south kiosk to be used with option 1 and/or 3. This would improve TSS performance of the SWMPs if used with option 3. If used with option 1, it wouldn’t be for TSS removal, but would add hydraulic retention in system, and reduce the volume and flow that is needed in diffuser to Perch Lake.

It is important to note that if an option is pursued, that no changes to the environmental, safety, or design basis are permitted.



## **5.5 Management and Administrative Measures**

### **5.5.1 Design Process and Quality Assurance**

The NSDF design started with conceptual design and was followed by 30%, 60%, 90%, 100%, and post 100% detailed design. The NSDF has been designed in accordance with Design Authority and Design Engineering [5-66].

The NSDF Project applied the Quality Assurance Manual (QAM)<sup>4</sup> [5-127] and Quality Program Selection Procedures [5-128] and [5-129]. The QAM defines an integral part of the processes: to prioritize, to design facilities, to analyze hazards, to identify and apply standards and controls, to procure equipment, to perform work, and to evaluate and improve performance.

Development of the NSDF included collaborations between CNL and contractors. To verify application of the QA Program, the NSDF contractor provided documentation, such as: NSDF Design QA Plan [5-130], NSDF Design Verification Plan [5-131], Proof of certification under CSA N286.7-99, Quality Assurance of Analytical, Scientific and Design Computer for developing numerical models, and Proof of accreditation by Canadian Association for Laboratory Accreditation (CALA) or the Standards Council of Canada (SCC) under ISO/IEC 17025 for conducting laboratory works.

### **5.5.2 Safety Classification**

Appropriate selection of safety classification, quality program level, and design requirements of the SSCs, was important to achieve the fundamental safety functions and is discussed in the NSDF Safety Analysis Report [5-119]. The NSDF safety classification applied a graded approach, commensurate with the nature of the hazards, design and operations [5-132], to capture the intent and principles of REGDOC 2.5.2 [5-133] and IAEA SSG-30 [5-134]. The SSC considered important to safety during the operations phase and post-closure phase, have been classified and documented in NSDF Systems Safety Classification [5-132], the Safety Classification and Design Rules [5-135], the Quality Program Selection procedure [5-136], Safety Classification of NSDF Systems [5-137], and Components for Safety Classified Systems [5-138]. The process was consistent with CNL's Programs for Equipment Reliability [5-139], Ageing Management [5-140] and Maintenance and Work Management [5-141]. A program of testing, monitoring, inspection (surveillance) and maintenance/repair will be implemented during the operation and closure period of the ECM and NSDF Facilities [5-142].

### **5.5.3 Operation and Experience**

The design has utilized the OPEX from similar facilities, including international experience as well as CNL's Port Hope and Port Granby Projects. Benchmarking site visits have been part of the design development. Application of OPEX will be continued during future phases of the Project. Lessons learned from OPEX at other sites is discussed in more detail in Section 6.

### **5.5.4 Human Factors**

A set of Human Factors (HF) activities were conducted throughout the design period, to ensure that human capabilities and limitations were appropriately integrated in the design. Human Factor evaluations were conducted at the 60% and 90% design to evaluate whether the Facility labour, equipment, tasks and work environment were compatible with human characteristics, capabilities, and limitations. The HF evaluations

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<sup>4</sup> The QAM has since been superseded by 900-514200-PDD-001 on 2019 July 31.

were conducted following the HF Engineering Program Plan [5-143]. Specific modifications that have been incorporated into the design were:

- Addition of a man gate at the main entrance to facilitate the access of operations personnel to laydown areas.
- Moved location of the kiosk to provide operations personnel line of sight to weigh scale stations.
- Lockable valves have been integrated on the sulphuric acid lines to the chemical precipitation tanks.

## **5.6 Waste Inventory and Acceptance Criteria**

The determination of the radionuclide inventory for the NSDF required several rounds of iteration before the Reference Inventory [5-144] and WAC [5-86] were developed, ultimately leading to the Licensed Inventory which is the final proposed inventory for the NSDF (discussed further in Section 5.7). The iterative process involved in the development of the Reference Inventory and WAC ensures that the Licensed Inventory meets the dose acceptance criteria of the safety assessments, as well as meets the requirements for the protection of biota and the environment.

Waste currently stored in CNL's WMAs, and projections from facility decommissioning and environmental remediation projects, are inputs to developing the Reference Inventory for the NSDF. The primary source of waste generation is the CRL site, with additional waste from other CNL's sites and small waste quantity from Canadian generators, such as hospitals and universities.

The proposed inventories were developed in three steps:

1. Assemble characterization data obtained or derived from waste records, facility decommissioning and environmental remediation projects.
2. Assess the data against the WAC and report total radioactivity and radionuclide concentrations.
3. Evaluate the reported inventory against the acceptance criteria to confirm it is acceptable for the PostSA.

The proposed inventories for the NSDF have evolved with the project based on various input, as they have become available; including the development of the NSDF WAC, public feedback from the review of the draft EIS, and PostSA modelling. Figure 5-21 represents the iterative process that led to the development of the NSDF Reference Inventory and Licensed Inventory.

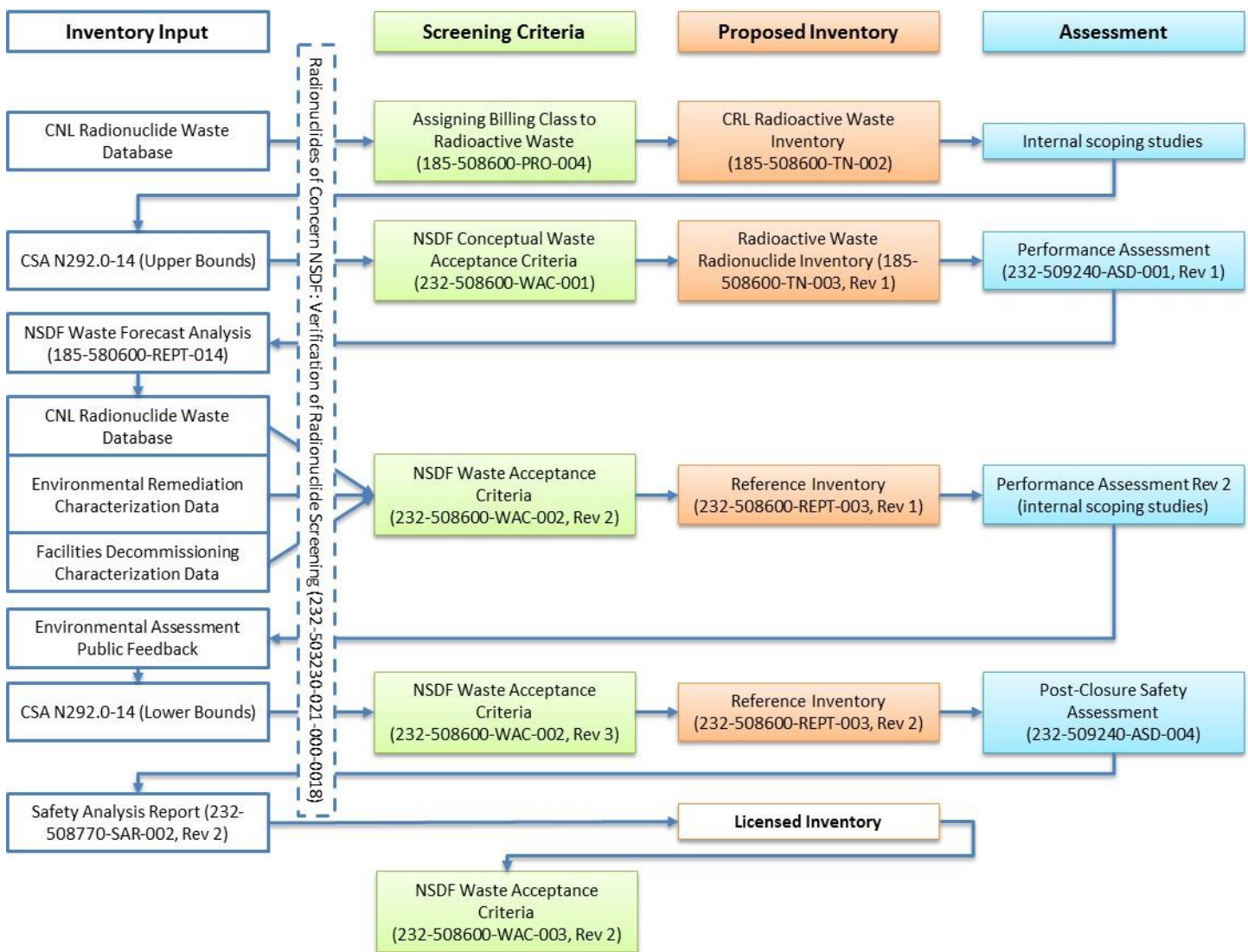


**Figure 5-21 Reference Inventory Development Iterative Processes [5-86]**

The outcome of the Reference Inventory development and iteration was a significant reduction in total radioactivity planned for disposal at the NSDF. The radioactivity assessed in the draft EIS of 2017 [5-145], was reduced to about 1% of initial values in the current Reference Inventory. Figure 5-22 illustrates the significant reduction in radionuclide inventory that occurred between the start and end of the Reference Inventory development [5-144]. The reductions were primarily driven by results of the PostSA [5-146], the desire to establish a larger safety margin with respect to the dose acceptance criteria, and to adhere to ALARA principles.

For dose optimization purposes, the radioactive inventory was reduced by removing higher activity wastes (i.e., the small amounts of ILW present in the initial waste inventory). This also addressed concerns raised by both Federal/Provincial authorities and from the public that the waste included ILW. To provide more confidence that the NSDF waste inventory contains only LLW, the WAC was adjusted to align with the lower bounds of the IAEA [5-147] and CSA [5-148] guidelines for LLW. Previous to this adjustment, the WAC reflected the upper bounds of these documents.

The IAEA and CSA guidelines for LLW, followed by the NSDF WAC [5-86] are provided below.

IAEA General Safety Guide (GSG)-1, Section 2.27 states the following for LLW:

*... a limit of **400 Bq/g** on average (and up to 4000 Bq/g for individual packages) for long lived alpha emitting radionuclides has been adopted in some States. For long lived beta and/or gamma emitting radionuclides ... the allowable average activity concentrations may be considerably higher (up to tens of kBq/g).*

Canadian Standards Association (CSA) N292.0-19, A.5.1, states the following for LLW:

*...a limit of **400 Bq/g** on the average (and up to 4000 Bq/g for individual waste packages) for long-lived alpha emitting radionuclides can be considered in the classification process. For long-lived beta and/or gamma emitting radionuclides ... the allowable average activity concentrations can be considerably higher (up to tens of kBq/g).*

The NSDF WAC has the following limits provided in Table 5-18 [5-86] for a single radionuclide; or in the case of a mixture of radionuclides, the sum of the component radionuclide limit fractions must not exceed 1 to demonstrate compliance and referred to the "Sum of Fractions" rule defined in Equation 5-1. The calculation of the concentration limits shall exclude the mass of packaging and shielding.

$$\sum_{i=1}^n \frac{\text{Concentration of Radionuclide } i}{\text{WAC Limit for Radionuclide } i} \leq 1 \quad (\text{Equation 5-1})$$

**Table 5-18**  
**Radionuclide Concentration Limits in the NSDF Waste [5-86]**

|                                                                           |                                                                                                                                                                                                                                                                                                                                                                                                             |
|---------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Limits for Bulk Waste &amp; Non-Leachate Controlled Packaged Waste</b> | <ul style="list-style-type: none"> <li>- 100 Bq/g for <math>\alpha</math> emitting radionuclides</li> <li>- 1,000 Bq/g for long-lived <math>\beta\gamma</math> emitting radionuclides (<math>t_{1/2} &gt; \text{Cs-137}</math>)</li> <li>- 10,000 Bq/g for short-lived <math>\beta\gamma</math> emitting radionuclides (<math>t_{1/2} \leq \text{Cs-137}</math>)</li> <li>- 100,000 Bq/g for H-3</li> </ul> |
| <b>Limits for Leachate Controlled Packaged Waste</b>                      | <ul style="list-style-type: none"> <li>- 400 Bq/g for <math>\alpha</math> emitting radionuclides</li> <li>- 10,000 Bq/g for long-lived <math>\beta\gamma</math> emitting radionuclides (<math>t_{1/2} &gt; \text{Cs-137}</math>)</li> <li>- 10,000 Bq/g for Cs-137</li> <li>- 10,000 Bq/g for Sr-90</li> <li>- 10,000,000 Bq/g for H-3</li> </ul>                                                           |

Tritium (H-3) is a short lived radionuclide with a half-life of about 12.3 years, and the WAC limits are derived from the Drinking Water Quality Guidelines [5-149], which limit tritium in drinking water to 7 000 Bq/L. This drinking water limit is derived on the basis that an adult drinks 730 L of water at the limit per year, and receives 0.1 mSv as a result (10% of the public dose limit) [5-150].

The discharge of treated effluent is to Perch Lake and Perch Creek. Neither of these are sources of drinking water for humans, yet the target is to meet the drinking water standards for those bodies of water. The leachate, surface water, and groundwater modelling performed for the Project, support the tritium WAC limits. Tritium is only a consideration during the operational phase. With a relatively short half-life of only 12.32 years, the tritium activity will decay to ~0.1% of the original values in about 120 years.

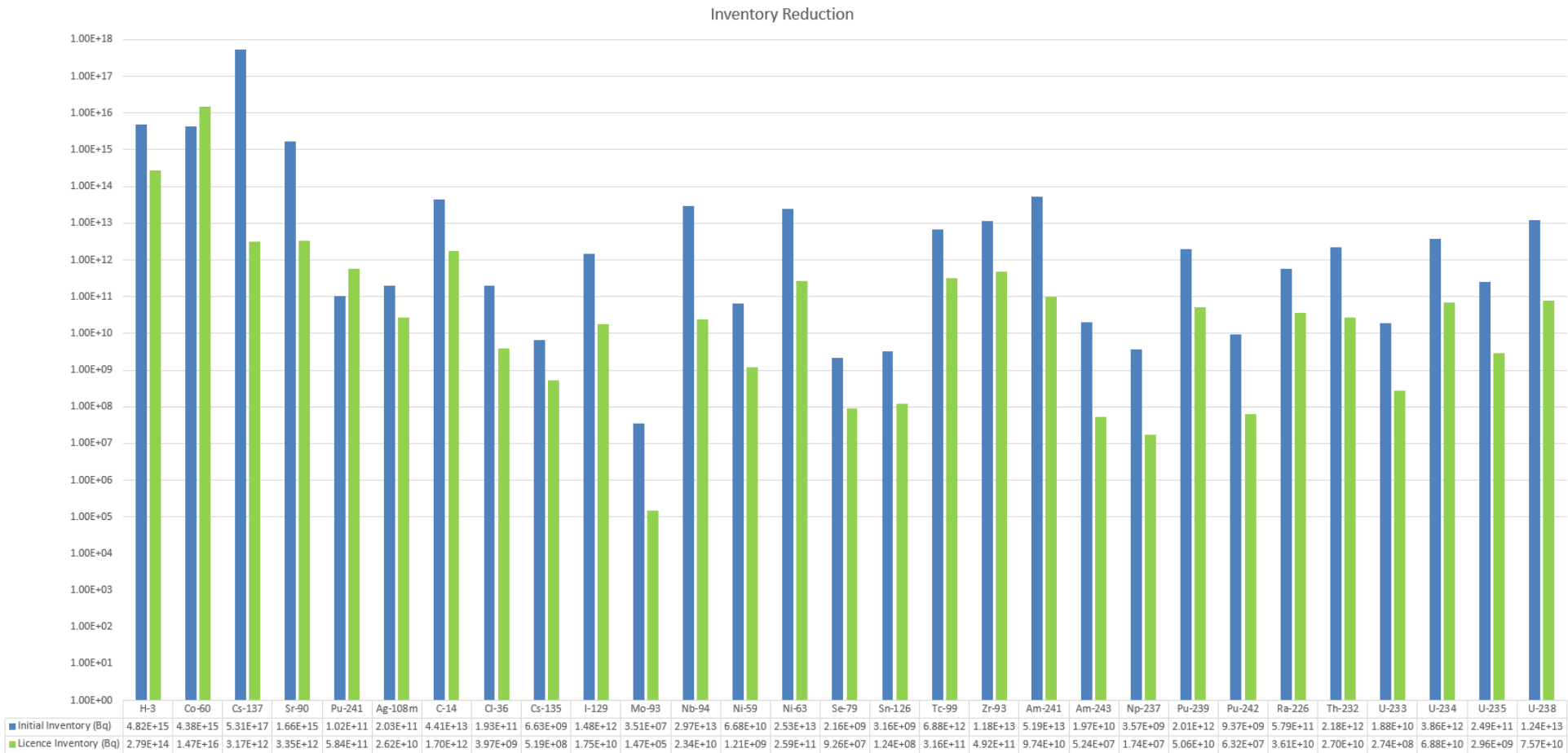


Figure 5-22 Inventory Reduction

## 5.7 Licensed Inventory

The Licensed Inventory [5-119] is the maximum radioactivity of the significant radionuclides at placement and at closure. The Licensed Inventory at closure, shown in Table 5-19, is a safety limit for the safe operation of the NSDF, and the ECM radiological inventory at closure shall not exceed the specific radionuclide activity (Bq) limits in the Licensed Inventory at closure [5-119].

The post-closure safety assessment modelling was used to refine the NSDF radiological inventory, Reference Inventory [5-144], which was used to inform the design and the safety analyses. During this iterative process, a decision was made to adjust the activity concentrations of many long-lived radionuclides, to ensure that the total radioactivity in the NSDF decays to near-background levels within a reasonable timeframe. As a result, the quantity of Zr-93 was reduced to 40.8%, and Nb-94 was reduced to 10% of the original Reference Inventory values in [5-144].

In the third iteration of the Post-Closure Safety Assessment [5-146], a recommendation was made to lower the maximum radioactivity of two radionuclides listed in the reference inventory, to support the claim that future public doses in the post-closure phase will be well below the long-term dose acceptance criteria. This recommendation was used in the NSDF Safety Analysis Report [5-119], to modify the reference inventory, and this modified reference inventory, known as the Licensed Inventory is part of the NSDF safety and licensing basis, and represents a maximum radiological inventory limit for the NSDF. In the Licensed Inventory [5-119], the radioactivity of both I-129 and Pu-239/Pu-240 were reduced to 58% of the reference inventory values [5-144] presented in Table 3-22.

**Table 5-19**  
**NSDF Licensed Inventory at Closure**

| Radionuclide | Maximum Activity (Bq) at Closure |
|--------------|----------------------------------|
| Ag-108m      | 2.62E+10                         |
| Am-241       | 9.74E+10                         |
| Am-243       | 5.24E+07                         |
| C-14         | 1.70E+12                         |
| Cl-36        | 3.97E+09                         |
| Co-60        | 1.47E+16                         |
| Cs-135       | 5.19E+08                         |
| Cs-137       | 3.17E+12                         |
| H-3          | 2.79E+14                         |
| I-129        | 1.75E+10                         |
| Mo-93        | 1.47E+05                         |
| Nb-94        | 2.34E+10                         |
| Ni-59        | 1.21E+09                         |
| Ni-63        | 2.59E+11                         |
| Np-237       | 1.74E+07                         |
| Pu-239/240   | 5.06E+10                         |
| Pu-241       | 5.84E+11                         |
| Pu-242       | 6.32E+07                         |
| Ra-226       | 3.61E+10                         |

| Radionuclide | Maximum Activity (Bq) at Closure |
|--------------|----------------------------------|
| Se-79        | 9.26E+07                         |
| Sn-126       | 1.24E+08                         |
| Sr-90        | 3.35E+12                         |
| Tc-99        | 3.16E+11                         |
| Th-230       | 5.30E+09                         |
| Th-232       | 2.70E+10                         |
| U-233        | 2.74E+08                         |
| U-234        | 6.88E+10                         |
| U-235        | 2.96E+09                         |
| U-238        | 7.57E+10                         |
| Zr-93        | 4.92E+11                         |

## 5.8 Post-Closure Performance Assessment Models

The PostSA and its associated models have been through several iterations and improvements since the first version performed in support of the draft EIS in 2017 [5-145]. This section describes the evolution and iterations of the PostSA from beginning of the Project up to the submission of this Safety Case report in 2019. Table 5-20 below provides a brief summary, with descriptions to follow.

**Table 5-20**  
**Post-Closure Analysis – Description and Summary**

| Revision name                          | Purpose                                                                             | Content                                                                       | Reference Inventory                                                                                                |
|----------------------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------|
| Performance Assessment (PA) Revision 0 | Submitted to support the draft EIS submission                                       | Portions of the pre-closure safety assessment.<br>All post-closure assessment | LLW, including 1% ILW                                                                                              |
| Performance Assessment Revision 1      | Refinements to RESRAD model, used to supplement CNSC staff review of Revision 0     | Portions of the pre-closure safety assessment.<br>All post-closure assessment | LLW, including 1% ILW                                                                                              |
| Performance Assessment Revision 2      | Removal of ILW, other refinements and updates in response to comments received.     | Portions of the pre-closure safety assessment.<br>All post-closure assessment | Removal of ILW, overall reduction to about 1% of initial radiological inventory                                    |
| Addendum 1                             | Change modelling tool from RESRAD to AMBER for greater resolution and capabilities. | Post-closure only                                                             | LLW only.<br>Reduction of Zr-93 inventory to allow for radiological decay to near-background concentrations sooner |
| Addendum 2                             | To address gaps in the assessment, related to the FEPs analysis.                    | Specific post-closure scenarios.                                              | Unchanged                                                                                                          |

|                                            |                                                                                              |                                                                                                                                           |                                                                                     |
|--------------------------------------------|----------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
|                                            |                                                                                              | Ecological Risk Assessment included.                                                                                                      |                                                                                     |
| Post-Closure Safety Assessment, Revision 3 | Consolidated PostSA package to support licence submission, including revised EIS submission. | Complete PostSA, including EcoRA and assessment of the non-radiological inventory.<br><br>ISAM adherence and driven by the FEPs screening | Reduction of Nb-94 to 10% of previous amount to reduce dose in a specific scenario. |

### 5.8.1 First Iterations of Post-Closure Assessments

The initial PostSA was performed in support of the initial draft EIS of 2017 [5-145]. At the time, this report was called the “Performance Assessment” (PA) a name typically used for this type of assessment by American and other international licensees of radioactive waste disposal facilities. The iteration of the PA used for discussion in this Safety Case document is called the PostSA, and is an evolution of the original PA.

The original PA used the software RESRAD to model doses to on-site and off-site receptors. While RESRAD is a well-respected tool used internationally, it is limited in how detailed the model can be, and limited with respect to changes in the model within time. RESRAD’s intended purpose is to assess contaminant migration from radiologically impacted sites, useful for establishing clean-up criteria and risk to the public in the long-term. It is difficult to take credit for the multiple barriers in the NSDF cover and liner system and also difficult to create a time-dependent change in the model, i.e., final cover or base liner barrier needs to be manually removed from the model to simulate their failure.

The original PA only assessed the radiological constituents in the waste in the long-term modelling.

The radiological consequence (dose) results for the original PA (Revision 0 and Revision 1,) were at the upper bounds of IAEA guidance, suggesting that an iteration of either the model, the inventory, or the design of the Facility was required.

The Project chose to refine the Reference Inventory to reduce the radiological consequence (dose). The primary change was the removal of the small amount of ILW that was present in the initial inventory as a dose optimization activity. The ILW removal, along with several other refinements, resulted in a radiological inventory that is about 1% of the original values. This revised Reference Inventory became the basis for the PA Revision 2. Revision 2 also addressed comments made by the CNSC and other Federal agencies.

### 5.8.2 Modelling Improvements

The NSDF contains multiple barriers with different physical and chemical properties. To more realistically model the NSDF and the surrounding environment, a model with more resolution and options was required. It was decided that an Addendum (#1) to the PA would be performed, this time using the AMBER software tool to assess the scenarios.



AMBER is a compartmental modelling tool and has been used previously in Canadian licensing processes, including the Ontario Power Generation Deep Geologic Repository for Low and Intermediate Level Waste. The use of AMBER allowed for the long-term modelling to include new functions, including:

- The ability to degrade barrier systems independently of each other, and at different rates.
- The ability to model the flow of water more realistically as barriers degrade (i.e., dependent on degradation of the barriers and the changing hydraulic conductivity values as a result).

In general, for near-surface disposal facilities, the capabilities of AMBER include the modelling of:

- Container failure.
- Leaching from the waste due to infiltration of rainwater.
- Water-borne transport through the engineered structure and unsaturated zone.
- Advection and dispersion through an aquifer.
- Abstraction of irrigation and other water.
- Leaching from the soil due to water infiltration.
- Erosion from the soil.
- Ingestion of drinking water.
- Ingestion of soil.
- External irradiation from soil.
- Inhalation of suspended atmospheric material.
- Ingestion of meat and milk.
- Ingestion of crops.

In addition to the software change from RESRAD to AMBER, it was decided to limit the Zirconium-93 (a longer-lived radionuclide) inventory by almost half. Low-Level Waste is not expected to contain significant amounts of Zr-93 which is an activation product in reactor materials. The result allows for the NSDF radiological inventory to approach background concentrations in a more reasonable timeframe.

### **5.8.3 Inclusion of Non-Radiological Constituents**

The work performed up to Addendum 1 had been focused on radiological safety and radiological impacts to receptors and the environment. The effects of the chemical, or “non-rads” in the Facility had not yet been analyzed.

One of the primary drivers for Addendum 2 was to study how the non-radiological constituents affect the radiological constituents, and how the non-rads migrate into the environment.

Although the NSDF is designed to be consistent with Ontario-Regulation 347, which restricts the amounts of leachable chemicals in surface disposal facilities, CNL made the decision to analyze some non-radiological constituents in the post-closure phase of the Project to demonstrate robustness and increase confidence.

Addendum 2 calculated the concentration of the important non-rads in environmental media during the post-closure phase, i.e., in surface water, groundwater, sediment, and soils. The calculated concentrations were then compared to environmental benchmarks and criteria. This work allowed for an EcoRA to be

conducted, which evaluates both the radiological dose and chemical exposure to biota. A similar exercise was carried out to evaluate the risk from chemical exposure to human receptors.

The work performed in Addendum 2, helped guide and direct the culminating assessments that form the PostSA, Revision 3.

#### **5.8.4 Post-Closure Safety Assessment, Iteration 3**

The PostSA, Iteration 3 [5-146], is the primary analysis that is referenced in this Safety Case document. It is the culmination of several years of iteration resulting from changes to the radiological inventory, and to address Federal government and public concerns.

The third iteration of the PostSA follows the ISAM process, which uses the most recent FEPs database to guide the scenario development. Over 300 FEPs were screened and evaluated for inclusion into the PostSA.

The previous PA and Addendum work provided valuable input and perspective for the third iteration. There were several changes incorporated into the PostSA document and discussed below.

##### **1. Radon**

Radon gas is naturally occurring in the ground. It is a product of the uranium decay chain. Uranium is present in most rock and soil, and therefore, radon gas is also present in rock and soil.

Radon gas typically only contributes to dose if a person is immersed in it for long periods of time. This is only possible in enclosed spaces built on the surface, and during periods of time where air is being recycled (i.e., windows closed during winter months). Radon is a noble gas, and does not incorporate itself into human tissue. Once it reaches the atmosphere it dissipates quickly and is no longer a hazard.

The average background dose from radon to Canadians is about 0.9 mSv/y [5-151], which is three times higher than the NSDF dose target of 0.3 mSv/y.

Previous iterations of the PostSA were including the dose from radon in the dose assessment. Since radon is naturally occurring, and contributes a large portion of an individual's background dose each year, its contribution was "overshadowing" contributions from other radionuclides. The inclusion of the radon dose was effectively including a source of natural background radiation in the calculation. Radon was removed because there is an alternative regulation for limiting public dose from radon exposure (Health Canada guidelines). As a result, radon gas concentrations became a Complementary Indicator of Safety in the PostSA Revision 3, and its contribution to the overall annual dose was removed.

##### **2. Receptor selection**

The 3<sup>rd</sup> iteration of the PostSA includes new receptor groups; one that respects the institutional controls and land-use restrictions, a group representing the residents of Sheenboro Quebec, and a group representing residents of Ottawa/Gatineau. The off-site receptor groups in Sheenboro and Ottawa/Gatineau were included to demonstrate to the public that the risk to downstream individuals is orders of magnitude below the natural background dose rates. Detailed information about all receptors can be found in Section 4 and in the PostSA.

##### **3. Scenario selection**

The 3<sup>rd</sup> iteration of the PostSA includes several new scenarios designed to illustrate deliberately extreme events, or to examine the effectiveness of a barrier system. The role of each major barrier system (the geosphere, cover, liner, and perimeter berms), are examined in these new scenarios. In addition, a mass

excavation and farming scenario was added to examine the effects of losing all containment of the Facility. Detailed information about all scenarios can be found in Section 4 and also in the PostSA.

#### **4. Inventory reduction**

There was a slight change in the radiological inventory as a result of preliminary PostSA results of the 3<sup>rd</sup> iteration. It was decided to limit the amount of Nb-94 to 10% of the previous amount to increase the safety margin between the calculated dose rate and the dose criterion of 0.3 mSv/y. Low-Level Waste is not expected to contain significant amounts of Nb-94 which is an activation product in reactor materials.

### **5.9 Integration of Data and Models Across Analyses**

Throughout the course of the NSDF Project there have been a number of studies performed, including, literature reviews, field surveys, monitoring and sampling campaigns, computation analysis, and academic testing programs. Data obtained via these methods was used in subsequent models and analyses to further develop the design and safety analyses of the NSDF Project. This section will describe some of the connections between data collection and analyses and/or model implementation within the Project.

#### **5.9.1 Geomembrane Testing and the PostSA**

The geomembrane testing program, as described in Section 5.3.4.5, was intended to enhance confidence in the longevity and structural integrity of the high-density polyethylene geomembrane material. The study suggests that the candidate geomembrane (GMB) can be expected to perform its function for up to 2000 years, which exceeds the facility design life of 550 years [5-23]. The confidence provided by this study was used as input into a sensitivity study in the PostSA [5-146], where the GMB was assumed to remain functional for the entire 2000 years (Sections 5.2.5.5.1 and 6.3.5 of the PostSA). The results of this case demonstrate an overall reduction in radiological dose to the receptors, as fewer contaminants are able to migrate from the Facility.

#### **5.9.2 HELP Model and the PostSA**

The HELP model is used to estimate water balances for land disposal systems, and was used for this purpose in the NSDF Project. The program models rainfall, run-off, infiltration, and other water pathways to estimate how much water builds up above each cover system. Section 5.3.5.2 of the PostSA [5-146] describes how the results of this modelling was used as a starting point in AMBER when calculating and extrapolating the water infiltration rate as the cover system degrades with time.

#### **5.9.3 Perch Lake Basin Characterization, Hydrogeology, and the PostSA**

The NSDF is proposed to be constructed in the Perch Lake Basin. This area of CRL site has been previously impacted by radioactive waste management practices of the pioneering days of the nuclear industry in Canada. As one of the areas of CRL impacted by anthropogenic radioactivity, the Perch Lake Basin is extremely well monitored and studied for over five decades. The years of sampling data and borehole measurements were used as inputs in the groundwater modelling [5-152] performed for all periods of the NSDF Project lifecycle, including the post closure period.

Hydrogeology models (as described in Section 3.1.4.4.1) and Post SA models have been developed for the NSDF. The hydrogeology models evaluate groundwater flows due to the NSDF. The results of the hydrogeology models form the basis of groundwater pathways through the geosphere, as inputs to the PostSA

models. One of the purposes of the PostSA models for the NSDF is to undertake a quantitative assessment of the post closure radiological and non-radiological safety of the proposed NSDF. The PostSA models have been implemented using the AMBER code.

Hydraulic conductivity (K) is one of the key parameters to affect the hydrogeological models. The presence of geological features (e.g., fracture zones or dykes) can potentially alter hydraulic conductivity (K) values and modelling results.

Considering the long timeframe as part of PostSA [5-146], geological features may potentially evolve in the future, for example due to a significant earthquake. Additional hydrogeology models ([5-153] [5-154]) have been developed to examine scenarios that take into account the hypothetical existence of potential geological features within the NSDF SSA. These models examined: the worst case of fracture zone conditions [5-154] and the case if undetected fracture currently exists [5-153].

Inclusion of a hypothetical bedrock fracture zone (e.g. higher permeability zone) in the EIS groundwater flow model initially simulated significantly lower (up to 7 m) groundwater elevations than those observed at groundwater monitoring locations in the vicinity of the ECM [5-154]. Recalibration of this model was reasonably achieved through a reduction in hydraulic conductivity of the bedrock units and the fracture zone, as well as an increase in the recharge rate applied in the ECM area [5-153]. The adjustments made to model input parameters were considered reasonable based on measured values thus providing confidence in the new model [5-153]. This recalibration resulted in simulations that are comparable to the initial model calibration completed [5-153].

A simulation of the post closure scenario with the revised model (including the hypothetical bedrock fracture zone) was completed [5-153]. This resulted in a minor change to the groundwater flow pathway, where a portion of groundwater released in the upper ECM area travelled through the fracture zone prior to reaching the overburden. The resulting groundwater travel times between the ECM and Perch Creek were similar with the hypothetical bedrock fracture zone included as compared to the base scenario (i.e., typically 7 to 10 years for the majority of groundwater particles, with the overall range of 5 to 15 years). The re-calibration and forecast simulation including the hypothetical fracture zone are documented in ([5-154] and [5-153]).

#### **5.9.4 Geotechnical Field Studies, Seismic Analysis, and the PostSA**

An extensive geotechnical campaign was carried out to characterize the CRL site, initially in support of the development of a geologic waste management facility [5-14], [5-30]. The borehole, core samples, and overall characterization of ground faults and bedrock features present on the CRL site were used as key inputs into justifying the seismic analysis performed for the NSDF Project. The seismic analyses completed for the NSDF Project (e.g., [5-71] and [5-76]) were used as inputs and justification for both the assessment timeframe and for some of the disruptive events analysed in the PostSA [5-146].

A site specific Probabilistic Seismic Hazard Assessment (PSHA) was conducted for the NSDF site to determine the level of seismic hazard for the ECM design and modelling [5-71]. The PSHA [5-71] utilized the 2015 National Building Code of Canada (NBCC) [5-155], the latest Canadian standard at the time of the design development. The analyses considered the geological features and past seismic events relevant for the NSDF site. The definition of the seismic criteria and assessment for the NSDF design is provided in [5-156].

Canadian Nuclear Laboratories has conservatively chosen a 1 in 10 000 year earthquake as the Design Basis Earthquake (DBE) for the ECM for the ECM's 550 year design life. This is the earthquake in the CSA N289.1 [5-157] standard that is to be applied to the design of a nuclear power plant. The adoption of this size of

earthquake is considered conservative because the inventory of radioactive material in the NSDF is significantly less than the radioactive inventory of a nuclear power plant; thus, the consequence of exceeding the DBE at the NSDF site during the 550 year design life is much less than the consequence of exceeding a DBE at an operating power reactor if the safety and containment systems do not mitigate the event as designed. The DBE is commensurate with the design life and the risk associated with the ECM.

Within the design, to mitigate potential liquefaction due to a seismic event, the NSDF design implements the “remove and replace” ground improvement technique at the locations where potential liquefaction was identified to mitigate potential liquefaction ([5-158], [5-76] and [5-64]). While this technique is currently limited to the overburden soil, this may be extended if in the future, it was discovered that the bedrock strength and features are not suitable during the geological verification program.

Within the PostSA, CNL demonstrates that there are no impacts to human health and the environment if more severe events than a design basis seismic event were to occur. In addition, quantitative analysis that the “Series of Landslides” scenario bounds the consequences from a more severe seismic event (i.e., 1 in 50 000-year earthquake) has been developed ([5-146] and [5-159]).

#### **5.9.5 Microshield, the Safety Analysis Report, and the Waste Acceptance Criteria.**

The development of the Reference Inventory, Licensed Inventory, and WAC is described in Section 5.6. The focus of that section is to describe how the maximum radioactivity limits of the Facility was determined.

However, the WAC [5-86] also received input from the Safety Analysis Report, where Microshield was used to study the external dose rates that could be present if the radiological WAC were followed with no other limits. As a result of these calculations, it was determined that the WAC must also include external dose rate limits on packages to protect the worker from undue radiological exposure during the operations period.

#### **5.10 Cumulative Effects**

Section 8 of the EIS [5-7] contains a comprehensive discussion about the potential cumulative effects that could result from the NSDF Project in combination with the effects of other activities that have, or will be carried out in the near future. The discussion includes cumulative effects to each of the primary environmental aspects (e.g., air quality, greenhouse gas, surface water quality, etc.)

Paragraph 6.84 of IAEA SSG-23 [5-4] states that *“In the event that several facilities are present or planned at a site, including disposal facilities, the cumulative radiological impacts from these facilities should be considered in the decision making process”*. A summary of the expected radiological cumulative effects from the NSDF and reasonably foreseeable sources of radioactivity on or near the CRL site is presented in this section. For discussion of other potential cumulative effects (e.g., socio-economic, traffic, etc.) please refer to the EIS [5-7].

The NSDF Project has the potential to interact with previous, existing and reasonably foreseeable developments or activities in the region. Table 5-21 provides a summary of the other projects considered in the Reasonably Foreseeable Developments (RFD) case studied in the EIS [5-7].

**Table 5-21**  
**Reasonably Foreseeable Developments Considered in the Assessment**

| Type of Project                                               | Location | Examples                                                                                                                                                                                                 | Timeframe       |
|---------------------------------------------------------------|----------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|
| <b>Activities related to CNL's Long-Term Strategy</b>         |          |                                                                                                                                                                                                          |                 |
| New/upgraded research and development facilities              | CRL      | Advanced Nuclear Material Research Centre<br>Small Modular Reactor                                                                                                                                       | 2019 and onward |
| New support infrastructure                                    | CRL      | Office buildings, maintenance facility, logistics facility                                                                                                                                               | 2018 to 2026    |
| Infrastructure decommissioning                                | CRL      | Over 100 buildings on CRL site including nuclear laboratories and conventional buildings                                                                                                                 | 2016 to 2026    |
| Environmental remediation                                     | CRL      | Remediation of affected lands and non-operating waste management areas (WMAs).                                                                                                                           | Ongoing         |
| In situ disposal of Nuclear Power Demonstration (NPD) reactor | Rolphton | The NPD Closure Project (in situ disposal of the NPD waste facility in Rolphton, Ontario)                                                                                                                | 2021 to 2023    |
| <b>Garrison Petawawa</b>                                      |          |                                                                                                                                                                                                          |                 |
| Construction of new infrastructure at Garrison Petawawa       | Petawawa | Construction of new facility for the Royal Canadian Dragoons (e.g., renovation of three existing buildings, and the replacement of eight obsolete buildings with a single, centralized 9,900 m facility) | 2020 to 2021    |

### 5.10.1 Ten-year Integrated Plan for the Chalk River Laboratories

Canadian Nuclear Laboratories 10-year science and technology strategic objectives to support the evolving science and technology needs of the Canadian and global industry are to [5-2]:

- Provide sustainable energy solutions, including the extension of reactor operating lifetimes, hydrogen energy technologies, and fuel development for the reactor designs of tomorrow,
- Demonstrate the commercial viability of advanced reactors, including the small and very small modular reactor (SMR);
- Continue to support radiochemical therapies, including collaboratively pioneering new alpha therapies; and
- Protect Canada's environment by removing and responsibly managing nuclear liabilities.

As presented in Table 5-21, these goals will be met through a combination of revitalization activities (i.e., developing new or upgrading existing research and development facilities at CRL, constructing new support infrastructure), decommissioning old infrastructure and conducting environmental remediation.

#### Small Modular Reactor

Three candidate sites were identified as feasible by CNL within the CRL site, under consideration for locating the SMR. The closest of these is located more than 1 km to the northeast of the NSDF SSA near the built-up area of the site, within the Ottawa River direct watershed.

Bounding estimated dates indicate site preparation and construction is planned to occur over approximately two years between 2021 and 2027 with operation of approximately 20 years between 2023 and 2054. The

construction of the SMR may overlap with the construction of the NSDF Project. Following the end of its operational life, decommissioning would occur over approximately two to three years between 2054 and 2058, with abandonment activities occurring over two to three years between 2058 and 2060.

### **Nuclear Power Demonstration Closure Project**

The purpose of the Nuclear Power Demonstration (NPD) Closure Project is to safely complete the decommissioning of the NPD Waste Facility, located near the CRL site at Rolphton, Ontario. In situ disposal is the preferred approach proposed by the project to carry out these activities.

The proposed in situ disposal activities include removing the above grade structure and placing contaminated materials into the below grade structure. The below grade structure, reactor vessel and systems and components will be sealed by grouting. The structure will then be capped with concrete and covered with an engineered barrier. In situ disposal will isolate the contaminated systems and components inside the below grade structure.

The conclusion of the Draft Environmental Impact Statement for the NPD Closure Project identifies that no residual adverse effects are identified as a result of the Project. As a result, there are no cumulative effects with NSDF.

### **Garrison Petawawa**

In support of Canada's defense policy, "Strong, Secure, Engaged," a pilot project was announced in 2019 January to deliver new and enhanced facilities for the Royal Canadian Dragoons at 4th Canadian Division Support Base, Garrison Petawawa, located adjacent to the CRL site. The project includes renovation of three existing buildings and replacement of eight buildings no longer in use with a single, centralized approximately 10 000 m<sup>2</sup> facility with construction planned for 2020 to 2021. Activities at Garrison Petawawa do not have the potential to introduce radioactivity into the environment, and therefore there are no cumulative effects with NSDF.

## **5.10.2 Evaluation of Radiological Cumulative Effects**

### **Air Quality**

The scale and modular construction technique for the SMR limits the length of its construction period, as well as associated equipment use. The locations for placement of the SMR under consideration are removed from the SSA within the CRL site. During operation of the SMR, dry cooling towers may be used to dissipate excess heat from steam condensation in operation of the steam turbine generator. No additional activities or new sources for release of indicator compounds are planned. With effective implementation of mitigation measures and monitoring programs, no cumulative residual effect is identified to air quality.

### **Geology and Hydrogeology**

New and upgrades to research and development facilities, construction and operation of the SMR and new support infrastructure are planned within areas of the CRL site removed from the NSDF Project site and generally within existing disturbed areas. Best practices, such as surface water management systems and waste management programs, are expected to be implemented to minimize any potential effects to measurement indicators for geology and hydrogeology, including soil quality, groundwater flow or quality during construction and operation of these facilities. No process intakes of water from or discharges to surface or groundwater are identified in the description of the planned SMR. As such, potential effects from

the construction and operation of the SMR or revitalization activities are not expected to spatially overlap with potential effects to geology or hydrogeology from the NSDF Project during normal operations. The end-state plan for the CRL site will be to return lands disturbed by site activities to a condition that is physically stable and safe in keeping with the land use and landscape of the day. Therefore, decommissioning and environmental remediation activities are anticipated to positively affect measurement indicators for geology or hydrogeology such as soil and groundwater quality. As well, no potable water wells are anticipated to be installed within the RSA during the time up to the end of the institutional control period during post-closure.

### **Surface Water Environment**

No process intakes of water from or discharges to surface or groundwater are identified in the description of the planned SMR. It is noted that a small amount of radioactive liquid waste from decontamination activities during the operation of the SMR will be monitored and stored in a holding tank for further processing. A septic field may be used to manage sewage from the SMR site, depending on the candidate site chosen, that would follow required standards and would be located approximately 2 km from the NSDF Project site. Consequently, potential effects from revitalization activities and through development of the SMR are not expected to spatially overlap with potential effects to surface water quality from the NSDF Project. The NSDF Project will enable the remediation of contaminated lands and legacy waste management areas, as well as decommissioning of outdated infrastructure at the CRL site and CNL's other business locations to support future CNL work. The end-state plan for the CRL site will be to return lands disturbed by site activities to a condition that is physically stable and safe in keeping with the land use and landscape of the day. Therefore, decommissioning and environmental remediation activities are anticipated to positively affect hydrology and surface water quality.

### **Aquatic Environment**

Potential effects from these RFD activities are not expected to spatially overlap with potential effects to the aquatic environment biodiversity from the NSDF Project. No primary pathways, and therefore, no measurable residual adverse effects were identified as a result of the Project to the aquatic environment. The end-state plan for the CRL site will be to return lands disturbed by site activities to a condition that is physically stable and safe in keeping with the land use and landscape of the day. Therefore, decommissioning and environmental remediation activities are anticipated to positively affect fish and fish habitat.

### **Terrestrial Environment**

Reasonable foreseeable developments expected within the CRL site (i.e., the RSA) that may interact with the terrestrial environment include new or upgrades to research and development facilities, construction and operation of the SMR, new support infrastructure, and ongoing decommissioning and environmental remediation activities. New support infrastructure and research and development facilities will generally be located within existing disturbed areas on the CRL site (i.e., no disturbance to largely undeveloped areas) where erosion and sediment control practices and surface water management systems already in place will be implemented. Disturbance of approximately 3.5 ha including potentially undisturbed areas of the CRL site, may be required for development of the SMR based on the candidate site selected. The three candidate sites for locating a SMR on the CRL site are located away from the SSA. It is expected that removal of and other potential effects on terrestrial habitat including to species at risk through development of a SMR will be reduced through consideration of siting and through mitigation similar to that implemented for the NSDF Project. Potential effects from these revitalization activities, as well as construction and operation of the SMR, are not expected to spatially overlap with potential effects on terrestrial biodiversity from the NSDF Project.



**Ambient Radioactivity, Ecological Health, and Human Health**

Reasonable foreseeable developments within the CRL site (i.e., the RSA) include only the new or upgrades to research and development facilities, construction and operation of the SMR, new support infrastructure, and on-going decommissioning and environmental remediation activities. Revitalization projects at the site (i.e., new or upgrades to research and development facilities, new support infrastructure) and decommissioning include several small projects staged over a 10-year period where best practices, mitigation and monitoring for management of emissions will to be followed. No process intakes of water from or discharges to surface or groundwater, or releases to air beyond potential for a limited amount of steam from dry cooling towers, are identified in the description of the planned SMR. During normal operations, the SMR will introduce a very small radiological exposure to the environment near the plant, within the CRL site. The incremental radiological (in proximity to the SMR) and non-radiological emissions from RFD Projects at any one time are expected to be small, distributed across the CRL site and removed from the more intensive activities within the SSA (i.e., the NSDF Project footprint). Potential effects from RFD Projects are not expected to spatially overlap with potential effects to ecological health from the NSDF Project.

The NSDF Project will enable the remediation of contaminated lands and legacy waste management areas, and decommissioning of outdated infrastructure at the CRL site and CNL's other business locations to support future CNL work. The end-state plan for the CRL site will be to return lands disturbed by site activities to a condition that is physically stable and safe in keeping with the land use and landscape of the day. Therefore, decommissioning and environmental remediation activities are anticipated to positively affect ecological health.

**5.10.3 Radiological Cumulative Effects Summary**

In the near future, CNL plans to engage in large scale decommissioning activities, environmental remediation activities, the building of new laboratory structures, close the NPD site, and host the construction and operation of an SMR. Additionally, it is recognized that there could be activities at Garrison Petawawa. The discussion above and detailed further in the EIS demonstrates that there are no expected cumulative effects between the NSDF Project and other reasonably foreseeable developments. This is largely because:

- The reasonably foreseeable developments near NSDF aren't expected to have significant residual effects, and therefore cannot contribute to cumulative effects; or
- The reasonably foreseeable developments do not spatially or temporally overlap with the NSDF Project, and therefore do not contribute to cumulative effects.

**5.11 Summary**

Table 5-22 presents the Iteration and optimization summary.

**Table 5-22**  
**Summary of the Iteration and Optimization**

| Aspect                              | Iteration and Optimization                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
|-------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Site Characteristics                | <ul style="list-style-type: none"> <li>• NSDF design utilized site-specific data.</li> <li>• Site characterization included bedrock depth and comprehensive survey locations, which reduced uncertainties in the design, numerical models, and improve safety of the system.</li> <li>• Changing of site boundary to protect archeological resources.</li> <li>• Start initiatives to protect species at risks, including turtles and bats.</li> <li>• Groundwater and air monitoring systems have been installed at the NSDF site.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
| ECM Design                          | <ul style="list-style-type: none"> <li>• Changes on the number of cells and phases and layout.</li> <li>• Design Concept Decision optimized:               <ul style="list-style-type: none"> <li>○ ECM Floor Elevation</li> <li>○ Leachate Collection System (LCS) and Leak Detection System (LDS)</li> <li>○ Base Liner Systems (Types)</li> <li>○ Final Cover System</li> </ul> </li> <li>• The ECM design has been optimized to withstand seismic hazard suitable for the NSDF site.</li> <li>• The design of the ECM incorporates ground improvement technique (i.e., remove and replace), to avoid potential liquefaction. Selection of the ground improvement technique was optimized.</li> <li>• Base liner and final cover systems have been optimized to withstand potential effects of leachate, freeze and thaw. In addition, the life-cycle performance of the base liner and final cover systems has been evaluated and can meet required design life.</li> <li>• The ECM design has been developed to manage potential gas migration.</li> </ul> |
| Design of WWTP and other structures | <ul style="list-style-type: none"> <li>• The WWTP process design considered the following analyses:               <ul style="list-style-type: none"> <li>○ Wastewater Quality and Quantity</li> <li>○ Wastewater Treatability</li> <li>○ Conducted laboratory scale testing and pilot scale testing</li> <li>○ Surface water modelling and evaluation</li> <li>○ Sensitivity analyses for wastewater quality and quantity</li> </ul> </li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| Waste                               | <ul style="list-style-type: none"> <li>• As a result of the dose modelling, as well as comments from intervenors, the ILW waste streams were removed. The inventory was reduced to about 1% of its original radio activities.</li> <li>• To ensure that only LLW is accepted into NSDF, the WAC limits are consistent with the lower bounds of IAEA and CSA guidance for LLW.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| PostSA models                       | <ul style="list-style-type: none"> <li>• The original PA used RESRAD.</li> <li>• AMBER used to optimize modelling capabilities.</li> <li>• PostSA results were used to optimize the Reference Inventory and the WAC, which led to the development of the Licensed Inventory.</li> <li>• Several iterations and scoping studies were performed using the PostSA.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |

| Aspect | Iteration and Optimization                                                                                                                                               |
|--------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|        | <ul style="list-style-type: none"> <li>Final iteration was developed using ISAM and FEPs screening. Includes assessment of the non-radiological constituents.</li> </ul> |

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## 6. MANAGEMENT OF UNCERTAINTIES

The overall strategy for the management of uncertainties can be summarised as: **identify, avoid, reduce, and assess and manage**. **Identification** and communication of uncertainties is essential for the development of the safety case and understanding the disposal system concept. The development of the disposal system is based on robustness and multiple safety functions, which means **avoiding** concepts and SSCs that would be difficult to understand and predict. The iterative design and development process of the disposal system allows the **reduction** of uncertainties by means of NSDF Project efforts including engineering, characterization and safety assessments. However, some uncertainties will always remain and have to be **assessed and managed** based on their relevance to safety and protection of the public, workers and the environment.

The management of uncertainties during the design phase and during safety assessment development, focuses on the use of sensitivity studies (systematic variation of input parameters), uncertainty analysis, and the use of conservative assumptions for deterministic models.

After construction and during the operations period, real data measurements from leachate monitoring and environmental sampling data, can be used to confirm the models inputs and outputs. If measurements are not consistent with the assumptions used in safety assessments, then these assessments are required to be updated using the real data as applicable.

A systematic identification and assessment of uncertainties that can affect the safety of the Facility should be part of the development, operation and closure, and should be factored in at each major decision point that relates, directly or indirectly, to the safety of the Facility [6-1].

The safety case should provide [6-2]:

- Identification of uncertainties in the behaviour and performance of the disposal system.
- Analysis of the significance of the uncertainties.
- Identification of approaches for the management of significant uncertainties.

The management of uncertainties determines the required robustness and reliability of the safety assessment and, for the operational period, includes the corresponding definition of limits, controls and conditions for the Facility documented in Section 7.

Other relevant factors are taken into account in a graded approach to safety assessment, including the use of proven design, practices and procedures, and of data on operational performance of similarly designed facilities, including uncertainties in the performance of such Facilities. Inaccessibility of key systems classified for safety and safety important components for maintenance and repair, is considered in establishing minimum safety design requirements and safety margins for uncertainties.

Uncertainties that have an impact on the safety analyses, design rules and decisions are addressed in uncertainty and sensitivity analyses. Uncertainty analysis refers mainly to the statistical combination and propagation of uncertainties in data, whereas, sensitivity analysis refers to the sensitivity of results to major assumptions about parameters, scenarios or modelling.

Analysis of the significance of uncertainties is completed in a deterministic approach with the objective to systematically identify key parameter uncertainties and provide sufficient safety margin. The deterministic approach is used to specify and apply a set of deterministic rules and requirements for the design and

operation of facilities or for the planning and conduct of activities. These deterministic rules and requirements are expected to provide a high degree of confidence that the level of radiation risks to workers and members of the public arising from the Facility will be acceptably low. The design is optimized to meet regulatory limits, which gives a margin that provides assurance of safety, consistent with the uncertainty of long-term predictions.

The management of uncertainties is described with a discussion about confidence, where an increase in confidence can reduce, or compensate for uncertainties. The following sections use the following methods to describe how uncertainty is addressed:

- Uncertainties and confidence in the modelling and waste inventory.
- Confidence in the physical design of the Facility.
- Confidence in the site characteristics.
- Confidence in the assessment results.
- Natural analogues.
- The treatment of uncertainties and the use of sensitivity cases.
- Benchmarking and lessons learned from similar facilities.
- Third party reviews of key project documentation.

As part of the safety assessment, sensitivity and uncertainty analyses were performed. This includes identification of the main sources of uncertainties, assessment of the impact of uncertainties on the results, and development of a program for reducing uncertainties, e.g., by additional research and development work.

## 6.1 Confidence in the Numerical Models

Confidence in the assessment results is obtained by developing models that accurately reflect the proposed disposal facility. Data used in the models has undergone a number of exercises and iterations to minimize uncertainty in the data and assumptions have been justified and independently validated. This further increases confidence.

All software used for the NSDF Project must meet the requirements of the project Quality Assurance Plan [6-3], which include verification and validation of software. The use of software is also subject to CNL's owner surveillance activities (audits) [6-4].

The majority of the safety analyses have relied on the use of commercially available software to develop numerical models to quantify the various scenarios. A more detailed list of software is given in Section 2. A brief description of the software used in the safety analyses:

**AMBER** - AMBER assesses the migration and fate of contaminants in a system, and has been used in a wide range of applications internationally. AMBER has been used for modelling:

- Near field radionuclide release and transport.  
Example use in PostSA: Normal evolution scenario for the Nuclear Waste Management Organization (NWMO), for the Adaptive Phased Management Deep Geologic Repository for Used Nuclear Fuel.
- Decommissioning and site closure.  
Example: Used by Japan Atomic Energy Agency to model remediation options for Fukushima, and Dounreay Site Restoration Limited for a number of projects relating to site closure.

- Modelling routine releases of radioactivity.  
Example: Uptake of C-14 in pasture following operational releases from the La Hague nuclear fuel reprocessing plant in Northern France.
- Borehole disposal of sealed sources.
- Near-surface disposal of LLW.
- Geological disposal of LLW and ILW.

**RESRAD** - RESRAD-OFFSITE (v. 3.2) is a computer code developed at Argonne National Laboratories for the US Department of Energy, and is an extension of the RESRAD (onsite) code, which has been widely used for calculating doses and risks from exposure to radioactively contaminated soils. The RESRAD-OFFSITE computer code evaluates the radiological dose and excess cancer risk to an individual who is exposed while located within or outside the area of initial (primary) contamination. Nine exposure pathways are considered in RESRAD-OFFSITE: direct exposure from contamination in soil, inhalation of particulates, inhalation of radon, ingestion of plant food (i.e., vegetables, grain, and fruits), ingestion of meat, ingestion of milk, ingestion of aquatic foods, ingestion of water, and ingestion (incidental) of soil.

**MicroShield (Version 9.02)** - MicroShield performs various shielding calculations and estimates the gamma exposure from radiation sources. There are 16 customizable geometries that can be utilized. This software is also utilized to design radiological shields and containers.

## 6.2 Confidence in the Waste Inventory

The NSDF waste inventory is referred to as the Reference Inventory; documented in [6-5]. The Reference Inventory is a product of iteration between the post-closure modelling of the PostSA [6-6] and the WAC [6-7]. The iterative process is described in Section 5.6, and in [6-5]. The Reference Inventory [6-5] addresses the following two questions:

- What wastes currently exist or will exist at CRL within the next 50 years? and;
- What wastes are appropriate for near-surface disposal at the selected CRL site?

The Reference Inventory was developed through conservative estimates and extrapolations. The main source of information was CRL's internal waste record keeping database, Waste Information Program (WIP). The quality and accuracy of information recorded in WIP, varies greatly depending on who was inputting data, whether the required data was entered and how accurate the waste characterization process was. There are many layers of conservatism introduced into the Reference Inventory by use of the WIP database:

- The WIP database does not decay its radioactivity. As a result, radionuclides with shorter half-lives are over-estimated in the data. This is of particular concern to the Cs-137, Sr-90, Co-60, and H-3 activity levels present in the waste. The presence of these radionuclides are key inputs for the design of the WWTP, the assessment of dose during both the operational and post-closure phase, as well as the discharge of tritium to the environment.
- The use of "hot-spot" measurements to represent the average radioactivity of an entire package. Often, the highest activity area of a package is used to estimate the radionuclide concentration, without consideration of the rest of the material which is much less radioactive. A "hot-spot" on a package could easily be 10 or 100 times more radioactive than the average over the entire mass. The result is that some packages may be reported as containing orders of magnitude more radioactivity than is actually present.

- The conversion of surface contamination to volumetric contamination. An example of this practice would be for the tracking of contaminated cinder blocks. Often, only a single face of the block would be contaminated, with the rest of the cinder block being relatively uncontaminated. In practice, the surface contamination was measured, and the calculated activity was applied to the entire mass. This greatly overestimates the activity of the cinder block, and other waste streams where only the surface was contaminated.
- The inconsistent use of “U-NAT”, “U-DEP” and “U-238” to report uranium activities. This practice may have led to the overestimation of the uranium currently in storage.
- Assuming that an entire waste stream contains a radionuclide at concentrations equivalent to the detection limit, especially with the acknowledgment that radiation survey devices have improved over the decades.
- The use of process knowledge to create waste entries. In the case where a waste package was not properly characterized or sampled before being placed into storage, its contents were often assumed based on knowledge of the waste stream. That is, if the package was known to come from a particular laboratory during a known time period, the contents of the package were conservatively assumed to contain the highest probable concentrations of radionuclides from the most probable waste stream arising from the activities performed in the particular laboratory. This practice has introduced significant over-estimation of the waste activity concentrations.
- Gross alpha and beta measurements were used to estimate activities of alpha and low energy beta emitting radionuclides. In these cases, it is assumed that the recorded radionuclide activities were intentionally conservative. It is possible that radionuclides were recorded that were not actually present in a package or waste stream.

In addition to the conservatisms present in the way data was recorded in WIP there is also conservatisms introduced with the extrapolation of the data. Waste Information Program records include packages stored during the period of 1995-2015, a period of time when the National Research Universal (NRU) reactor was operating, as well as the associated Molybdenum-99 Production Facility. A large portion of the waste records include hazardous and long-lived radionuclides associated with the operation of NRU and molybdenum production. The NRU was permanently shut down in early 2018, and therefore, the waste streams associated with its normal operation and isotope production have also ceased. The extrapolation of future packaged waste streams have not taken this into consideration. The extrapolation assumes that research-reactor waste is continued to be produced throughout the next 50 years of CNL operations. This is a significant conservatism in the waste inventory.

The data for 18 000 m<sup>3</sup> of waste packages was extrapolated to estimate the waste that would be produced in the next 50 years of CNL operations. The conservatisms and overestimates of waste activity have been multiplied and extrapolated, greatly increasing their significance on the reference inventory.

The confidence that the Reference Inventory is appropriate for the NSDF is demonstrated through the PostSA. The disposal of waste meeting the Licensed Inventory results in doses that meet the dose acceptance criteria, and environmental releases that meet environmental standards for the protection of biota and aquatic life, as presented in Section 4.

### **6.2.1 Waste Characterization**

Canadian Nuclear Laboratories waste characterization processes and procedures [6-8], are essential to building confidence that the NSDF will contain the radionuclides present in the Licensed Inventory. Canadian Nuclear Laboratories procedures follow the relevant CSA guidance required by the CRL Licence Condition Handbook [6-9]. Near Surface Disposal Facility operations are required to track the radiological inventory that is accepted for disposal.

The NSDF Licensed Inventory does not qualify any specific materials for disposal; all waste will be evaluated against all requirements of the licensed NSDF (i.e., the NSDF Waste Acceptance Criteria). All waste is subject to the Waste Management Process, described in Management of Waste [6-10]. The Waste Management process includes the planning, generation, transportation, processing, storage, and disposal of waste. The purpose of the Waste Management Process is to ensure that all waste generated or received at CNL managed sites are compliant with all applicable licences, regulations, standards and guidelines [6-11].

Waste planning is a mandatory part of the process that defines the characteristics of the waste and the requirements to properly manage the waste (e.g., packaging and handling requirements). Waste characteristics must be known to meet the requirements of the planned disposition route. An overview of requirements specific to waste characterization can be found in Waste Characterization [6-8]. Through the application of the Waste Management Process, the waste characteristics are defined; thus, reducing uncertainty in the waste inventory.

### **6.3 Confidence in the Design**

Similar designs exist for both the ECM and the WWTP. Many other ECMs have been successfully constructed and licenced for disposal. See Section 6.7.1 for a description of the benchmarking activities were completed in support of the Project.

There is an example of an effective engineered cover on the CRL site. Waste Management Area C contains legacy radioactive wastes in a “mound” type of structure. Due to water infiltration, there is a radioactive plume of groundwater exiting the WMA C. In 2013, the WMA C engineered cover was installed over the waste to mitigate water infiltration. About three years later, groundwater sampling demonstrates a very large reduction in contaminants, approaching background levels. The WMA C engineered cover is similar in design to the NSDF cover, and is currently working as designed and expected.

The WWTP is based on the Best Available Technology Economically Achievable. The WWTP is designed to treat the expected wastewater constituents and concentrations, but is also flexible enough to support the addition of processes which would allow the plant to treat unforeseen contaminants.

#### **6.3.1 Design Process**

Uncertainty in design is managed by following an established design process, which is briefly described below:

The process for the production of design documents involves the following steps [6-12]:

1. Document planning
2. Document preparation
3. Document review and verification
4. Document preliminary release (optional)

## 5. Document release

The design process for external design documents involves the following steps [6-12]:

1. Receive and distribute design deliverables, (i.e., document or drawing)
2. Review design deliverables
3. Accept design deliverables

The requirements and process for design planning at CNL are defined in Design Planning [6-13]. The NSDF Project is a Design Grade 1N, which is used for any design work that involves the creation of a new nuclear facility [6-13]. Table 6-3 shows the mapping of the minimum document requirements for the Design Grade 1N [6-13] to the NSDF Project design documentation.

The design verification plan, constructability review, CQA, and owner surveillance activities were done as part of the development of the detailed design.

### 6.3.2 Good Engineering Practice

Uncertainties are managed by applying good engineering practices during all phases of the design process.

#### Methodologies

Engineering best practice has been used in the conduct of NSDF analyses, design, and site characterization processes. The design and site characterization uses approaches outlined in IAEA SSG-29 [6-1]: probabilistic and deterministic approaches; as well as conservative and realistic assessments.

The majority of the analyses for the NSDF design were performed using a deterministic approach, because the majority of design features have been defined and comprehensive site characteristic information were available. Selected aspects were analysed using probabilistic approaches, for example, the PSHA which determined the ECM seismic load and the associated sensitivity analyses on the waste engineering properties of the seismic models. To reduce uncertainty in the WWTP process efficiencies and capabilities, pilot and laboratory scale testing was performed which used leachate simulant. This is an example of realistic assessments performed for the NSDF Project.

In addition to these combined approaches and assessments, analyses to support the design and site characterization were utilized to improve confidence in the analyses. An example of this was for the seismic analyses that utilized both analytical and several 2D and 3D models to estimate displacements and differential settlements.

#### Qualified Personnel for Design and Site Characterizations

Development of the detailed design and the site characterization involved collaboration between personnel from CNL and contractor staff for the development of the detailed design, site characterization activities, and the development of reports and analyses such as the EIS and PostSA. All project activities meet relevant quality standards, most commonly ISO 9001 (2015).

The Project used SMEs from industry, as well as academic institutions to provide support and review for selected aspects of the design.

#### Professional Engineers Ontario (PEO)

The engineering profession in Canada is regulated. Professional Engineers Ontario is the licensing and regulating body for professional engineering in the province of Ontario. *“Individuals licensed by PEO are the*



*only people permitted by law to undertake and assume responsibility for engineering work in Ontario” [6-14].*  
The NSDF design has been sealed by licensed members of PEO.

#### Academic Institutions

The Project involved SMEs from academic institutions on selected aspects of the Project, including:

1. Dr. R. Kerry Rowe, Ph.D., P.Eng, provided review and consultation related to the ECM design and base liner systems.
2. Dr. Gail Atkinson, Ph.D., P.Geo, provided review of the PSHA.

#### Application of Research and Development

New R&D projects were initiated in support of the NSDF Project. Examples include the geomembrane testing program, and the comprehensive multidisciplinary site characterization of the NSDF site.

#### Managing Potential Conflict of Interest

Potential conflict of interest were recognized and managed in the NSDF Project.

1. The HDPE testing program was performed in an academic setting independently of CNL, the NSDF design contractors, or the HDPE manufacturers. The group performing the HDPE testing are not Stakeholders of the NSDF Project, nor are they affiliated with CNL or the design consultants.
2. The contractor providing site characterization data/information was independent of CNL or the design consultants.
3. The waste generator (primarily CNL), is both the operator and responsible for determining the acceptability of placing waste in the ECM. Although conflict of interest may appear to be a possibility, NSDF operations are subject to all applicable laws and regulations and must adhere to the site licence and Safety Case for the facility. The NSDF operations responsibilities are defined in Program Description Documents and throughout CNL's procedures. Operation of the NSDF is subject to independent oversight by the CNSC. Processes are in place to report potential conflicts of interest at CNL, such as the Ethics and Disclosures office.

#### Record Management and Knowledge Preservation

Project electronic records are stored in the CNL's record management system. The NSDF Project recognizes the needs for long-term knowledge preservation for hundreds of years into the future. Record management includes the storage of physical records/samples, including geomembrane samples and rock samples from CRL site. Retaining samples allows for additional testing in the future, if required. The NSDF has publications on public websites as well as scientific conferences and journals, which can facilitate intergenerational knowledge preservation. Canadian Nuclear Laboratories record management system will provide the records and documentation needed to preserve knowledge of the design into the future.

### **6.3.3 Engineered Containment Mound**

The ECM design follows industry best practice, and is being designed by a team of qualified personnel, including those responsible for the design of several other ECMs in Canada and the USA, including:

- Port Granby Long-Term Waste Management Facility, Ontario.
- Waste Control Specialists Facility, Texas.

- Maxey Flat Facility, Kentucky.
- Environmental Management Waste Management Facility, Tennessee.
- Idaho Comprehensive Environmental Response, Compensation, and Liability Act Disposal Facility, Idaho.

The ECM design is equivalent to the Generic Type II landfill design as specified in Ontario Regulation 232/98 [6-15]. The Landfill Standards [6-15] suggests two types of engineered barrier systems, differentiated by the number of composite liner systems present.

The NSDF design is equivalent to the Generic Design Option II – Double Composite Liner shown in Figure 3 in [6-16] (i.e., “Generic Design Option II”). To demonstrate this, the NSDF base liner system is compared to “Generic Design Option II” specified in Ontario Regulation 232/98 and the landfill guideline [6-16]. Figure 6-1 shows the base liner system for “Generic Design Option II” and for “NSDF design”.

It should be noted that the landfill guidelines [6-16] states that:

*“A site specific design could be undertaken where it can be shown that the design criteria for the proposed site (e.g. the expected leachate characteristics) are different from those given in the Regulation.”*

Considering that the proposed NSDF is for disposal of LLW, the expected leachate characteristics will be different from Municipal Solid Waste (MSW) landfills. For that reason, the NSDF Project did not directly adopt the “Generic Design Option II” (Figure 6-1a), but applied the best technologies that were available at the time of detailed design development.

Although total thickness of the base liner system in the NSDF is thinner than the one in the “Generic Design Option II”, the base liner system in NSDF is designed to meet the performance of the one in the “Generic Design Option II”. Comparing the thickness of “engineered clay layer” (Figure 6-1a) and “CCL” in NSDF in (Figure 6-1a) or comparing the total thickness alone is not sufficient to draw a reasonable conclusion with respect to liner performance. Components of the base liner system, their material properties and how they will work together as a composite liner system to contain the waste must be considered.

Similar to “Generic Design Option II” (Figure 6-1a), the NSDF base liner system (Figure 6-1b) is comprised of a LCS, Primary Composite Liner, LDS and Secondary Composite Liner, but with different materials. Table 6-1 provides the list of materials for “Generic Design Option II” [6-16] and “NSDF base liner system” [6-17]. Comparison of each components are discussed below.

### 1. Leachate Collection System (LCS)

Located above the 0.3 m thick layer of gravel in Generic Design Option II (Figure 6-1a), the NSDF’s LCS (Figure 6-1b) includes: 0.3 m thick Granular ‘A’ filter layer and to add additional protection for the base liner system, a nonwoven geotextile filter as a separator between the gravel and sand. In addition, the NSDF design also adds a 0.5 m Granular “A” sacrificial cover and sacrificial liners to be removed prior to waste placement. Similar to the Generic Design Option II (Figure 6-1a), the collection pipes are also part of the NSDF’s LCS, but are not shown in Figure 6-1b. The LCS pipe size was selected to provide adequate capacity for handling the peak rate of leachate flow predicted to occur for the largest lined cell area within the ECM during its operation [6-17].

### 2. Primary Composite Liner

Instead of using a combination of High Density Polyethylene (HDPE) Geomembrane (GM) and 0.75 m CCL (“GM/CCL liner”) in “Generic Design Option II” (Figure 6-1a), the NSDF design selects a composite liner system comprising of HDPE GM and Geosynthetic Clay Liner (GCL) (“GM/GCL liner”) (Figure 6-1b).

The GCL is a factory-manufactured hydraulic barrier; a combination of geosynthetics and bentonite clay material. The GCL has significantly lower hydraulic conductivity than a CCL. As part of the NSDF design, the hydraulic conductivity of the GCL is  $5 \times 10^{-11}$  m/s, while for the CCL it is  $10^{-9}$  m/s [6-18].

Although the GM/GCL liner (Figure 6-1b) seems to be significantly thinner than a GM/CCL liner (Figure 6-1a), the performance of GM/GCL liner as a waste barrier is significantly better than a GM/CCL liner. A GCL has a typical thickness of approximately 10 mm. Publication by Rowe (2005) [6-19] concluded that composite liners involving a GCL have resulted in a substantially less reported leakage rate than those involving a CCL. This has been attributed, at least in part, to better contact between the GM and GCL and a consequent small interface transmissivity. Based on data reported by Bonaparte et al. (2002) [6-20], typical measured leakage rates were 0.6-1.5 litres per hectare per day (lphd) for GM/GCL while they were 50 to 90 lphd for GM/CCL.

In addition to the use of GM/GCL liner, the NSDF's primary liner system also comprises a 2 mm thick textured HDPE GM, which is thicker than the GM in the "Generic Design Option II". The textured feature of the NSDF HDPE GM will improve the shear strength of the composite liner system. Following the recommendation of the finding at the Queen's University research, a 0.2 m sand layer overlaying the HDPE GM was added to reduce the strain and improve the long-term performance of the HDPE GM.

### *3. Leak Detection System (LDS)*

The NSDF's LDS is comprised of a 9.5 mm clear stone layer, which is a smaller size stone than "generic design option II, to provide additional protection for the HDPE GM. A non-woven geotextile is added to separate between the clear stone and 0.2 m sand layer. The LDS component of each sump includes a 9.5-mm clear stone layer containing a section of perforated, 300 mm diameter, HDPE pipe with the perforations being 100 mm apart.

### *4. Secondary Composite Liner*

Similar to the primary composite liner, a 0.2 m sand cushion is added on top of HDPE GM for the secondary composite liner to reduce its maximum strain and improve its long-term performance. The NSDF secondary composite liner is comprised of a combination of GM/GCL/CCL liner. As discussed previously in primary liner system, the GM/GCL liner alone in NSDF will perform better than GM/CCL liner in "Generic Design Option II". Considering that 0.75 m thick of CCL is also part of the secondary composite liner below the GM/GCL liner, the secondary composite liner in the NSDF will be better than the generic design option II.

### *5. Attenuation Layer*

In the NSDF design, the material below the base liner system will be native overburden soil or bedrock when ground improvement is not required. The design identified the need for ground improvement in some areas. In this case, a backfill material will be placed underneath the base liner system on this location.

The hydraulic conductivity of the native overburden soil and bedrock at the NSDF site have been characterized and reported in [6-24]. The hydraulic conductivity of the overburden soil at the NSDF site was found to range from  $1.4 \times 10^{-7}$  m/s to  $1.6 \times 10^{-6}$  m/s with a geometric mean of  $1.4 \times 10^{-6}$  m/s. The hydraulic conductivity of the shallow bedrock at the NSDF was found to range from  $2.3 \times 10^{-9}$  to  $1.5 \times 10^{-5}$  m/s with a geometric mean of  $9.2 \times 10^{-8}$  m/s. The bedrock materials were characterized as having very low permeability due to the very closely packed mineral assemblages.

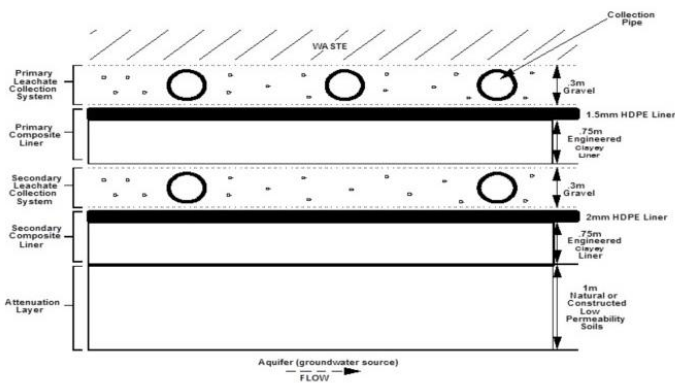
**Table 6-1**  
**NSDF Base Liner System Compared to General Type II Landfill Design**

| <b>Component</b>                 | <b>NSDF Base Liner System* [6-17]</b>                                                                                                                                                                                                                                                                                                                                                        | <b>General Type II of Landfill Design [6-16]</b>                                                                                            |
|----------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| Leachate Collection System (LCS) | <ul style="list-style-type: none"> <li>• 0.5 m Granular “A” sacrificial cover (to be removed prior to waste placement)</li> <li>• Sacrificial liner (to be removed prior to waste placement)</li> <li>• 0.3 m thick Granular ‘A’ filter layer</li> <li>• nonwoven geotextile filter</li> <li>• 0.3 m thick of a 19-mm clear stone drainage layer (Gravel)</li> <li>• LCS pipes **</li> </ul> | <ul style="list-style-type: none"> <li>• 0.3 m Gravel</li> <li>• Collection pipes</li> </ul>                                                |
| Primary Composite Liner          | <ul style="list-style-type: none"> <li>• 0.2 m thick sand cushion layer.</li> <li>• Textured HDPE Geomembrane (GM) 2mm</li> <li>• Geosynthetic Clay Liner (GCL)</li> </ul>                                                                                                                                                                                                                   | <ul style="list-style-type: none"> <li>• 1.5 mm HDPE liner</li> <li>• 0.75 m Engineered Clay Liner or Compacted Clay Liner (CCL)</li> </ul> |
| Leak Detection System (LDS)      | <ul style="list-style-type: none"> <li>• 0.3 m thick 9.5-mm clear stone layer,</li> <li>• LDS pipes in the sump portion **</li> <li>• a nonwoven geotextile separator,</li> </ul>                                                                                                                                                                                                            | <ul style="list-style-type: none"> <li>• 0.3 m Gravel</li> <li>• Collection pipes</li> </ul>                                                |
| Secondary Composite Liner        | <ul style="list-style-type: none"> <li>• 0.2 m thick sand cushion layer.</li> <li>• Textured HDPE Geomembrane 2 mm</li> <li>• Geosynthetic Clay Liner (GCL)</li> <li>• 0.75 m Compacted Clay Liner (CCL)</li> </ul>                                                                                                                                                                          | <ul style="list-style-type: none"> <li>• 2 mm HDPE Liner</li> <li>• 0.75 m Engineered Clayey Liner or Compacted Clay Liner (CCL)</li> </ul> |
| Attenuation Layer                | <ul style="list-style-type: none"> <li>• The bedrock materials below NSDF are characterized as very low permeability</li> </ul>                                                                                                                                                                                                                                                              | <ul style="list-style-type: none"> <li>• 1 m low permeability soil.</li> </ul>                                                              |

Note:

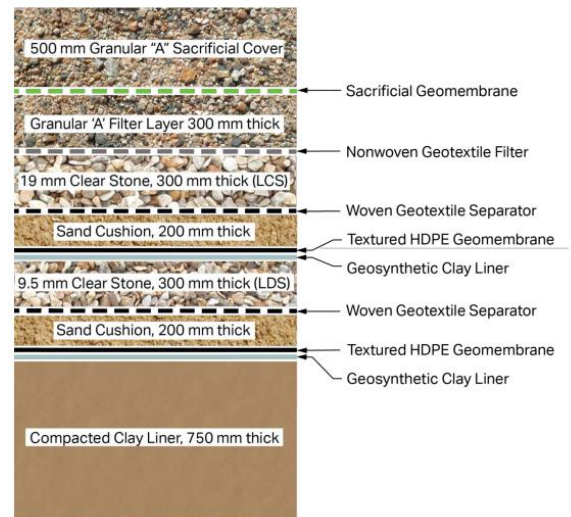
\* The material listed in the table is for the base of the ECM. Some thickness of the materials are adjusted for side slope portions of the ECM.

\*\* The piping system is part of the LCS and LDS sump, however, the LCS and LDS are not shown in Figure 1B.



(a)

Generic Design Option II Double Composite Liner from  
 Landfill Guideline (after Figure 3 in [6-16])



(b)

Base Liner System of the NSDF [6-17]

**Figure 6-1 Base Liner Systems from Landfill Guidelines Compared to the NSDF Design**

To address the uncertainty of the consequences of a Beyond Design Basis Event earthquake, CNL examined how the ECM would react in this type of scenario.

Canadian Nuclear Safety Commission REGDOC 2.11.1 Vol. III [6-44] states that “disruptive event scenarios postulate the occurrence of unlikely events leading to possible penetration of barriers and abnormal loss of containment”. Thereby a disruptive event scenario should first describe/characterize the event to occur, and then assess the potential impacts to the Facility and various endpoints from its occurrence.

Assessment of the ECM due to severe seismic events are required as an input to develop PostSA scenarios. Seismic analysis was conducted to assess the ECM behaviour during the BDBE [6-23]. The BDBE seismic analysis is defined as a 50 000 year return period ground motion, corresponding to PGA of 1.75g [6-23], consistent with [6-22]. The purpose of BDBE seismic analysis is to provide input for the PostSA, not for the ECM design.

The BDBE corresponds to significantly higher seismic level than the design basis earthquake for the ECM design (i.e., PGA of 0.55 g) [6-21]. The analysis is conducted using FLAC 2D finite difference analysis software [6-23]. The analysis results show that significantly increased deformations are expected for the 50 000 year BDBE [6-23]. This is expected to result in significant cracking of the perimeter berm, which could be exacerbated by surface water erosion and infiltration and could result in further slope instability. Significant movement of the cap is expected, exposing the cover liner geomembrane. Tensile strains in the cover and base liner geomembranes are within acceptable levels (<5%) so the integrity of the geomembrane is not likely to be compromised by the seismic movements.

The consequence of potential failures due to the DBE are addressed in the PostSA (discussed in Section 5.8). There are several scenarios that are performed in the PostSA that model complete failure of engineered barriers, similar to the consequences of this BDBE. The “Series of Landslides” scenario evaluates the consequence of complete berm failure, and the “Mass Excavation” scenario evaluates the consequences of

the entire waste material being brought to the surface and used agriculturally. The results of both of these analyses demonstrate that all acceptance criteria are met even during the worst-case scenarios.

Detailed design of the ECM is described in Sections 3, 4 and 5.

#### Remaining Uncertainties and Recommendations

Remaining uncertainties on the ECM design have been recognized, which include:

##### *1. Spatial Variation of the NSDF Waste and Differential Settlement*

The waste in the ECM may affect structural stability. The properties of the waste are assumed during the design phase, and confirmed during operations. Spatial variation of NSDF engineering properties was considered partially during the development of the detailed design. Wastes that will be in the containers may result in subsidence or differential settlement. Currently, this variation for bulk waste will be controlled by compaction. For waste in the containers, Controlled Low Strength Material (CLSM) is being considered to fill voids.

##### *2. Clay Source for CCL, Landslide, and Slope Stability*

The NSDF site has low susceptibility to landslide, according to the landslide susceptibility map of Canada [6-25]. In the vicinity of St. Lawrence River Valley, the presence of marine clay, or Leda clay, should be taken into consideration to limit landslide susceptibility. The results of NSDF site investigation confirmed that there is no Leda clay observed on the NSDF Site. The clay for the CCL is selected and sourced by the construction contractor in accordance with the design specifications and confirmed through CQA.

##### *3. Construction Quality Assurance*

The importance of comprehensive CQA have been highlighted by the SMEs to ensure base liner and cover of the ECM perform as designed. Construction Quality Assurance plans are being optimized to ensure proper installation of the HDPE liners.

##### *4. Availability of Selected HDPE Geomembrane in the Future*

The HDPE required for the final cover will not be needed for approximately 50 years from now. There is a possibility that the material may no longer be available in the future; the material may no longer be manufactured due to advancements in other competing technologies or materials, or because the manufacturers are no longer in business. The Project recognized this possibility. In this case, different material will need to be selected and the design of the cover and liner systems will need to be modified.

The Project records have included the HDPE geomembrane samples to facilitate continuity for future testing. The ingredient list for the HDPE material is not available due to the manufacturer's intellectual property rights. The Project has recorded the manufacturer's batch number to help identify the resin ingredients.

### 6.3.4 Waste Water Treatment Plant

The WWTP has been designed specifically for the wastes contained in the NSDF, and for the expected concentrations of leachate. Sections 3, 4 and 5 provide a detailed description.

The WWTP is designed to allow for a large degree of flexibility in the ability to treat unexpected constituents in leachate. The plant's treatment processes are modular and designed to connect to each other in a variety of configurations. New treatment skids can be introduced if the wastewater requires unique treatment processes.

#### 6.3.4.1 Material and Energy Balance

The WWTP Material and Energy Balance Report [6-26], provides the basis and calculations for the full-scale WWTP hydraulic flow rates, COPC concentrations, and COPC mass loads at various process stages. The major processes of the WWTP were selected based on testing results and on the Best Demonstrated Available Technology Economically Achievable (BDATEA) documented in the "Leachate and Wastewater Treatability Assessment (WWTP)" report [6-27]. The WWTP Material and Energy Balance Report [6-26] provides:

- Removal efficiencies for each COPC at each process treatment stage, to determine the residual concentration of each COPC at each stage, comparing the predicted final effluent concentration to the discharge targets [6-28].
- Estimates the concentrations of COPC in the solid residuals and spent media (IX resins) that will be disposed in the ECM.
- Estimates chemical quantities used for chemical precipitation and pH adjustments.
- Estimates quantities of IX resins, zeolite and GAC needed.
- Energy usage for major equipment.

"Leachable quantities" of waste refer to the portion of waste materials that are available to migrate with water ingress into the Facility, forming leachate. There is uncertainty in the leachable quantity of waste materials present in the ECM, and many factors that contribute to the uncertainty. The parameters that have the largest impact are the total wastewater quantities,  $K_d$  values, and the quantity of radionuclides and non-radiological constituents available for leaching. The design of the WWTP has a considerable degree of flexibility to adapt to changing conditions. An independent review of the WWTP design concluded that, with the exception of tritium, alternate treatment technologies could easily be installed in the WWTP to reduce effluent concentrations for the constituents listed above as potentially problematic in the effluent [6-29].

Another option being considered is to reduce the leachable quantities disposed in the ECM. A reduction in the maximum leachable quantities from 3 000 kg to 360 kg for fluoride and from 20 000 kg to 800 kg for nitrite, would yield fluoride concentrations in the effluent that meet the discharge effluent targets. The reduced inventory of nitrite would result in a lower nitrite concentration in the effluent; however, the concentration is predicted to exceed the discharge effluent target. If required, additional treatment using anion exchange resins could be implemented.

The phosphate discharge effluent target is an "investigation level" which triggers analysis of the impacts if exceeded (phosphate is accounted in total phosphorous loading). An analysis has been completed indicating

minimal impacts on Perch Lake and East Swamp for the projected phosphorous loading [6-30] and [6-31]. The results of the analysis will be verified by monitoring Perch Lake water quality under winter conditions [6-28].

### 6.3.5 Sensitivity Analysis for Waste Water Quality

A sensitivity study [6-32] evaluated potential changes in the constituent concentrations in wastewater by varying the following input parameters related to leaching:

- Waste density.
- Waste/soil moisture content.
- Distribution coefficients ( $K_d$ ).

The constituent concentrations in leachate have a non-linear relationship with the waste density, moisture content, and distribution coefficients. A representative range of  $K_d$  values were selected to show the effects of each variable on the constituent concentrations.

Using this leaching model, hypothetical leachate concentrations were calculated for a constituent with a unit concentration (1 Bq/kg or 1 mg/kg) in waste. The leachate concentrations were first calculated using the baseline values of waste moisture content (0.2181) and waste density (1.5 g/cm<sup>3</sup>) [6-33]. Then each parameter was varied separately to assess its effect on the calculated concentration. Each parameter (moisture, density, and  $K_d$ ), were increased by 10% and the resulting changes in the leachate concentration are tabulated in Table 6-2.

The sensitivity analysis of leaching-related parameters, builds on the qualitative uncertainty analysis discussed in Section 2.2.3 of the “Leachate and Wastewater Characterization (Quantity and Quality)” report [6-33]. Sensitivity results show constituent concentrations in leachate caused by a unit concentration of that constituent in waste for several representative  $K_d$  values. As shown in Table 6-2, in all cases, as the  $K_d$  increases, the leachate concentration decreases.

Changes in leachate concentrations resulting from variations or uncertainties in waste density or moisture content will have relatively minor, predictable effects and will not change the leachate or wastewater properties in a way that would require redesign of the WWTP processes.

Increasing the moisture content results in either a decrease or no significant change in constituent concentration. The magnitude of the change is dependent on the  $K_d$  value.

Any potential variations in leachate concentrations would have a diminished effect on the overall wastewater characteristics because of mixing with contact water. In the baseline analysis, the leachate volume is less than one quarter of the total wastewater volume. In the sensitivity case, the leachate volume includes dust suppression water which together comprise less than one-third of the total wastewater volume.



**Table 6-2**  
**Sensitivity Results for Leachate Concentrations and Percent Changes**

| K <sub>d</sub> Value<br>(ml/g) | Baseline<br>Concentration (a) | Increase Waste Moisture 10% |                                          | Increase Waste Density 10% |                                          | Increase K <sub>d</sub> 10% |                                          |
|--------------------------------|-------------------------------|-----------------------------|------------------------------------------|----------------------------|------------------------------------------|-----------------------------|------------------------------------------|
|                                |                               | Concentration<br>(a)        | Change from<br>Baseline<br>Concentration | Concentration<br>(a)       | Change from<br>Baseline<br>Concentration | Concentration<br>(a)        | Change from<br>Baseline<br>Concentration |
| K <sub>d</sub> = 0             | 6.88E+00                      | 6.25E+00                    | -9.1%                                    | 7.57E+00                   | 10.0%                                    | 6.88E+00                    | 0.0%                                     |
| K <sub>d</sub> = 1             | 8.73E-01                      | 8.62E-01                    | -1.3%                                    | 8.83E-01                   | 1.2%                                     | 8.03E-01                    | -8.0%                                    |
| K <sub>d</sub> = 10            | 9.86E-02                      | 9.84E-02                    | -0.14%                                   | 9.87E-02                   | 0.13%                                    | 8.97E-02                    | -9.0%                                    |
| K <sub>d</sub> = 100           | 1.00E-02                      | 9.98E-03                    | -0.015%                                  | 9.99E-03                   | 0.013%                                   | 9.08E-03                    | -9.1%                                    |
| K <sub>d</sub> =<br>1,000      | 1.00E-03                      | 1.00E-03                    | -0.0015%                                 | 1.00E-03                   | 0.0013%                                  | 9.09E-04                    | -9.1%                                    |
| K <sub>d</sub> =<br>10,000     | 1.00E-04                      | 1.00E-04                    | -0.00015%                                | 1.00E-04                   | 0.00013%                                 | 9.09E-05                    | -9.1%                                    |

(a) Concentrations are based on a unit waste concentration of 1 Bq/kg for radionuclides or 1 mg/kg for non-radioactive constituents; leachate concentrations are in Bq/L for radionuclides or mg/L for non-radioactive constituents. Baseline moisture and density are 0.2181 and 1.5 g/cm<sup>3</sup>, respectively.

### 6.3.6 Confidence in the Site Characteristics

There are several waste management and waste dispersal areas to the west of the proposed NSDF site, which are also located in the Perch Lake Basin. Some of these WMAs were established in the 1950s and 1960s, as the original disposition route for solid and liquid radioactive wastes, including the LDA. The depositing of liquid waste directly into the ground and sand in the area is an unacceptable practice by today's standards, but was performed at the time.

As a result of the waste contained there, the Perch Lake Basin has become one of the most studied and well understood plots of land in North America. By examining the tritium and strontium plumes emanating from the wastes, CNL has an understanding of how radionuclides migrate through the groundwater and soils in this location. Similar studies on the CNL property have led to the development of sorption coefficients and distribution coefficients that form the basis of accepted industry values in CSA standards.

In addition to the decades of research done on the Perch Lake basin, the NSDF Project has also performed borehole excavations and groundwater surveying to better understand the NSDF footprint.

Specific for the NSDF Project, a comprehensive multidisciplinary site investigation has been conducted at the NSDF Site and discussed in Sections 3, 4 and 5. The results include investigation of soil and bedrock engineering properties required for the design and modelling (up to 32 m depth), and reduced the uncertainties of site characterizations and the design. The site characterization was completed in accordance with current acceptable methodologies in geotechnical/geological engineering. Additional field and laboratory tests have been identified as part of the NSDF design [6-34].

Uncertainty exists in the expected water table levels under the ECM footprint after blasting. Groundwater models [6-35] have been developed using best practices and calibrated with known values, but the rock blasting of the underlying bedrock may not lower the water table as expected. There are also some uncertainties in the water table level fluctuations, as CNL has only collected NSDF site-specific data for a few years. To address this uncertainty, groundwater monitoring wells have been installed at the NSDF Site, including several wells in the ECM footprint. The groundwater quantity and quality will be part of the operational control monitoring for the NSDF. If results of future groundwater monitoring indicate significant discrepancies between measured results and the assumptions used in the PostSA, then the PostSA will be updated to reflect the new data.

### 6.4 Confidence of Assessment Results

It is important that any safety assessment is developed in a manner that builds confidence of all stakeholders in the relevance of its outcomes. Confidence building can be achieved by:

- The use of a systematic assessment methodology that allows the assessment to be undertaken using a well-structured, transparent and traceable manner.
- The use of an iterative approach that allows the results of previous assessments to be used to inform the current assessment.
- The use of a range of strategies to identify and manage the various uncertainties associated with the assessment.
- The demonstration that the system will maintain its integrity and reliability under extreme conditions (i.e., the system is robust) using "What-If?" calculations.

- The use of multiple lines of evidence to support key findings.
- The application of a quality management system to the assessment.
- The peer review of the assessment and its results.
- The comparison of the engineered system with natural systems that have evolved over relevant timescales.

Confidence of stakeholders in the safety analyses can be established at two levels. The first level involves establishing confidence within each stage of the assessment process (i.e., assessment context, system description, development and justification of scenarios, formulation and implementation of models and associated data, analysis of the results, and review and modification). The second level involves gaining overall confidence in the safety analyses and associated implications for further data gathering, assessment and design optimization. Various measures and attributes that can be used to develop confidence in the assessment at these two levels are summarized in the PostSA [6-6].

Regulatory and international guidance recognizes that the process of safety assessment inherently involves uncertainties, such that absolute measures of safety cannot readily be applied. Consequently, there is an emphasis on building confidence in safety through a variety of methods which, together, provide a robust case that the NSDF will be safe in the future. The following are recognized as key contributors to confidence, and the way in which they have been addressed in the safety analyses:

- Process – A systematic, transparent and auditable process for developing and analyzing models to evaluate safety is an essential element to building confidence in the assessment. This is because the process demonstrates that the scenarios, models and data have been carefully selected making the best use of available information, and recognising the uncertainties present. The safety analyses have rigorously applied best practice in their assessment approach to develop scenarios, models and data that are specifically designed to address the safety performance of the NSDF.
- Comparison with criteria – Regulatory safety criteria, and constraints derived from them, are set to prevent an unacceptable level of harm or risk to people or the environment. The safety analyses show that the expected levels of radiation dose will be orders of magnitude below these criteria.
- Range of performance measures – The calculated doses in the safety analyses have been presented alongside other measures of performance to give additional context and address the issue that there may be uncertainties in the nature of exposures to species.
- Range of calculations – The range of results calculated with the ensemble of calculation cases and scenarios, in the SAR [6-36], PostSA [6-6] and EcoRA [6-37], provide confidence-building measures, as they demonstrate that even under a range of different assumptions and conditions, the safety criteria are not exceeded. The range of calculations illustrate the intrinsic robustness of the system that come from a range of barriers and a range of safety functions.

Confidence in the safety performance of the disposal facility has been achieved by:

- Regulatory and IAEA guidance advocates an iterative approach to safety assessment to reduce uncertainties and build confidence in the projected outcomes. In producing the supporting documentation to this safety case, CNL has performed several iterations of each document revising them based on new findings, internal peer reviews and independent third -party reviews.

- Independent verification by the use of CNL's internal peer review process, and a suitability qualified independent third party for the peer review, has been used to increase the level of confidence in the supporting technical studies.
- Quantitative analysis and testing of engineering barrier performance, providing important information on the overall envelope of safety performance and the importance of specific design aspects.
- The application of extreme "What-If?" cases to demonstrate the performance of barriers by analyzing their effectiveness by making extreme model assumptions that show the impact of the barrier not being present or severely degraded.
- Examining natural analogues to provide supporting evidence and to enhance the confidence in the long-term extrapolations required for long-term safety assessments.

The use of post-closure monitoring to promote confidence in the closure system and to provide a defensible rationale for implementing corrective actions, if required.

#### **6.4.1 Operational Safety Analysis – Quantitative Analysis Uncertainty**

Uncertainties in quantitative analyses can arise because of the limitations associated with the definition of the radiological inventory or source term, scenarios and available data. Uncertainties are accounted for in the safety analysis and quantitative analysis through [6-36]:

- The adoption of conservative radiological inventory or source term. The NSDF source terms are defined in Waste Characterization [6-38] and WWTP Material and Energy Balance Report [6-39].
- The quantitative analysis was completed following the appropriate methodology for the accident scenario and the methodology reference documents are provided in the reference sections for the quantitative analyses.
- The use of appropriate conservatism, engineering judgement and justified assumptions in the quantitative analyses, ensures that the estimates of radiological consequences (dose) are conservative.
- Verification of calculations.
- Use of CNL approved codes MicroShield Version 9.02 and RESRAD OFFSITE Version 3.2.

#### **6.4.2 Building Confidence in the PostSA**

Confidence building in the PostSA is achieved by adhering to [6-40] and [6-1]:

- The use of a systematic assessment methodology that allows the assessment to be undertaken using a well-structured, transparent and traceable manner.
  - Including the FEPs and their interaction with the post-closure assessment will help such a transparency and traceability.
  - The derivation of scenarios from the FEPs will enhance the systematic and well-structured nature of the assessment.
- The use of an iterative approach that allows the results of previous assessments to be used to inform the current assessment.
- The use of a range of strategies to identify and manage the various uncertainties associated with the assessment.

- Demonstration that the system provides multiple barriers for the containment and isolation of the waste, and demonstration that safety is not overly reliant on any one.
- The demonstration that the system will maintain its integrity and reliability under extreme conditions (i.e., the system is robust) using “What If?” calculations.
  - This has been done for scenarios such as the Mass Excavation.
- The use of multiple lines of evidence to support key findings.
- The application of a quality management system to the assessment.
  - Including Verification and Validation of the analysis tools.
- The comparison of the ECM with natural systems that have evolved over relevant timescales.

Confidence of stakeholders in the PostSA can be established at two levels. The first level involves establishing confidence within each stage of the assessment process (i.e., assessment context, system description, development and justification of scenarios, formulation and implementation of models and associated data, analysis of the results, and review and modification). The second level involves gaining overall confidence in the PostSA and associated implications for further data gathering, assessment and design optimization. Various measures and attributes that can be used to develop confidence in the assessment at these two levels are summarized in Table 6-3.

**Table 6-3**  
**Confidence Building Measures and Attributes**

| <b>Confidence in each Stage of the Assessment Process</b> |                                                                                                                                                                                                                                                                                           | <b>Confidence in Overall Safety</b>                                                                                                                                                                                                                                           |
|-----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Stage</b>                                              | <b>Confidence Building Measures and Attributes</b>                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                               |
| Assessment Context                                        | Demonstration of understanding of the key components of the assessment context.                                                                                                                                                                                                           | <ul style="list-style-type: none"> <li>• Use of a systematic approach consistent with international practice and recommendations.</li> <li>• Adequate understanding of the NSDF system and its uncertainties.</li> <li>• Use of safety and performance indicators.</li> </ul> |
| System Description                                        | Demonstration of adequate understanding of engineered and natural aspects of the system (ECM, geosphere and biosphere) and associated uncertainties.                                                                                                                                      |                                                                                                                                                                                                                                                                               |
| Scenarios                                                 | The set of scenarios needs to be sufficiently comprehensive and developed in a systematic, transparent and traceable manner, based on an updated FEPs report. However, the specific scenarios included in this PostSA are constrained by the scope of work of this study.                 |                                                                                                                                                                                                                                                                               |
| Models and Data                                           | <p>The conceptual models and associated data are consistent with the assessment context, system and scenarios.</p> <p>The software tools have the ability to adequately solve the problems under consideration.</p> <p>Alternative models, codes, data and approaches are considered.</p> |                                                                                                                                                                                                                                                                               |

| Confidence in each Stage of the Assessment Process |                                                                                                                                                                                                                | Confidence in Overall Safety                                                                                                                                                                               |
|----------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Stage                                              | Confidence Building Measures and Attributes                                                                                                                                                                    |                                                                                                                                                                                                            |
| Analysis of Results                                | Key assumptions are documented and justified.<br>Results are plausible and explainable.<br>Uncertainties are adequately addressed.<br>Compliance with regulatory requirements and recommendations is analysed. | <ul style="list-style-type: none"> <li>• Clear presentation of the assessment and its results.</li> <li>• Application of a quality management system.</li> <li>• Peer review of the assessment.</li> </ul> |
| Review and Modification                            | Modifications are implemented in a structured and well-documented manner.                                                                                                                                      |                                                                                                                                                                                                            |

#### 6.4.2.1 Comparison using RESRAD

RESRAD-OFFSITE is a software used to assess radiation exposures of a human receptor located on top of or at some distance from soils contaminated with radioactive materials. The software is developed and maintained by the Argonne National Laboratory.

Canadian Nuclear Laboratories has performed a comparison study in RESRAD-OFFSITE to enhance confidence in the AMBER model [6-41]. The comparison was done for the “permanent bathtub” scenario as this was deemed the best fit for RESRAD-OFFSITE [6-41].

The results of the RESRAD-OFFSITE analysis is a dose to the receptor of 2.6E-02 mSv/y [6-41], whereas the AMBER model calculated 4.0E-02 mSv/y. The RESRAD dose results are less than an order of magnitude smaller than the AMBER results, indicating alignment between the two software applications. The comparison demonstrates confidence that the AMBER model is correctly representing the inventory and environmental transport of contaminants.

#### 6.4.3 Uncertainties Identified in the Ecological Risk Assessment

The EcoRA [6-37], was performed to evaluate the effects of both the radiological and non-radiological contaminants on the environment and non-human biota. Section 6 of the EcoRA [6-37], contains a discussion on the uncertainties present in the assessment. An excerpt is presented here.

Uncertainties will likely lead to an overestimation or underestimation of exposure, toxicity or risk and may occur in the following areas of the EcoRA [6-37]:

- (a) Problem formulation, as a result of available ecological and toxicological information;
- (b) Exposure assessment, as a result of uncertainty in monitoring data and models;
- (c) Toxicity/effects assessment, due to limited data for some ecological species, life stages, or endpoints of interest, or extrapolation from laboratory to field conditions; and,
- (d) Risk characterization, due to uncertainties in exposure or toxicity, or uncertainties about the combined effects of multiple contaminants or physical stressors.

In recognition of these uncertainties, conservative assumptions were used throughout the assessment to ensure that the potential for a residual effect would not be underestimated. The major assumptions are outlined below:

- **Receptor Occupancy & Home Ranges:** All mobile receptors were assumed to be present in exposure locations for the entire year, despite any potential migratory behaviour. In addition, the home range of all mobile receptors was assumed to be limited to the location of maximum activities, when in reality, several mobile receptors have large home ranges and the location of a maximum concentration might represent only a small portion of their overall range. Thus, exposures are likely to be conservatively overestimated.
- **Receptor Characterizations/Exposure Parameters:** The characteristics of ecological receptors – mobile receptors in particular – represent another source of uncertainty, since receptors will generally adjust and vary their diet and behaviour according to the food and water sources available and regional conditions. The characteristics (e.g., body weight; food, water, and soil consumption rates, etc.) for all receptors, were selected based on a review of available information in various credible literature sources. However, for some (though not all) literature sources, these parameters are obtained from studies involving animals in captivity, and therefore, may not be fully representative of free-range animals in the wild. An underestimate of exposure might result from this – for example, by assuming a body weight that is greater than for animals in the wild – but there are other conservative assumptions that may compensate (e.g., assuming the receptor spends all of its time on-site in the exposure location).
- **Screening Procedure for Radiological COPCs:** In the screening process, if dose coefficients were not available for a radionuclide, then the radionuclide was ‘screened-out’, since the radiation dose associated with the radionuclide cannot be estimated without a dose coefficient. The exclusion of a radionuclide from the assessment because a dose coefficient is not available, would result in an underestimation of the total dose and any potential effects. However, it should be noted that in this EcoRA, no radionuclide exceeding an environmental screening criterion was excluded from the assessment due to the lack of available dose coefficient.
- **Exposure Point Concentrations:** Predicted (modelled), as opposed to measured, radionuclide activities and contaminant concentrations were used in all of the scenarios assessed in the EcoRA. For each scenario, the chosen EPCs were the maximum values predicted over time (10 000 years) in each environmental medium in the PostSA, with added background for non-radiological COPCs (i.e., total concentrations). Using the peak activity/concentration (regardless of the time of the peak) for each environmental medium is conservative, as it ensures biota are assessed for the worst predicted exposure even though realistically these peaks would occur at different times (e.g., the soil peak concentration may occur at 100 years post-closure, but the creek peak concentration may occur hundreds of years later). As a result, exposures are likely to be conservatively overestimated.
- **Transfer Factors:** The concentrations/activities in biota had to be estimated using transfer factors from literature as well as food intake calculations. There is some uncertainty involved in the use of transfer factors and data that are not site-specific; however, in the absence of measured data, this approach provides the only method for estimating concentrations and for estimating transfer up the food chain. This is likely to conservatively overestimate doses.
- **Benchmark Values:** The benchmark values used in the assessment were obtained from reputable sources; nonetheless, they are always associated with uncertainty due to the extrapolation of testing on lab species (e.g., rats) to field conditions as well as to the ecological receptors considered in this assessment. This is likely to conservatively overestimate doses.

- **Toxicity Assessment:** As discussed in CSA N288.6-12 [6-42], there is inherent uncertainty in the use of toxicity reference values (TRVs); however, the TRVs that were used were selected using a hierarchy of recent, credible sources, which include, but are not limited, to those recommended in CSA N288.6-12 [6-42]. These sources have already applied uncertainty factors to their TRVs. Therefore, while the inherent uncertainty in the TRVs cannot be removed, it has been controlled to the extent possible. It is also noted that toxicity information for a COPC was used regardless of its form in the test procedure, even though this may not be the same form used in the assessment (e.g., an oxide form compared to a more soluble form). It is difficult to determine the effect of these assumptions.
- **Risk Estimation:** The risk estimation reflects the uncertainties identified in the exposure assessment and toxicity assessment. The EcoRA did not include an assessment of multi-stressor effects, including interactions between contaminants. When dealing with toxic chemicals, there is potential interaction with other chemicals that may be found at the same location. It is well established that synergism, potentiation, antagonism or additivity of toxic effects occurs in the environment. A detailed quantitative assessment of these interactions is beyond the scope of the present study, and, for many COPC-receptor combinations there is not an adequate base of toxicological evidence to examine these interactions. This may result in an underestimate of the risk for some COPC combinations.

#### 6.4.4 Confidence in the Managerial/Administrative Controls

Canadian Nuclear Laboratories follows an established management system consistent with applicable Canadian standards such as CSA N286-12 [6-43] and CNSC REGDOC-2.1.1 [6-44]. Details on the CNL management system can be found in Appendix A.

Canada has significant experience in terms of exposure to, and working with nuclear technology. As one of the pioneering countries of nuclear technology, Canada has a long history of a strong nuclear safety culture and experienced regulatory body.

Chalk River Laboratories are currently operated by a third-party consortium of experienced nuclear engineering and consulting firms. Atomic Energy Canada Limited, a Crown corporation, provides the oversight and management of the operating contract on behalf of the Federal Government. Atomic Energy of Canada Limited continues to be the owner of the CRL property regardless of who currently holds the operating contract and responsibilities.

As the enduring Federal entity, AECL has committed to enforcing land-use restrictions on the NSDF site into the future, for as long as possible. This commitment reduces administrative uncertainty into the future.

In addition to administrative controls, AECL, and by extension the NSDF, benefits from a financial guarantee from Natural Resources Canada [6-45], and therefore, the Federal Government. This increases certainty and confidence that the NSDF Project, once approved, will be completed and not fall victim to funding limitations.

#### 6.5 Natural and Anthropological Analogues

The PostSA assesses long time periods, up to 10 000 years. This can be a difficult endeavor, since the data used for the assessment are mostly based on observations from relatively short-term laboratory and field experiments.

It is common for a PostSA to rely on natural analogues to provide supporting evidence and to enhance the confidence in the long-term extrapolations required in assessment models.



Natural analogues are natural features that are similar to those features that are expected in the waste facility. These can include both natural and man-made (anthropogenic) materials, provided that the processes that affect them are natural (i.e., weather effects, corrosion, etc.). These analogues can provide understanding or demonstrations of how the NSDF would behave over long time-scales. Analogues exist for the engineered and natural barriers in the NSDF, as well as for the impact of societal memory and institutional control. There are numerous examples of natural analogues in the literature [6-46], not all of which are relevant for the NSDF. The following sections describe some analogues related to the NSDF barrier systems.

### **6.5.1 What Features do we Define Natural Analogues for?**

The barriers restricting radionuclide/contaminant release from the NSDF include both natural and engineered materials. Of these barriers, the natural materials of rock, sand, and clay can be discussed with natural analogues to the ECM. In addition to the barriers, there will also be a discussion of the existence of these analogues and how they demonstrate that societal memory and institutional control can persist for centuries.

#### **6.5.1.1 Cover System**

The NSDF final cover system is a multi-layer cover, containing layers of topsoil, sand, crushed rock aggregate, clay liner, and HDPE. The final cover system will be graded to promote surface water run-off towards the southern portion of the Facility, due to gravity. While the final cover is designed with the best engineering practices, specifically with the Chalk River site characteristics in mind, it is assumed that these barriers will eventually degrade.

The PostSA assumes that the cover has an initial leakage rate, with an increasing rate as the cover begins to degrade up to the 550 year design life when leakage is at its peak.

Anthropogenic analogues provide support for the possibility of using a multi-layer cover to keep the Facility dry for a long period of time [6-46]. Thus, ancient tombs with wooden coffins have stayed dried when covered by such layers for ~1300-1 years and are generally well preserved [6-47] and [6-48].

These observations provide credibility to the conservative nature of the assumptions in the PostSA [6-6].

#### **6.5.1.2 Base Liner System**

The NSDF base liner system is a multi-layer liner containing sand, crushed rock aggregate, GCL, HDPE, and compacted clay. The engineered materials are designed to last at least 550 years. The natural materials are expected to last much longer.

The PostSA assumes that the CCL experiences a reduction in containment capacity by about 10 times over 5000 years. That is, the CCL's effectiveness at slowing the flow of water through it goes down to about  $1\text{E-}08$  m/s.

A relevant natural analogue for assumptions on clay and its effectiveness at slowing the rate of water flow is work performed by AECL in the 1990s [6-49], studying Cigar Lake uranium deposits, specifically the migration of uranium. Clay is found to be a good barrier at preventing the migration of contaminants, with an average permeability of between  $10^{-8}$  and  $10^{-9}$  m/s.

## **6.5.2 Existing Earthen Mounds/Anthropogenic Analogues**

Large earthen mounds have been built by humans for thousands of years. Several of them still exist today, demonstrating that earthen mounds can be constructed to withstand thousands of years of natural evolution and weathering effects. Furthermore, the existence of these structures today demonstrates that humans are able to recognize human-made structures, and are willing to leave them relatively undisturbed for centuries. This section describes several human-made earthen mounds in existence today and supports the idea that a near-surface facility can be constructed to last thousands of years.

### **6.5.2.1 Newgrange, Ireland**

Newgrange is a type of tomb known as a passage-grave, located in Meath, Ireland. Constructed in about 3000 Before Common Era (B.C.E), (5200 years ago), it is older than Stonehenge and the Great Pyramids of Giza [6-50]. The mound is 76 meters across, 12 meters high, and covers 1.1 acres of ground. It is completely constructed of natural materials, built of alternating layers of earth and stones. The cover contains medium-sized pebbles, 15-22 cm across. The Newgrange structure demonstrates that a large earthen mound can be built out of natural materials and remain undamaged by the effects of the environment for over 5 000 years.

Newgrange's location in Ireland is a particularly good comparison to the NSDF climate, specifically the amount of precipitation received. Meath, Ireland receives about 73 cm of precipitation per year [6-51], compared to Chalk River's 86 cm per year [6-52].

### **6.5.2.2 Sutton Hoo, England**

Sutton Hoo is a burial site located at Sutton, in Suffolk, England. Earthen mounds dating to the 6<sup>th</sup> and 7<sup>th</sup> centuries were discovered at this site. There are approximately 20 earthen mounds that were used as cemeteries, and a large mound containing an entire ship-burial [6-53].

The ship contained in the mound was found to be about 27 meters long. While the wood of the ship did not survive, nearly all of the iron planking rivets were in their original places.

Many metallic objects were recovered during the site investigation of Sutton Hoo: Helmets, bowls, spoons, weapons, and armour. While the items had corroded with time, the findings support the idea that water ingress into the ship burial mound was minimal over many hundreds of years.

### **6.5.2.3 Serpent Mound, USA**

The Great Serpent Mound is a 411 m-long, about 1 metre high, 20-foot wide effigy mound located in Adams County, Ohio. Carbon dating suggests that it was constructed around 300 B.C.E, making the mound over 2000 years old. It likely served a mortuary function, directing spirits of the dead from burial mounds northward. The Great Serpent Mound still exists today, demonstrating that human-made mounds can be constructed to persist thousands of years [6-54].

### **6.5.2.4 Burial Mounds of British Columbia**

There are many burial mound sites identified in British Columbia [6-55] and [6-56]. A selection of them are described here, to demonstrate that earthen mounds can exist undisturbed for over a thousand years, even in the wet climate of British Columbia.

### **The Scowlitz Site**

The Scowlitz site is located at the confluence of the Harrison and Fraser Rivers, and was historically the base of an important transportation route from the Fraser River valley to the Lillooet River valley [6-55].

There are 42 visible burial features found at the site, dating between 1600 and 1100 years old. The mounds vary in size and form. The largest mound is 12 m on each side of the rectangular base, reaching a height of 3 metres. At the center of the mound is approximately 500 boulders, sitting on a thin layer of clay. Beneath this rock layer are the well preserved remains of an adult male. Radio-carbon dating for this mound indicates an age of about 1300 years.

Items found preserved in these mounds include clam shell bowls, knives, worked quartz, stone pendants, composite harpoons, copper objects, and granite bowls.

### **Cadboro Bay**

An earthen mound approximately 5.5 m diameter and 0.9 m high. This mound contained a skeleton [6-55].

### **Port Hammond**

Two circular mounds reported, approximately 7.3 m diameter and 1.5 m and 3 m high, respectively. Skeleton and human remains were found in both [6-55].

### **Hatzic**

Several circular mounds of earth were found. The largest of note was 7.3 m in diameter and 2.1 m high. A skeleton was found inside, along with a broken copper needle and a small piece of fabric [6-55].

#### **6.5.2.5 Monks Mound**

Monks Mound is the largest Pre-Columbian earthwork in the Americas and the largest pyramid north of Mesoamerica. The beginning of its construction dates from 900-955 CE. Located at the Cahokia Mounds UNESCO World Heritage Site near Collinsville, Illinois, the mound size was calculated in 1988 as about 100 feet (30 m) high, 955 feet (291 m) long including the access ramp at the southern end, and 775 feet (236 m) wide, resulted in area of 6.9 hectares [6-57].

This makes Monks Mound roughly the same size at its base as the Great Pyramid of Giza (5.3 hectares). Monks Mound is taller than the NSDF ECM (30 m for Monks Mound versus 18 m for the ECM), but has a smaller area (i.e., 6.9 hectares for Monk Mound versus 16 hectares for the NSDF ECM). The geotechnical site characteristics of the mound have been studied extensively and reported in [6-58], with the purpose of understanding construction methodology. Surficial geology and seismic hazards are also available in [6-59] and [6-60]. The level of seismic hazard at the Monks Mound site is comparable to the NSDF site.

The existence of Monks Mound demonstrates that man-made structures, built using earth materials, can last longer than 1000 years, even with limited construction methods and engineering knowledge.

#### **6.5.3 Site Specific Characteristics Comparison**

When discussing natural analogues, it is important to also compare the local climate and seismic characteristics, as these are the most important factors affecting the long-term performance of a facility on the surface. Table 6-4 below compares the annual yearly precipitation and PGA at each of the sites. The PGA selected corresponds to a 2% probability of exceedance in 50 years. The Chalk River site characteristics are

comparable to the other sites, especially those with coastal climates. Canadian seismic data are from [6-61], American seismic data is from [6-62], and weather data is from [6-63].

**Table 6-4**  
**Comparison of Seismic and Precipitation Data**

| Site                               | PGA (g) | Annual Precipitation (mm) |
|------------------------------------|---------|---------------------------|
| NSDF Site, Chalk River, ON, Canada | 0.25    | 852                       |
| Newgrange, Ireland                 | <0.05   | 730                       |
| Sutton Hoo, England                | <0.04   | 523                       |
| Adams County, Ohio (Serpent Mound) | 0.079   | ~1129                     |
| Scowlitz, BC, Canada               | 0.222   | ~1000+                    |
| Carboro Bay, BC, Canada            | 0.573   |                           |
| Port Hammond, BC, Canada           | 0.311   |                           |
| Hatzic Island, BC, Canada          | 0.272   |                           |
| Monks Mound, IL, USA               | 0.265   | ~980                      |

#### 6.5.4 Conclusion

The use of natural analogues to support long-term safety assessment models has its limitations. In particular, the materials and environmental conditions involved are somewhat different in the analogue compared to the NSDF and its environment. In addition, the purpose of the mounds are not always the same – many are burial sites, not disposal facilities. This is typical of natural analogues. Therefore, we are using the above examples as an additional line of evidence that does not replace the safety assessment. Nonetheless, these examples support the concepts of the long-term containment provided by the NSDF and illustrate similar long-term behavior of natural and anthropogenic systems.

#### 6.6 Treatment of Uncertainties

The treatment of uncertainty is central to any assessment to establish the safety of a radioactive waste repository. Marivoet *et al.* [6-64] note that uncertainties in PostSAs can be categorized into three types<sup>5</sup>.

- **Future or scenario uncertainty:** uncertainty in the evolution of the system and human behavior over the timescales of interest.
- **Model uncertainty:** uncertainty in the conceptual, mathematical and computer models used to simulate the behavior of the system (e.g., uncertainties related to approximations and simplifications in the representation of the system).
- **Data uncertainty and variability:** uncertainty in the data and parameters used in the modelling (e.g., due to incomplete site-specific data, and parameter estimation errors from interpretation of test results).

These uncertainties are managed in the PostSA in the following way:

- The assessment of a range of scenarios, models and data with a suite of calculation cases.
- The adoption of conservative scenarios, models and data.

<sup>5</sup> The boundaries between these categories can overlap in that, depending upon how models are formulated, an uncertainty may be classed as a model or a data uncertainty.

- Natural variability is taken into account, e.g., through suitably averaging over space or time, where this is possible.
- Uncertainty analysis of key parameters.

Each aspect of the approach is discussed further in the following subsections.

#### **6.6.1 Range of Scenarios, Models, and Data**

In the PostSA [6-6], uncertainty in the future evolution of the site and human behavior is addressed by assessing an appropriate range of scenarios that describe the range of potential evolution pathways of the system. A systematic scenario identification process ensures that key uncertainties are identified, and scenarios are defined to explore their consequences. This draws on the outcome of an assessment of FEPs, which categorizes the significance (in terms of likelihood and consequence), of all potential aspects of the disposal system. Some future uncertainties are amenable to representation with parameter values, in which case they are explored in the same way as other data uncertainties.

Conceptual and mathematical model uncertainties are identified using a structured model development process, also making use of the FEP analysis. These can be represented with alternative calculation cases, which quantify the consequences of alternative representations of the disposal system. Some conceptual and mathematical model uncertainties are also amenable to representation with parameter values, and so are investigated using the methods applied to data uncertainties.

Uncertainties in data are identified and documented during the data selection process. Two approaches can be used to analyze data uncertainties:

- Multiple deterministic calculations – in which alternative sets of parameter values, which provide a self-consistent representation of the system, are adopted. The results are then compared to a Reference Case (using best estimate values of parameters) and the differences explored, providing a clear illustration of the impact of specific uncertainties or uncertainty combinations. Often a set of calculation cases whose parameters span the range of interest, is evaluated in order to build up an appreciation of the possible impacts of varying parameter values, and to develop an understanding of the system. A limitation of the deterministic approach is that there is often no systematic or complete coverage of the uncertainty space using discrete sets of parameter values.
- Probabilistic calculations – in which a set of key parameters is assigned probability distribution functions that describe the uncertainty. The model is evaluated a large number of times, in each case using randomly selected values from the distributions. The model output is a distribution of results. The strength of the probabilistic approach lies in its ability to be comprehensive in exploring the space of the phenomena considered, and their associated model parameters. Its weakness is the possibility that the statistical sampling may choose parameter combinations outside their range of validity. In addition, unless the uncertainties are very well characterized, probabilistic distribution functions can themselves introduce uncertainties into the calculations. Furthermore, when a range of parameters are treated in this way it can be challenging to interpret and communicate the results.

In light of the above discussion, the approach in the PostSA [6-6] is to explore uncertainties through deterministic calculations, selecting parameter values that are characterized as either “best estimate” or “conservative”. A further uncertainty analysis for the PostSA is presented in [6-85] to ensure that key parameters were sufficiently investigated and to bound potential scenarios by co-varying multiple input parameters.

### 6.6.2 Conservative Scenarios, Models, and Data

Throughout the assessment process, it is necessary to make various assumptions that influence the design of the assessment – whether they relate to scenarios, models or data. Assumptions are often categorized as ‘realistic’<sup>6</sup> or ‘conservative’<sup>7</sup>, although care needs to be taken when using such terms. The key is to ensure that each major assumption used in the assessment is considered and documented, and that the potential implications are understood.

A generally conservative approach is applied throughout the assessment where uncertainties are present. This approach allows the uncertainties to be bounded. Best estimate values are selected where there is little uncertainty or such values are readily justified. It should be noted that care is needed as the net effect of an aggregation of many conservative assumptions can be an unrealistic estimate of impacts. Furthermore, some analyses (e.g., optimization studies) can be meaningless if the assessment is dominated by conservative assumptions.

### 6.6.3 Uncertainties Addressed in the PostSA

A large source of uncertainty for the NSDF Project is associated with understanding and modelling the future conditions of the Facility and site for thousands of years. Sensitivity Cases are used to understand the effects of input parameters, while the Disruptive Events and other scenarios examine the effects of uncertainties in human behavior, barrier degradation rates, and natural processes.

The PostSA [6-6] examines a number of scenarios designed to demonstrate compliance with the dose acceptance criteria, even under a variety of parameters and assumptions.

A further uncertainty analysis is presented in [6-85] to ensure that key parameters were sufficiently investigated and to bound potential scenarios by co-varying multiple input parameters.

Sensitivity Cases determine the consequences of varying a specific parameter or set of parameters. Disruptive Events examine lower probability but feasible variations to the normal evolution scenario. The Defence-in Depth and “What-If” scenarios examine extreme cases which help us understand the value of the barriers, and reduces uncertainty for some “worst-case” outcomes.

Table 6-5 below, summarizes how each Sensitivity, Disruptive, Defence-in Depth, and “What-If?” scenario addresses some uncertainty about the evolution of the ECM during the assessment timeframe [6-6]. Table 6-5 also contains the summary of the uncertainty analysis in [6-85].

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<sup>6</sup> Realism is defined as “the representation of an element of the system (scenario, model or data), made in light of the current state of system knowledge and associated uncertainties, such that the safety assessment incorporates all that is known about the element under consideration and leads to an estimate of the expected performance of the system attributable to that element” [6-65].

<sup>7</sup> Conservatism is defined as “the conscious decision, made in light of the current state of system knowledge and associated uncertainties, to represent an element of the system (scenario, model or data) such that it provides an under-estimate of system performance attributable to that element and thereby, an over-estimate of the associated radiological impact (i.e. dose or risk)” [6-65].

**Table 6-5**  
**Cases to Address Uncertainties [6-6]**

| Scenario                                  | Brief Description                                                                                        | Uncertainty(s) Addressed                                                                                                                                        | Results Summary                                                                                                                                                          |
|-------------------------------------------|----------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Sensitivity Cases</b>                  |                                                                                                          |                                                                                                                                                                 |                                                                                                                                                                          |
| Inventory                                 | The radioactivity in the Reference Inventory is increased by a factor of 10                              | Addresses uncertainties related to the actual emplaced inventory due to operator error or human error during waste characterization.                            | The dose calculations are almost linear with inventory, i.e., an increase in radioactive inventory increases dose to the receptors.                                      |
| Institutional control period              | The ICP is reduced to 100 years (from 300 years)                                                         | Addresses the uncertainty in the effectiveness of land-use restrictions placed on the ECM footprint, and Federal government oversight into the future.          | A shorter ICP increases radioactivity concentration of shorter-lived radionuclides. A 100-year ICP increases the dose to a receptor who digs or intrudes into the waste. |
| Sorption Coefficient                      | The sorption parameters are reduced by a factor of 10                                                    | Addresses uncertainties related to the composition of the waste, biosphere, and geosphere resulting in greater mobility and therefore, release of contaminants. | Higher mobility in the environment allows for radionuclides to travel faster to receptors, increasing dose but also moving the period of peak dose.                      |
| Transit time                              | The groundwater transit time from the ECM to Perch Creek is reduced to 5 years (from 7 years in the NES) | Addresses uncertainties in the surface water and groundwater modelling.                                                                                         | Similar to the sorption coefficient, the reduction in transit time increases dose and changes the period of peak dose.                                                   |
| Degradation of cover and liner            | The engineered barriers degrade much faster than the design life (includes enhanced erosion)             | Addresses uncertainty in the manufacture, installation, and quality of the engineered barriers.                                                                 | Faster degradation of the engineered barriers increase the radionuclide rate of release and increase the dose to receptors.                                              |
| Reduced Hydrologically Effective Rainfall | Increased rainfall, higher temperatures, changes in evapotranspiration                                   | Addresses uncertainty in the climate change assumptions of the NES.                                                                                             | Less hydrologically effective rainfall results in the drying of the marshland, allowing the farmer to use this land for livestock. Doses slightly increase as a result.  |
| Receptors of Public Interest              | Inclusion of additional public receptors                                                                 | Addresses uncertainty in the location and behaviors of the public (off-site) receptors.                                                                         | Calculated dose to the additional receptors is lower than the normal receptors.                                                                                          |
| Self-Sufficient Indigenous Receptor       | Receptor analyzed lives traditional lifestyle, most food and drink harvested on or near the NSDF site    | Addresses uncertainty in human behaviors and land use in the future.                                                                                            | Doses are higher compared to the NES receptors, but still meet acceptance criteria.                                                                                      |
| Degradation of Berm                       | Not quantitatively assessed. Bounded by Role of Berm (Series of Landslides).                             |                                                                                                                                                                 |                                                                                                                                                                          |
| Key Parameters [6-85]                     | Key parameters were investigated to bound                                                                | Twelve key parameters were identified as having significant                                                                                                     | Uncertainty in the inventory and near field sorption coefficients                                                                                                        |

| Scenario                              | Brief Description                                                                                                 | Uncertainty(s) Addressed                                                                                                          | Results Summary                                                                                                                                                                                                                        |
|---------------------------------------|-------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                       | potential scenarios by co-varying multiple input parameters.                                                      | uncertainties, which could affect the calculated peak dose or peak environmental concentrations of non-radiological contaminants. | are the biggest contributors to uncertainty in dose estimates, with concentration ratios being the third most significant source of uncertainty.                                                                                       |
| <b>Disruptive Events</b>              |                                                                                                                   |                                                                                                                                   |                                                                                                                                                                                                                                        |
| Human Intrusion (Borehole)            | An exploratory borehole is dug into the waste. Exhumed material used in garden                                    | Addresses uncertainty in type of intrusion, specifically intruding directly into higher activity packaged wastes.                 | Doses increase slightly due to additional exposure from garden.                                                                                                                                                                        |
| Human intrusion (house with basement) | The resident/farmer's house has a basement. Exhumed waste used in garden                                          | Addresses uncertainty in type of intrusion, specifically intruding directly into the top layer of wastes                          | Doses increase slightly due to additional exposure from garden.                                                                                                                                                                        |
| Enhanced Erosion                      | Faster erosion rate of the cover materials, resulting in wastes exposed and transported to the swamp              | Addresses uncertainty in the cover system's ability to resist erosion, and the overall assumed erosion rate.                      | Doses increase as a result of increased exposure to the waste.                                                                                                                                                                         |
| Localized Cover Failure               | A tear or hole in the cover exists, in a location that would maximize water infiltration                          | Addresses uncertainty in the CQA of the geomembrane and cover system.                                                             | Doses increase only marginally. Scenario demonstrates that bathtubbing begins early, too little overall effect.                                                                                                                        |
| Localized Liner Failure               | A tear or hole in the liner exists, allowing more leachate to exist the Facility into the groundwater             | Addresses uncertainty in the CQA of the liner system.                                                                             | Doses decrease slightly. Allowing water to escape the ECM through the bottom reduces the bathtubbing effect. Water exiting the ECM through the liner becomes sorbed by the geosphere, and less available to the surficial environment. |
| Damage to the Berm                    | A portion of the berm erodes, and allows increased flow of water out of the ECM                                   | Addresses the uncertainty in the CQA of the berm.                                                                                 | Doses increase slightly as a result of increased contaminants exiting the ECM.                                                                                                                                                         |
| <b>Defence in Depth</b>               |                                                                                                                   |                                                                                                                                   |                                                                                                                                                                                                                                        |
| Role of Geosphere                     | No sorption or retardation of contaminants in the environment is credited                                         | Addresses uncertainty in the role that the geosphere plays in the overall confinement of contaminants.                            | Change to dose rates are negligible, as doses are primarily driven by the bathtub effect, and not the presence of the geosphere.                                                                                                       |
| Role of Cover                         | The cover system is assumed to perform very poorly, resulting in bathtubbing immediately at 300 year post closure | Addresses the uncertainty in the importance of the cover system in overall dose and risk mitigation.                              | Doses increase slightly as a result of increased rate of water infiltration and earlier bathtubbing.                                                                                                                                   |



| Scenario           | Brief Description                                                                                                            | Uncertainty(s) Addressed                                                                                                                         | Results Summary                                                                                                                                                                                                                                |
|--------------------|------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Role of Base Liner | The base liner system is assumed to not act as an effective barrier, represented instead as a sand barrier                   | Addresses the uncertainty in the importance of the base liner in the post-closure phase.                                                         | Doses decrease as a result of less bathtubbing. However, contaminant concentrations in groundwater increase as a result of leakage below the ECM.                                                                                              |
| Role of Berm       | A series of landslides removes much of the berm material. Some of the material is deposited into the swamp area.             | Addresses the uncertainty in the importance of the berm.                                                                                         | Doses increase as a result of reduced containment of the wastes, and increased rate of water release.                                                                                                                                          |
| <b>What-If?</b>    |                                                                                                                              |                                                                                                                                                  |                                                                                                                                                                                                                                                |
| Mass Excavation    | The entire Facility (waste and barrier material), is excavated and the material is dispersed                                 | Addresses a bounding, worst case scenario, where containment is completely lost and the material fully exposed to the environment and receptors. | Doses increase, as expected, by at least an order of magnitude as compared to the NES. However, doses to the residents remain under 1 mSv/y, indicating that the waste form itself is a low hazard.                                            |
| Shallow Well       | The resident receptor receives all of their drinking water from a shallow well directly in the path of the contaminant plume | Addresses uncertainty in predicting human behavior and well-digging preferences of the future.                                                   | Doses increase as expected. The resident is effectively drinking undiluted leachate from the Facility. Resulting dose rates are higher than other scenarios, but still lower than the 2 mSv/y natural background experienced by all Canadians. |
| Permanent Bathtub  | The liner does not ever degrade significantly, resulting in permanent bathtubbing                                            | Addresses the uncertainty in the CCLs hydrological properties.                                                                                   | Doses increase as a result of continued contaminant release, due to the bathtub effect. Doses continue to meet the 0.3 mSv/y design criteria.                                                                                                  |

### 6.6.3.1 Inventory Uncertainty

The Reference Inventory [6-5] for the NSDF was developed as an iterative process between PostSA [6-6] modelling and the WAC [6-7]. The process is described in more detail in Section 6.2.

Canadian Nuclear Laboratories waste characterization [6-8], is the primary method for reducing uncertainty in the amount of radioactivity accepted into the NSDF for disposal. During operations, the waste inventory will be tracked and recorded upon acceptance by the Facility, and the accumulated quantities of each radionuclide disposed in the ECM will be known.

To further address the uncertainties in the Reference Inventory [6-5], a sensitive analysis was performed to determine the effects of disposing of 10 times more radioactivity than planned.

### **6.6.3.2 Institutional Control**

Institutional control is assumed to be 300 years, which is consistent with international practice and assumptions for disposal facilities. During the ICP, land-use restrictions on the site are enforced, meaning that no person is allowed to take up residence on the NSDF site. During the ICP, it is assumed that monitoring and maintenance is performed on the ECM periodically and as required. Atomic Energy Canada Limited is committed to enforcing land-use restrictions on the NSDF site for as long as necessary. The term “as long as necessary” is meant to communicate that the enforcement of institutional controls on the property is not intended to end, and will continue for as long as legally required by either federal or provincial regulations. This approach is consistent with how other land disposal facilities are managed. Any changes to institutional control requires approval by the respective regulatory agency and will be based on factors including: the presence and state of the engineered barriers, the remaining radioactivity concentration, and environmental monitoring results. The sensitivity case examines the effects of an early lapse in institutional control, reduced to only 100 years after closure.

### **6.6.3.3 Sorption Coefficient**

Sorption coefficients are the mathematical inputs that determine how quickly a contaminant moves through the environment. The PostSA uses site-specific sorption coefficients where possible, and conservative inputs for all other parameters. The sensitivity case examines the effect of reducing the parameters by a factor of 10, which allows for contaminants to move more quickly through the environment.

### **6.6.3.4 Transit Time**

Groundwater monitoring and modelling for the NSDF Site suggests that the transit time of groundwater from the ECM to the surface is about seven years. There is uncertainty in how the construction of the ECM will affect the groundwater table level and therefore, the groundwater transit times. The sensitivity case examines the effect of reducing the transit time to five years.

### **6.6.3.5 Physical Barriers**

There is a large amount of uncertainty in how the physical barriers of the ECM will degrade with time. Factors affecting the barrier degradation include:

- Quality of the HDPE geomembrane (i.e., if the HDPE was manufactured to correct specifications and defect rates).
- Installation of the HDPE geomembrane (i.e., limited wrinkles and defect potential).
- Degradation rate of the HDPE geomembrane.
- Effectiveness of the “peaks and valley” or “herringbone” design of the final cover (i.e., the ability to control water flow and impact on erosion rates).
- Quality of the clay barrier (i.e., correct mixture and specifications).
- Degradation rate of the CCL.

The following sections provide more detail in how uncertainties are being addressed in the post-closure modelling, by maintaining conservatism with respect to engineered barrier inputs and performance.

### 6.6.3.5.1 Engineered Barrier Systems and their Degradation

The Engineered Barrier Systems comprise the final cover and base liner. These are designed to minimize infiltration and generation of leachate, and control release of leachate respectively. Figure 6-2, shows the layers that make up the final cover. Figure 6-3 shows the layers that make up the base liner.

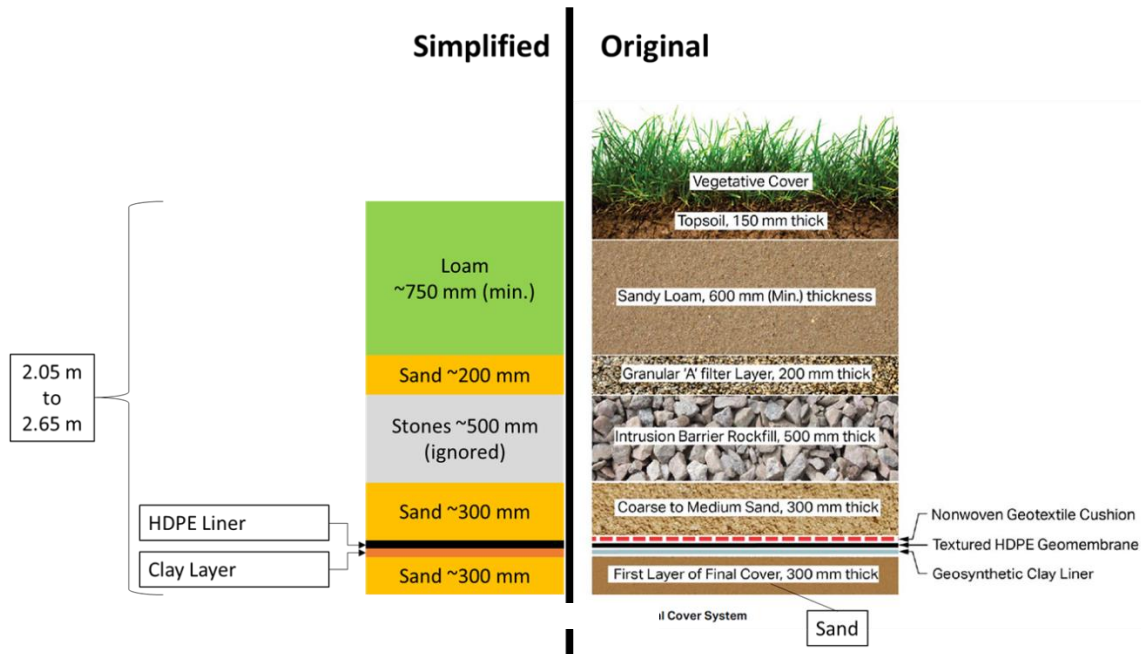


**Figure 6-2 Conceptualization of Final Cover Layers**

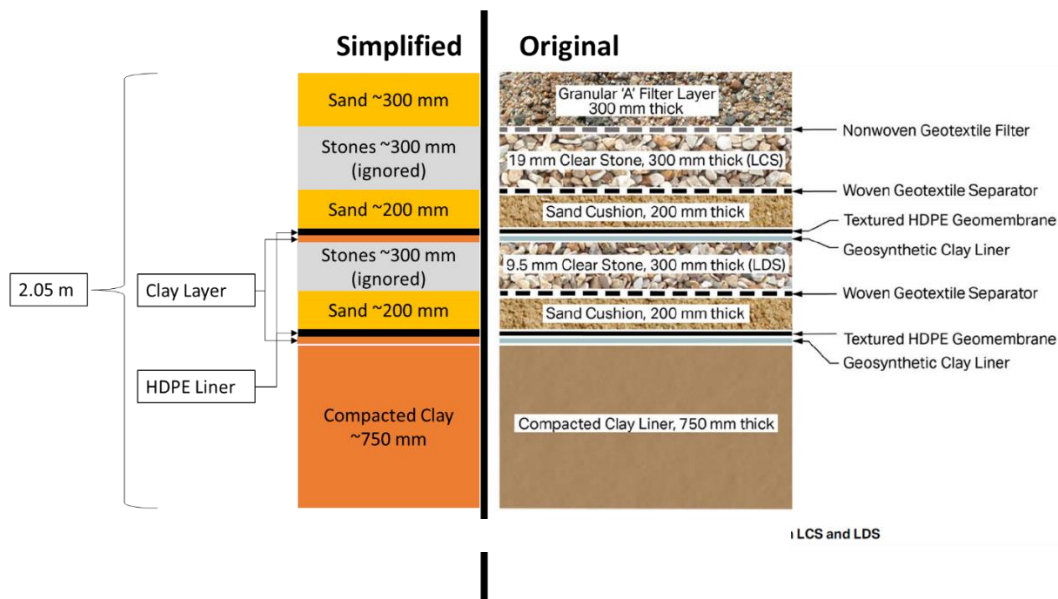


**Figure 6-3 Conceptualization of Base Liner Layers**

#### 6.6.3.5.1.1 Conceptual Model of Final Cover Performance and Degradation

The resistive layer in the ECM's cover is formed by a 2 mm thick HDPE geomembrane, combined with a 5 mm thick GCL (bentonite). The hydraulic conductivity of the GCL would not be as low as the HDPE geomembrane, but it will contribute to sealing defects in the HDPE when water comes into contact with the GCL.

Four processes can result in damage to an HDPE geomembrane: degradation by radiation energy; degradation by oxidation; aging effects and strain induced degradation. The Base Liner and Final Cover Performance and Lifecycle Evaluation [6-66], assessed the impact of these processes on the performance of the ECM cover. They concluded that the primary form of degradation of the geomembrane is oxidative degradation. The rate of oxidative degradation is sensitive to the temperature: it increases exponentially with increasing temperature. The report [6-66], concluded that the service life of the geomembrane could exceed the 550 year design life of the ECM. Studies, such as Rowe et al. [6-67], Koerner et al. [6-68], support this conclusion.

A testing program on the HDPE Geomembrane, part of the NSDF Project, aims to provide scientific-based information that will: (1) support the regulatory licensing process, (2) demonstrate 550 year design-life will be met and (3) refine geomembrane specification to particular brand/product/formulation, prior to its acquisition.

Based on available data and the interpretation, two of the candidate GMBs are considered suitable for the NSDF ECM, and have predicted service-lives to be well in excess of the required 550 year design-life.

One of them has a predicted service-life greater than 1200 years at 10°C and an expected service-life under the most reasonable assumptions in excess of 2000 years [6-67]. More information on the GMB testing program is found in Section 5.

Two key processes can degrade the GCL: chemical alteration through cation exchange reactions; and stresses resulting from settlement. The report [6-66], noted that the cover materials would have low calcium and magnesium content, so degradation by cation exchange should not be significant over the 550 year design life of the ECM. Considering the long-term performance of the supporting geogrid, it is not expected that significant strains will develop in the final cover. However, the organic content of the wastes, the extent to which the organics have degraded at the time of final cover placement, and hence, the residual settlement remaining to be expressed, are uncertain.

Given that there are uncertainties in the waste materials to be disposed in the ECM, the amount of settlement/differential settlement that could occur, and in the durability of HDPE geomembranes over the design life of the ECM, in the assessment models it is assumed that:

- The performance of the final cover has degraded by 37%<sup>8</sup> at the end of the 550 year design life of the ECM. Even if the GMG has significantly degraded, the GCL will significantly limit infiltration into the site.
- The final cover degrades quite quickly beyond the design life. It is assumed that the cover has fully degraded after 650 years. Infiltration through the degraded cover is similar to that through natural soils.
- The logarithm (base 10) of the infiltration rate through the cover increases linearly as the final cover degrades.

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<sup>8</sup> This value is determined by the assumption that the cover has fully degraded at 650 year, and the assumed logarithmic increase in the infiltration rate as the cap degrades.

These assumptions are consistent with final cover durability that is towards the lower end of the range of the expected long-term performance. Since the final cover is a key feature for containment of contaminants, these assumptions are conservative.

#### **6.6.3.5.1.2 Conceptual Model of Base Liner Performance and Degradation**

Two 2 mm thick HDPE geomembranes are present in the base liner of the ECM. Each GMB is combined with a 5 mm thick GCL. The two composite liners are separated by a LDS. The lower composite liner is underlain by a CCL.

The Base Liner and Final Cover Performance and Lifecycle Evaluation [6-66], assessed the performance of the geomembranes in the base liner. While they would be exposed to different chemical and stress conditions to the geomembrane in the cover, the report [6-66], concluded that their service life could exceed the 550 year design life of the ECM.

The report [6-66], also assessed the performance of the GCLs in the base liner. Cations leached from the wastes would result in faster degradation through cation exchange compared with the GCL in the cover. However, the impact of a given amount of cation exchange on the hydraulic conductivity of the GCL in the base liner would be much lower than for the GCL in the cover due to the higher confining pressure. The report [6-66], concluded that the service life of the GCLs in the base liner would exceed the design life of the ECM.

In the assessment models, the performance of the composite liners in the base of the ECM is similar to the performance of the composite resistive layer in the cover. The secondary base composite liner could continue to perform beyond the lifetime of the primary composite liner, as the primary liner will act to protect the secondary liner from solutes. In the assessment models both composite HDPE/GCL liners, within the base liner, degrade at the same rate.

The lower base composite liner is underlain by a CCL. Some of the mechanisms that could lead to degradation of the CCL will only be relevant once the composite liners in the base have failed.

Canadian Nuclear Laboratories [6-66], evaluated the potential degradation of the ECM's CCL considering: differential settlement of the subgrade; the thermal gradient across the CCL; clay-leachate interaction; freeze thaw action; and desiccation from below due to atmospheric pumping. Except for some potential damage to the CCL on the side slopes due to freeze-thaw action, CNL [6-66] considered that none of these processes would lead to significant damage to the CCL. This implies that the CCL could continue to perform over long timescales.

The vaults at the UK Low Level Waste Repository (LLWR) are underlain by geomembranes and Bentonite Enhanced Soil (BES) layers. Degradation behaviour of the BES layers below the vaults has been elicited [6-69]. The experts involved in the process elicited a best estimate initial ('as built') hydraulic conductivity of  $1\text{E-}10$  m/s. The BES would not start to degrade until the overlying geomembrane has failed. The best estimate long-term elicited hydraulic conductivities were  $1\text{E-}9$  m/s 1000 year after failure of the geomembrane, and  $1\text{E-}8$  m/s approximately 5000 year after failure of the geomembrane. (Longer timescales were not considered as the LLWR is anticipated to be disrupted by coastal erosion on timescales of a few hundred to a few thousand years).

The BES would contain a mix of sodium bentonite and sand. Degradation would be by exchange of sodium for calcium, leading to permeability increase, and washout of bentonite. Calcium would be sourced from the large quantities of cement used in the overlying vaults.

There are several differences between the ECM and the LLWR that could affect the lifetime of CCL, compared with the BES at the LLWR:

- The composition of the ECM's CCL has not yet been defined but will likely comprise local clays rather than BES [6-66]. These may be less sensitive to chemical degradation.
- The calcium loading in the ECM's leachate is likely to be far lower than the vault leachate at the LLWR (this may not be relevant depending on the composition of the CCL).
- LLWR's assumptions regarding long-term cover performance are consistent with a lower flux of water through the Facility for longer than the design life assumed for the ECM's cover. This means that the flux of water, and associated solute loading, passing through the clay liner is lower for a longer period than assumed for the ECM.

Overall, it is concluded that the base CCL of the ECM will perform for at least several thousand years, and possibly longer. For the NES, the CCL is assumed to start to degrade 650 years after construction of the base and has fully degraded 5000 years post-closure. There is not a firm basis for the value of 5000 years, however, the CCL is likely to perform for at least as long as the BES below the LLWR vaults.

The consequence of these assumed degradation times, is that the ECM could potentially bathtub, because infiltration through the cover might exceed drainage through the base liner. This would most likely occur between 450 and 4200 years. If, and when bathtubbing occurs, will depend on the amount of infiltration through the cover and the hydraulic properties assumed for the CCL. An alternative scenario is that the CCL does not degrade, so once the GMB in the cover fails, bathtubbing will occur throughout the rest of the assessment timeframe.

#### **6.6.3.6 Reduced Hydrologically Effective Rainfall**

To understand the uncertainty associated with climate change, the PostSA evaluates a Climate Change Sensitivity Case. Changes to the base NES are described below:

For the climate sensitivity case, there is a small decrease in Hydrologically Effective Rainfall (HER), suggesting slightly reduced surface and groundwater flows; however, the uncertainties are inherently greater for the climate sensitivity case than the NES:

- The assumed linear relationship between temperature increase and rainfall, may not hold true for temperature increases above those considered in the NES.
- Changes in temperature and rainfall may not be distributed evenly throughout the year. For example, the distributions of climate projections shown in the EIS [6-52], indicate that temperature increases may be greatest in July to October, but increases in rainfall may be greatest in September to January.
- The ratio of Actual Evapotranspiration to Potential Evapotranspiration could be less than that value of 0.8 assumed for the NES, and retained for this case, if soils are drier in summer.

To bound the potential impacts of climate change in the safety assessment, it is appropriate to assume a greater decrease in HER than 35 mm/year in the climate change sensitivity case. It is appropriate to explore

the consequences of increased seasonality, i.e., reduced HER and dryer soils in summer, and increased HER and wetter soils during the autumn (fall).

For the climate change sensitivity case, HER decreases from 300 mm/year [6-70] to 250 mm/year. The greatest reduction in HER is assumed to occur in the summer, which may lead to increased irrigation of crops during the summer. Note that in the climate sensitivity case, the climate is the same as the NES for the first 100 years. The more extreme climate changes occur post-2200 resulting in reduced HER.

#### **6.6.3.7 Receptors of Public Interest**

As a result of public interest in the Project, additional receptors are examined as Sensitivity Cases. The additional receptors are further away from the Facility, and therefore, doses to the additional receptors are expected to be lower than the groups examined in the NES. This sensitivity case reduces uncertainty in the radiological consequences (dose) to those living further from the site.

#### **6.6.3.8 Key Parameters**

The PostSA uncertainty analysis [6-85] analyzes 12 key parameters that were identified as having significant uncertainties that could affect the calculated peak dose or peak environmental concentrations of non-radiological contaminants. Table 6-6 provides the twelve key parameters selected with a description of the parameter uncertainty [6-85].

**Table 6-6**  
**Key Parameter Uncertainty**

| <b>Key Parameter</b>                                          | <b>Description</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|---------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Inventory                                                     | Uncertainty in the radionuclide inventory used in the PostSA arises from several factors. A log-uniform distribution of $\pm$ one order of magnitude was used to investigate the impact of varying the contaminant inventory.                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Sorption coefficients (wastes, drainage and resistive liner)  | Sorption coefficients values determine the rate of migration of contaminants relative to that of groundwater and are key factors in controlling the retention of contaminants in the NSDF, particularly for the bulk wastes, which comprise the majority of the volume of the ECM. The values of sorption coefficients are well-known to be a major source of uncertainty and can be assumed to vary by $\pm$ one order of magnitude with a log-uniform distribution.                                                                                                                                                                                              |
| Solubility limits                                             | Solubility limits are well accepted to be significantly dependent on local conditions (such as groundwater chemistry), and are an important source of uncertainty. The upper solubility limit values were used as reference values for the NES, and a log-uniform distribution of $\pm$ one order of magnitude from these values was used.                                                                                                                                                                                                                                                                                                                         |
| Solubility enhancement factors and sorption reduction factors | There is significant uncertainty around the magnitude of the solubility enhancement and sorption reduction, depending on factors such as the concentration of EDTA present and radionuclide speciation. A log-uniform distribution of $\pm$ one order of magnitude from these solubility enhancement and sorption reduction factor values was used. The uncertainty in solubility enhancement factors and sorption reduction factors is highly correlated as it depends on the concentration of EDTA and radionuclide speciation. One scaling factor was used to assess uncertainty in the solubility enhancement and sorption reduction factors for all elements. |
| Timing of EDTA washout                                        | A range for uncertainty in the timing of EDTA washout can be calculated in the EDTA AMBER model from estimated uncertainty in the initial amount of EDTA in the waste and rate of infiltration through the cap. Assuming an order of magnitude uncertainty in each, this suggests that the timing of EDTA washout could vary with a uniform distribution between 0 y and 1000 y (with best estimate of 520 y).                                                                                                                                                                                                                                                     |

|                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|---------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Hydrologically effective rainfall           | The water balance in the model, which controls the advective transport of contaminants, is affected by the assumed HER, i.e., rainfall minus evapotranspiration. For this uncertainty analysis, additional HER is assumed to act as additional runoff to investigate uncertainties in the overland flow (and impact on the flow rate into the creek). An estimated plausible range of HER is 0.2 m/y to 0.4 m/y, i.e., a range of $\pm 0.1$ m/y with a uniform distribution from the reference value.                                                                                                                                                                                                                                    |
| Sorption Coefficients (soils, sediments)    | In the near field and the geosphere, sorption is an important barrier to contaminant release and migration; sorption onto solid materials slows contaminant transport and therefore benefits the case. Sorption coefficients for soils and sediments are prescribed in CSA N288.1-14 [6-86] for four different soil types, with loam soil used as the reference value for the NES. The values vary by differing degrees, but in cases an order of magnitude or more. Therefore, a log-uniform distribution of $\pm$ one order of magnitude is used for the uncertainty analysis.                                                                                                                                                         |
| Creek and River flow rates                  | Several key exposure pathways in the NES result from contamination of Perch Creek and Ottawa River including ingestion of fish from Ottawa River and ingestion of game that drink water from the creek and the river. The average flow rates of Perch Creek and Ottawa River for the deterministic assessment are estimated as $2.04 \times 10^6$ m <sup>3</sup> /y and $1.35 \times 10^{10}$ m <sup>3</sup> /y, respectively. There is significant variance in the measured flows at these locations, as shown by data from Environment Canada. An estimate of uncertainty can be based on historical annual variation in mean flow, which suggests a range of $\pm 50\%$ , assigned to a uniform distribution.                         |
| Concentration factors (plants, animals and) | Concentration factors for various biota determine the extent to which radionuclides accumulate within them, and subsequently the exposure of people who ingest foodstuffs derived from them. In the NES, ingestion of beef and garden foodstuffs is a key exposure pathway for the onsite resident/farmer, and ingestion of game and fish is a key exposure pathway for the hunter/recreational receptor. The concentration factors for fish, plants and animal products are scaled together by a log-uniform distribution of $\pm$ one order of magnitude                                                                                                                                                                               |
| Animal food source areas                    | Several key exposure pathways for the NES involve the consumption of animal products; particularly fish, beef and game (goose). The concentration of radionuclides in these animal products depends on the estimated food source areas for the animals. Source areas for animals' food and drinking water are estimated based on the home range of each animal group. Local fractions for food and drinking water are assumed to vary by a factor of 2 in each direction, with a uniform distribution. This is applied for the three highest contributors to dose; fish, beef and goose. The three organisms are assessed separately, but for geese, the local fraction for aquatic and terrestrial food consumption will be correlated. |

The uncertainty analysis included partial (partially sampled) and full (fully-sampled) sensitivity analysis [6-85]. Illustrative uncertainty distributions were selected for each of these parameters; these were chosen to encompass a wide range of plausible values for investigating model sensitivity, not to represent the distributions of probability of values.

Partial sensitivity analysis involves varying only a single parameter of the defined set, with others held at "best estimate" values. In this study, the best estimate values were the same as those used in the NES. Partial sensitivity analysis provides a way of clearly identifying the effect of a single parameter variation, without complicating the analysis by varying values for other parameters. Partially-sampled sensitivity cases were run for each key parameter in turn, to explore the relationship between these parameters and the receptor peak dose. This analysis identified that inventory, near-field sorption coefficients and concentration ratios appeared to have particularly strong relationships with the receptor peak dose, whereas other parameters had a much smaller effect or no effect [6-85].

Relationships with peak environmental concentrations of Pb and U were also investigated. Environmental concentrations were shown to be mainly sensitivity to inventory, sorption coefficients and solubility limits,



although it was demonstrated that concentrations of Pb and U in different media show inverse relationships with some parameters [6-85]. Therefore defining a conservative value for these parameters is not straightforward.

Full sensitivity analysis involves varying all parameters together. Over the large combined uncertainty ranges used (two orders of magnitude for most parameters), the peak doses to the onsite resident/farmer and hunter/recreational receptors were shown to vary by up to four orders of magnitude [6-85]. From the 500 samples, the mean peak dose to the site resident was  $4.6 \times 10^{-2}$  mSv/y and the mean peak dose to the adult hunter was  $1.1 \times 10^{-1}$  mSv/y [6-85]. These values are higher than the best estimate doses from the NES ( $1.5 \times 10^{-2}$  mSv/y and  $1.2 \times 10^{-2}$  mSv/y respectively) due to the log-uniform distributions used for many parameters, which skew the results towards a higher linear average [6-85]. The median doses, which exclude the effects of outliers, are much closer to the best estimates at  $1.7 \times 10^{-2}$  mSv/y and  $2.0 \times 10^{-2}$  mSv/y, respectively [6-85].

The results from the partially-sampled and fully-sampled sensitivity studies demonstrate that uncertainty in inventory and near field sorption coefficients are the biggest contributors to uncertainty in dose, with concentration ratios being the third most significant source of uncertainty [6-85]. Building confidence in the values of these parameters would be the most efficient way to reduce uncertainty in the dose calculations [6-85].

#### **6.6.3.9 Other Sources of Uncertainty in the PostSA**

The following sections include other sources of uncertainty in the PostSA modelling, that aren't necessarily assessed through specific scenarios, but have been addressed through the use of conservative inputs and assumptions that can be verified or confirmed during the appropriate timeframe (either during construction, closure, or during the ICP).

##### **6.6.3.9.1 Generation and Sources of Gas**

Gas (e.g., carbon dioxide, methane, and hydrogen) generation will affect the migration of trace gases through the ECM. The generation rate of gases will significantly depend on the nature and quantity of organic and metal wastes. The inventories of metal and organic wastes are provided in Section 3.3.1 [6-71].

To enable a quantitative analysis given the current uncertainties, models that are used for the UK's LLWR trenches are applied in the PostSA [6-6] to inform the rates of generation of gases and C-14 gases. The LLWR is a reasonable analogue to choose because the trenches at the LLWR are anticipated to have broad commonalities in materials inventory and biogeochemical conditions with the ECM. Both the LLWR and the ECM will have low gas generation rates compared with a commercial landfill because both facilities are expected to have lower organic content than commercial landfill. A detailed model of the evolving near-field biogeochemistry at the UK LLWR has been built, which calculates gas generation and incorporation of C-14 into carbon dioxide and methane. At the LLWR, gas generation rates are calculated to be at a maximum initially and progressively decline over time as the inventory of organic wastes decreases, and the remaining wastes are progressively less easily degraded. Gas generation largely stops after approximately 700 years and 80% of gas generation has occurred by 500 years. Generation of C-14 gases broadly mirrors gas generation.

Examining the LLWR and using empirical data, is a method to reduce the uncertainty in the NSDF modelling.

### Impact of gas ventilation system

For the purposes of the PostSA, it is assumed that the gas vents installed as part of the final cover system are sealed before the end of institutional control. If this is not the case, there is a chance that the continued exchange of air between the atmosphere and the gas within the repository might lead to relatively oxidizing conditions in the unsaturated zone within the NSDF. This could have an impact on contaminant release rates. Due to the conservatism in the contaminant transport model, this potential impact is unlikely to cause higher release rates or change the results of the dose assessment. Nonetheless, this process is identified here as a potential area of future study in future iterations to the PostSA and Safety Case.

#### **6.6.3.9.2 Biogeochemical Conditions**

The biogeochemical conditions do not affect the configuration of the AMBER model, and are not calculated explicitly in the AMBER model. The biogeochemical conditions are reflected in AMBER by the chosen element specific solubility limits and sorption distribution coefficients ( $K_d$ ) that control the mobility of contaminants.

At the current stage of development of the NSDF Project, only limited information is available on the composition (and speciation) of the wastes to be disposed, and a near-field biogeochemical evolution model has not been developed. Time variation in solubility limits and sorption distribution coefficients to reflect changing biogeochemical conditions have not been included in the assessment models.

Biochemical conditions are a source of uncertainty in the current environment and PostSA modelling. This uncertainty can be assessed in the future using monitoring results.

#### **6.6.3.9.3 Nature of Waste Forms**

There is little detailed information about the physical composition and packaging materials of the wastes to be placed in the ECM, and consequently, considerable uncertainty about the identities and speciation of non-radioactive constituents that might promote the transport of radionuclides from the wastes.

Uncertainty in the nature of the waste forms is managed and reduced by ensuring that wastes placed in the NSDF meet the WAC, including the chemical and physical criteria.

In addition, there is uncertainty in the exact waste placement of packages and bulk waste. Although there is a requirement to place the more concentrated waste forms in the bottom third of the Facility, the exact placement of wastes in each operational layer is uncertain. Exact knowledge of the composition of each layer could result in more refined models.

#### **6.6.3.9.4 Contaminant Release Delay from Packages**

By volume, the majority (~85%) of the waste planned for disposal in the NSDF is considered "bulk", meaning that the waste is mostly soils and construction material debris from demolished buildings. However, the majority of the radioactivity is contained in packaged waste.

The packages used may include steel barrels, steel liners, and other kinds of higher integrity containers designed to maintain their containment capabilities under pressure and possibly wet conditions. There is uncertainty around what kinds of packages will be included, and their respective properties and effectiveness for delaying the release of contaminants.

This uncertainty has been addressed in the PostSA by ignoring the packages. The PostSA gives no credit to the protection provided by the packaging of waste. Therefore, the PostSA is conservative with respect to contaminant release rates.

#### **6.6.3.9.5 Chelating Agents**

Chelating agents are defined in [6-7] as: Chemical compounds (usually organic compounds) that form complexes with metal ions or other substrates. They are usually used to modify the solubility of metal ions or other substrates.

Chelating agents have been used at CNL for decontamination of equipment, in laboratory scale experiments and in historical fuel reprocessing type activities. Examples of chelating agents that have been used include ethylenediaminetetraacetic acid (EDTA), citric acid (and related salts), oxalic acid and tri-butyl phosphate. Typically chelating agents are used in aqueous form and as such, it is expected that any chelating agents in the NSDF will exist as surface contamination on solid waste or as a minor component in solidified waste.

Chelating agents typically increase solubility of heavier ions, which increases mobility, which increases the rate at which the contaminant is able to migrate out of the ECM.

Canadian Nuclear Laboratories evaluated the potential for chelating agents in the waste streams, based on process knowledge and informed assumptions [6-72]. It was estimated that, on average, the total waste may contain up to 0.00044% EDTA by waste mass.

#### **6.6.3.9.6 Dose Coefficients/Conversion Factors**

Comments received from third party reviewers indicate that there are potentially different dose coefficients (DCF) that could be used in the PostSA that would have an impact on the calculation of radiological dose consequence. These DCFs have been discussed and proposed in scientific literature, but are not yet a part of Canadian guidance/standard documentation.

The PostSA in its current state uses conservative inputs/methodologies. Taking these recommendations into consideration removes some conservatism in some cases. A discussion of the DCFs used in the PostSA follows.

International Commission on Radiological Protection 114 [6-75] was published in 2009. The PostSA preferentially obtains DCFs from Canadian guidance documents, namely, CSA N288.1 [6-83]. The third iteration of the PostSA was drafted in 2019. In 2019, the published version of CSA N288.1 was the 2014 version (including subsequent Errata). Ingestion and inhalation DCFs in the 2014 version of CSA N288.1 are ultimately obtained from ICRP 72 [6-73], aside from C-14, tritium in water (HTO), tritium gas (HT), and organically bound tritium (OBT), which are derived differently (see CSA N288.1, Appendix C, Section C.2). External DCFs in CSA N288.1 are from Eckerman & Leggett [6-74] (aside from Ar, Kr, and Xe which are from ICRP 72).

Dose Conversion Factors for OBT are conservative in that they impart a greater dose per Bq than other tritium forms. For waterborne releases, given that the ECM will contain organic material, it would be challenging to argue that no organically-bound tritium would be present in drinking water contaminated by ECM releases. Thus, without good rationale to rule it out, it is conservative to use OBT DCFs.

According to Puncher [6-76], uncertainties in accepted DCFs range from factors of 2-3 for ingestion and 2-6 for inhalation for the following radionuclides studied: U-238, Ra-226, Pu-239, Am-241, Cs-137, Sr-90, I-131, and H-3.

Assumptions used in the PostSA regarding particle size for dust inhalation are conservative and lead to a higher dose rate. Use of the more realistic or accurate particle size has the potential to reduce the dose from inhalation for some radionuclides.

In summary, the PostSA can only reference the latest acceptable CSA and ICRP dose coefficients until new ones are accepted by these organizations. The uncertainty inherent in the DCFs, and the restrictions of referring to only accepted DCFs in the Canadian standards is noted here in the Safety Case. Future iterations of the PostSA may be able to take credit for improved DCFs and demonstrate that the expected radiological consequence (dose) is actually lower than originally calculated.

#### **6.6.3.9.7 Accuracy of the Near-field Modelling**

The PostSA model in AMBER uses a simplified approach to modelling the water balance and contaminant migration in and around the ECM, an area referred to as the “near-field”. The AMBER model assumes that water overtopping the berm due to the bathtub effect flows over the berm and becomes surface water. This is a conservative assumption and modelling approach, as it allows contaminants to immediately interact with the surface environment. This leads to conservative results for environmental concentrations of contaminants, and subsequently higher doses to both human receptors and biota.

A more detailed near-field model [6-77] was developed for the NSDF to confirm that the assumptions made in the PostSA were accurate, or at least conservative.

The objective of the near-field modelling are:

1. Provide a rigorous calculation of fluid saturations and flows within the NSDF during different stages of the cap and liner performance, using a near-field model of the NSDF ECM, and
2. Provide a rigorous calculation of the infiltration through the cap and into the NSDF using a column model of the NSDF cap. These calculations are conducted in support of the near-field model of the ECM.

The near-field model took into account the results of the groundwater flow modelling [6-35]. The model uses the material properties of both the ECM and the surrounding environment (e.g., sands, glacial till, bedrock). Most importantly, the model takes into account the liquefaction mitigation measures of “remove and replace”, which involves the removal of overburden material to the bedrock, and replacement with compacted engineered granular fill material, which allows water to pass through it more effectively.

The results of the modelling indicate that the bathtub effect does not necessarily cause all of the overtopping water to exit over the berm and become surface water. Due to the design of the berm and the inclusion of granular material, water is able to flow through it. As a result, water overtopping the berm is more likely to be absorbed into the ground and become groundwater. The groundwater pathway allows for significantly more decay time and adsorption into subsurface materials, greatly reducing the amount of contaminants that reach the surface environment.

The near-field modelling confirms that the assumptions used in the PostSA are conservative, and likely over-estimate the environmental concentration of contaminants, and thus receptor radiological consequences (dose).

### 6.6.3.9.8 Radionuclide Selection and Screening

The Reference Inventory report [6-5] and Section 5.6 of this document describes how the radionuclides were chosen, based on factors such as radiotoxicity and quantities in storage. The Project received feedback indicating that some radionuclides that were expected to be included in the Reference Inventory were omitted. As a result of this concern, the Project evaluated the NES of the PostSA with the addition of the following radionuclides [6-78] and corresponding activity levels added to the Reference Inventory, shown below in Table 6-7.

**Table 6-7**  
**Additional Radionuclides Considered in the PostSA [6-78]**

| Radionuclide     | NSDF Reference Inventory at Emplacement |                                        | NSDF Reference Inventory at Closure |                                        |
|------------------|-----------------------------------------|----------------------------------------|-------------------------------------|----------------------------------------|
|                  | Total Activity (Bq)                     | Averaged Activity Concentration (Bq/g) | Total Activity (Bq)                 | Averaged Activity Concentration (Bq/g) |
| Am-242m, Am-242* | 4.73E+05                                | 4.95E-07                               | 4.16E+05                            | 4.35E-07                               |
| Cm-243           | 2.90E+07                                | 3.03E-05                               | 1.64E+07                            | 1.71E-05                               |
| Cm-244           | 1.91E+09                                | 2.00E-03                               | 8.13E+08                            | 8.50E-04                               |
| Cm-245           | 4.53E+02                                | 4.73E-10                               | 4.52E+02                            | 4.72E-10                               |
| Cm-246           | 7.94E+01                                | 8.30E-11                               | 7.91E+01                            | 8.26E-11                               |
| Pu-238           | 1.35E+10                                | 1.41E-02                               | 1.10E+10                            | 1.15E-02                               |
| Pu-239           | 3.07E+10                                | 3.21E-02                               | 3.07E+10                            | 3.20E-02                               |
| Pu-240           | 4.60E+10                                | 4.81E-02                               | 4.59E+10                            | 4.80E-02                               |
| Sm-151           | 7.43E+10                                | 7.76E-02                               | 6.09E+10                            | 6.36E-02                               |
| U-236            | 8.34E+07                                | 8.72E-05                               | 5.63E+07                            | 5.88E-05                               |

\*Am-242m and Am-242 are treated as being in secular equilibrium since Am-242 has a short half-life of 16 hours

The conclusions of this additional study are:

- Only Cm-244, Pu-238, Pu-240, and U-236 get screened into the assessment (based on the same screening process presented in Section 5.3.2.1.2 of the PostSA).
- The results indicate that the addition of these radionuclides does not affect peak doses or environmental concentrations in the NES.

Therefore, CNL's decision to omit the radionuclides listed in Table 6-7 is justified, as they are not present in high enough quantities or concentrations to affect the outcomes of the PostSA.

### 6.7 Other Similar Projects

Studying projects similar to the NSDF, and learning from them, can help build confidence in the Safety Case. Engineered containment mounds have been used for the disposal or long-term management of LLW at multiple sites around the world. Some examples are listed below:

- Port Hope Long Term Waste Management Facility, Canada.
- Port Granby Long Term Waste Management Facility, Canada.
- Energy Solutions Clive, Utah, USA.
- Environmental Management Waste Management Facility, Tennessee, USA.

- Environmental Restoration Disposal Facility, Washington, USA.
- Barnwell Disposal Facility, South Carolina, USA.
- On-Site Disposal Facility at Fernald, Ohio, USA.
- Texas Compact Waste Facility, Texas, USA.

### **6.7.1 Benchmarking, Lessons Learned, and Applicability to NSDF**

In an effort to manage and reduce the uncertainty in the design and operations of the NSDF, a benchmarking tour was performed by a team of CNL staff who visited some of the sites listed above in Section 6.7.

Observations and lessons learned were applied to NSDF design and preliminary operating plans.

This section summarizes some of the lessons learned from the benchmarking exercise.

#### **6.7.1.1 Surface Water Management Issues**

The Port Granby Long Term Waste Management Facility (LTWMF) Project, includes the construction of an ECM, as well as the remediation of approximately 450 000 m<sup>3</sup> of existing LLW. A WWTP is on-site to treat contact water from both the construction and remediation areas. In 2018, the Port Granby WWTP treated 195 114 m<sup>3</sup> of effluent and there were approximately 262 000 kg of filter press solids and 80 000 kg of slurry dryer solids [6-79]. The design of the Port Granby LTWMF includes an 11 000 m<sup>3</sup> Equalization Pond where the contact water is collected prior to treatment.

During construction and remediation activities, the Port Granby Project experienced challenges in managing the quantity of contact water produced by the Facility. Higher than expected rainfalls in 2017, infiltration of surface water into the remediation areas, coupled with operational challenges with the solids processing, resulted in capacity issues with the Equalization Pond. To mitigate this, the Port Granby Project utilized temporary water storage in Baker tanks, 6 000 m<sup>3</sup> lake tanks, and created berms to redirect clean surface water from neighbouring fields away from the remediation area. The Port Granby Project has had three events resulting in small quantities of untreated contact water being released into the environment. In each case, there was capacity in the Equalization Pond to receive the contact water, and other operations caused the small overflows (pipe break in remediation area, valve changing caused back up and overflow in the gorge, inflow of water into a sump).

The NSDF's WWTP is designed with three large Equalization Tanks. The purpose of the Equalization Tanks is to receive leachate and contact water from the ECM and allow for storage capacity before the treatment of the water. These tanks have a combined working capacity of 5 700 m<sup>3</sup>, which is enough to receive the combined water volume of two, 1-in-100-year storm events, back to back, with capacity left over.

#### **6.7.1.2 Management of Contact Water, need for Sacrificial Liners**

The Environmental Management Waste Management Facility (EMWMF) in Oak Ridge, Tennessee is a bulk LLW disposal facility with a capacity of about 1.3 million m<sup>3</sup>. The EMWMF experienced contact water/leachate management difficulties. Since the EMWMF did not have a dedicated WWTP, all contact water and leachate was collected and treated off-site. The volume of leachate was higher than expected or manageable.

To mitigate the volumes of contact water, Enhanced Operational Covers were placed over areas of waste that were exposed to the environment. Water shed from the liners was then treated as non-contact water, and therefore, did not require treatment prior to release from the environment.

The NSDF has implemented the use of “sacrificial” liners to be placed on the waste faces exposed to the environment during operation. They are called “sacrificial” because they are to be removed before the final cover is installed, and not part of the final construction of the mound.

#### **6.7.1.3 Dust Mitigation**

The Environmental Restoration Disposal Facility (ERDF) at Hanford Washington has a planned capacity of 7 million m<sup>3</sup>. The ERDF routinely accepts bulk LLW for disposal. The ERDF experiences dust control challenges. Water trucks and the use of fixatives are in continuous use at the site.

The NSDF operations team is aware that dust control is required and the necessary precautions and mitigations measures are planned to be in place.

#### **6.7.1.4 Separation of Contact and Non-contact Water**

The Barnwell Disposal Facility in South Carolina accepts mostly containerized LLW disposed into clay lined trenches. Barnwell diverts non-contact water to large on-site non-contact water ponds. In 37 years, they have never measured a sample of non-contact water that was above background concentrations.

A unique challenge at Barnwell is related to public perception of the non-contact water. They experience difficulties convincing environmental advocate groups that the non-contact water is uncontaminated.

The NSDF will be supported by CRL’s Environmental Protection program, which will co-ordinate the sampling and measuring of the non-contact water ponds. The results of these sampling campaigns will be reported.

#### **6.7.1.5 Benchmarking Summary**

Members of the NSDF Project’s future operating team visited several other LLW disposal facilities similar in design to the NSDF. The lessons learned were communicated internally, and have impacted decision making process for operational considerations.

For example, both Port Granby and the EMWMF provide lessons learned on the effects and mitigation measures for contact and non-contact water. The NSDF is using sacrificial liners as a result of the lessons learned, and has confirmed that the specifications for the Equalization Tanks adequately meet the design targets for the design basis precipitation event.

While a number of lessons learned have been incorporated in the NSDF design, the majority of the NSDF design features are very similar to existing LLW disposal facilities. A comparison between the NSDF and existing LLW disposal facilities confirms that the NSDF is designed using best available technology economically achievable.

### **6.8 Third Party Reviews and Findings**

To reduce uncertainties and increase confidence in the safety assessments performed in support of the NSDF, several third party reviews were performed at various stages in the Project lifecycle. Third-party reviewers were identified based on experience with LLW Facilities around the world. The findings and recommendations of the third-party reviewers were considered during the iterative development of the design and safety assessments for the Project.

An international expert panel led by the U.S. Department of Energy (DOE) was formed to provide an independent third party review of the NSDF safety case and the supporting safety assessment documents

PostSA and SAR. A review report with reviewer observation forms was provided to AECL and CNL for consideration in determining the completeness and defensibility of the NSDF Safety Case and assessment document. The review conducted from 2019 June 24 through 2019 November, consisted of document reviews, an on-site visit, activity observations, webinars, and interviews.

The review scope was bounded by the EIS and Safety Case document and the PostSA Revision #3, with all the referenced underpinning documents. The international expert panel evaluated the documents consistent with the non-binding expectations for a safety case and safety assessment from the IAEA Specific Safety Requirements on Disposal of Radioactive Waste (SSR-5) [6-80], the IAEA Specific Safety Guide on The Safety Case and Safety Assessment for the Disposal of Radioactive Waste (SSG-23) [6-2], and U.S. DOE Directives.

The review was focused on the descriptions and justifications for assumptions regarding:

- The conceptualization of the natural and engineered system and any evolution over time.
- The inventory and source term.
- The exposure scenarios.

Overall the initial panel's conclusions were that the Facility will be conservatively designed to dispose of the planned radioactive inventory and have future releases much below all appropriate standards. The final report contained 35 recommendations, 76 suggestions, and five good practices identified by the international expert panel. Recommendations are proposed where aspects are missing, incomplete, or inadequately implemented. Suggestions, or opportunities for improvement are means of achieving improvements and are not directly related to inadequate conformance with expectations and standards. A good practice is identified in recognition of an outstanding organization, arrangement, program or performance superior to those generally observed elsewhere. Most of the recommendations and suggestions have already been incorporated into the Safety Case or otherwise addressed. The remaining items have been assessed to have no safety significance and a corrective action plan has been developed to address them in the future stages of the Facility lifecycle as appropriate.

Table 6-8 summarizes the additional third-party reviews performed in support of the NSDF Project.

**Table 6-8**  
**Third Party Review Summary**

| <b>Reviewer</b>         | <b>Documents or design features reviewed</b>         | <b>Summary of findings or suggested improvements</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|-------------------------|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| AMEC Foster Wheeler, UK | Early iteration of the Performance Assessment [6-81] | <ul style="list-style-type: none"><li>• The project appears to have a very ambitious timescale, and that the original PA document may not reflect the maturity of the design.</li><li>• The PA document covers too much ground (from operations to post-closure, from worker to public, and biota). It was suggested that a document hierarchy be created (implying the need for a Safety Case document).</li><li>• Level of detail not sufficient to independently reproduce calculations and results.</li></ul> |



| Reviewer                                                                  | Documents or design features reviewed                      | Summary of findings or suggested improvements                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------------------------------------------|------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Safety Review Committee (SRC) (CNL independent internal peer review team) | Safety Analysis Report                                     | The SRC provided comments on the calculated dose rates, the monitoring of contamination, flooding and water levels, the identification of Operating Limits and Conditions, frequency of accident conditions, and the application of IAEA guidance to the project.                                                                                                                                                                                                   |
| Arcadis Canada                                                            | Performance Assessment, waste inventory, and WAC           | Arcadis provided CNL a report with feedback on a range of topics, including the radionuclide inventory, WAC, hazard identification, scenario development & assessment, and general transparency of the report.                                                                                                                                                                                                                                                      |
| Orano, UK (formally Areva)                                                | Performance Assessment                                     | Orano provided written comments in spreadsheet form, commenting on the general content and structure of the report. Recommendations were made on how to improve the assessment and document in general.                                                                                                                                                                                                                                                             |
| PLC Fire Solutions                                                        | Fire Hazard Assessment                                     | Three separate third-party review reports were performed on the NSDF fire safety design to capture design changes over the course of the NSDF design process.<br><br>Comment and review sheets were used to track findings. CNL confirmed that the suggested changes and improvements were implemented by the primary design contractor.                                                                                                                            |
| LRI Fire Protection & Building Code Engineers                             | Code Compliance Review                                     | The report provided a summary of the application of the 2015 National Building Code of Canada, 2015 National Fire Code of Canada, the 2016 edition of National Fire Protection Association 820 "Standard for Fire Protection in Wastewater Treatment and Collection Facilities", and 2013 edition of Canadian Standards Association N393 "Fire protection for facilities that process, handle, or store nuclear substances" to the proposed buildings for the NSDF. |
| Dr. Gail Atkinson                                                         | Probabilistic Seismic Hazard Assessment                    | Dr. Gail Atkinson provided a written report and recommendations on the NSDF Project's initial Probabilistic Seismic Hazard Assessment (PSHA). As a result of her review, the PSHA was updated to use the Geological Survey of Canada database, as well as other technical improvements to the methodology and assessment.                                                                                                                                           |
| SNC Lavalin                                                               | Waste Water Treatment Plant design and optimization [6-82] | <ul style="list-style-type: none"> <li>The WWTP is flexible, can accommodate changes in chemistry and ion exchange to mitigate unforeseen influent characteristics.</li> <li>The design employs the best available technology.</li> <li>WWTP has greater level of redundancy than typical.</li> <li>The influent source term is speculative, and the design contains all technology components to be responsive and flexible.</li> </ul>                            |

| Reviewer                                   | Documents or design features reviewed | Summary of findings or suggested improvements                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------------------------------|---------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                            |                                       | <ul style="list-style-type: none"> <li>An additional footprint should be identified for addition of reverse osmosis end train polishing and thermal treatment of concentrates, as a mitigation for unknown and unforeseen influent characteristics.</li> <li>CNL should review the construction contract mechanism to achieve greater accountability of vendors.</li> </ul>                                                                                                                                     |
| Arcadis (independent subcontractor)        | Safety Case                           | <ul style="list-style-type: none"> <li>Arcadis provided a resource with PostSA experience with the Nuclear Waste Management Organization to perform a review of the DRAFT NSDF Safety Case. Comments received helped CNL make adjustments to further align with regulatory guidance and expectations.</li> </ul>                                                                                                                                                                                                |
| International Independent Peer Review Team | PostSA Safety Case                    | <ul style="list-style-type: none"> <li>A team comprised of specialists from the US Department of Energy and the UK nuclear industry reviewed several of the NSDF Project documents, with a focus on waste acceptance, PostSA, and safety case.</li> <li>The feedback was that approximately 35 recommendations, 76 suggestions, and 5 good practices have been identified by the international expert panel.</li> <li>More detailed discussion on this review team is presented prior to this table.</li> </ul> |

## 6.9 Uncertainty in the Environmental Assessment

The EIS [6-52] includes the assessment of impacts to the environment due to the construction and operation of the NSDF. There are uncertainties in many aspects of environmental modelling. This section presents some discussion of uncertainties present in the EIS. Topics include:

- Air quality.
- Greenhouse gas emissions.
- Hydrogeology.
- Hydrology.
- Surface water quality.
- Terrestrial environment.
- Ambient radioactivity and ecological health.
- Human health.

### 6.9.1 Air Quality

Effects to air quality were assessed in the EIS [6-52]. Potential sources of uncertainty in the assessment of air quality include:

- Potential modifications associated with the location, physical footprint and activity level of the NSDF Project.
- The accuracy and representativeness of the activity data and emission factors used to estimate emissions.
- The accuracy and representativeness of the waste inventory.
- The accuracy and representativeness of the meteorological data used in the AERMOD model.
- The accuracy of formulations within the AERMOD dispersion modelling system.
- The representativeness of the ambient data used to represent background concentrations.
- The potential error associated with omitting some emission sources.

Uncertainties were managed using the following conservative assumptions in the emission estimation and dispersion modelling:

- Waste receipt for the maximum capacity of 1 000 000 m<sup>3</sup> was used in determining emission rates for dispersion modelling. All emission rate calculations were completed for the maximum amount of waste received during the entire life of the NSDF Project.
- The ECM was modelled as an area source. Modelling the ECM emissions as an area source, assumes that emissions are being released from the entire area, however in reality emissions will only be emitted from discrete areas on the source.
- The modelling assessment includes all operations occurring simultaneously and continuous for each individual source's modelling period.
- The influence of natural mitigation from events such as rainfall, snowfall, residual moisture, or snow cover was not considered in determining fugitive dust emission rates for all sources, except unpaved roads and grading. The modelling will likely yield higher concentrations since contaminants will be deposited from the air by dry or wet depletion and deposition processes.
- The 90<sup>th</sup> percentile observed concentration was added to maximum predicted concentrations for short-term averaging periods to account for existing background emission sources. The use of 90<sup>th</sup> percentile background concentrations is conservative, in that it assumes that the maximum predicted concentration and the 90<sup>th</sup> percentile background concentration will occur at the same time, even though background concentrations greater than or equal to the 90<sup>th</sup> percentile occur only 10% of the time.
- Five years of meteorological data are used as an input to the model to provide that a full range of possible meteorological conditions is evaluated.

### 6.9.2 Greenhouse Gas Emissions

For the assessment of GHGs, the main sources of error are the accuracy of the activity data and hours of operation used to estimate emissions to the NSDF and the omission of some emission sources. These uncertainties were managed using conservative assumptions in the emission estimation, including:

- Maximum handling and operating capacities were used in determining emission rates.
- All equipment on-site was assumed to operate concurrently.

- With respect to the GHG emissions and production levels used to calculate emission intensity factors, the information was derived either from the Federal and Provincial GHG reporting websites or from recent environmental assessments.

### 6.9.3 Hydrogeology

Hydrogeological modelling was completed to estimate the groundwater flow pathways from the ECM and the rates of groundwater flow from the SSA to downstream receptors. To achieve this objective, a deterministic approach was used where a 3D numerical (MODFLOW) groundwater model was constructed and calibrated to represent the “best estimate” of groundwater flow conditions based on the conceptual model described above. The model was calibrated through an iterative process where steady-state model runs were completed with adjustments to the model input parameters (within acceptable ranges), until model results provided an acceptable match to observed conditions (groundwater elevations, groundwater flow directions, baseflow estimates, and advective flow paths from the Reactor Pit 2 source area). Additional simulations were completed to address the uncertainty associated with the “best estimate” configuration and to examine the sensitivity of model results to some of the key controlling parameters of the hydrogeological system and assumptions made in the development of the conceptual model. A total of ten sensitivity scenarios were evaluated, which addressed potential variation in the hydraulic conductivity of the bedrock and sand units, the recharge distribution, the position of the model boundaries, and various aspects of the ECM design (e.g., the liner, blast zone, cover evapotranspiration and exfiltration gallery flow).

Contaminants released to groundwater are transported uniquely based on their chemical form and specific hydrogeological characteristics. A key parameter influencing the mobility of contaminants in groundwater is the water-soil distribution coefficient. The PostSA includes a sensitivity analysis case that tests the uncertainty of the distribution coefficient on groundwater transport predictions.

### 6.9.4 Hydrology

The surface water run-off was modelled using Visual Otthymo 4.0 software for the 2 year through to 100 year rainfall events and the regional storm event for the area was also modelled along with the probable maximum precipitation. Visual Otthymo is a hydrologic management model that is capable of simulating run-off from single storm events. It is well suited to hydrologic studies of watersheds and sub-watersheds surface water designs and surface water management design. Rainfall intensity data inputted into the model was sourced from the Town of Arnprior, as the storm data were more recent than that available from Environment Canada for the area. This rainfall distribution is a synthetic distribution and presents a heavy front-loaded storm with reduced infiltration leading to higher run-offs than may be seen with intensities more evenly distributed throughout the storm. This results in conservative model outputs with the resultant surface water management systems capable of handling larger storm events than those modelled.

### 6.9.5 Surface Water Quality

The following conservatisms were identified for the assessment of surface water quality:

- For the majority of the COPCs in the assessment, the maximum projected wastewater concentration was lower than the effluent discharge target.
  - For a subset of the COPCs (i.e., aluminum, cobalt, iron, manganese, nitrate, nitrite, sulphate, and cobalt-60), the maximum projected wastewater concentration was higher than the treated effluent

discharge trigger (e.g., aluminum: wastewater concentration = 150 µg/L; treated effluent discharge trigger = 50 µg/L).

- In each discharge scenario, the water quality model was run without decay or sorption mechanisms, whereas in actuality concentrations may be subject to chemical, physical, radioactive decay, and biological processes that can remove them from the mass balance as they progress downstream.
- Background concentrations obtained from previous reports were typically presented as averages from 2010 to 2018, which include data measured below detection. For data measured below detection, the detection level was used in the averaging calculation; the true existing baseline concentrations may not have been as high as used. Nonetheless, these as-stated averages used in the model are considered a conservative estimate of the existing baseline concentrations.

### 6.9.6 Terrestrial Environment

The predicted residual effects are based on scientific inference and logical reasoning, which are associated with uncertainty. Consequently, a description of the level of confidence that can be assigned to the residual effect analysis was presented for each terrestrial biodiversity valued component.

Primary factors affecting confidence in the predictions made in the terrestrial biodiversity assessment include:

- Availability and accuracy of baseline data.
- Efficacy of mitigation applied at CNL.
- Accuracy of vegetation spatial data and inferences on habitat associations.
- Level of understanding of the strength of primary pathways (i.e., mechanisms), in terms of the effects they are likely to have on each valued component.
- Level of certainty associated with the effectiveness of proposed mitigation specific to the NSDF Project, where applicable.
- Level of understanding of the cumulative drivers of change in measurement indicators and associated effects on assessment endpoints.

Uncertainty in the assessment was managed by:

- Reviewing historical and current data and relevant studies conducted in the study areas.
- Conducting desktop studies to understand potential interactions between the proposed NSDF Project and terrestrial biodiversity, and supplementing with local and regional data to the extent possible.
- Comparing assessment results with relevant published literature to make inferences about ecological interactions and mechanisms of change.

Remaining uncertainty was primarily addressed by making assumptions that overestimated rather than underestimated potential effects of the NSDF Project. This approach meant that when uncertainty was identified, the assessment was likely to overestimate predicted residual effects. For example, EMR is an existing road that will be used as the main access road for the NSDF Project. The north and south ends of EMR require upgrading, but no or little additional clearing to widen and have sufficient clearance for operational needs is needed. East Mattawa Road was not mapped as “unclassified” in the modelling dataset; it was considered to be part of the forested polygon. Consequently, the amount of physical disturbance to vegetation communities from the NSDF Project was overestimated in these areas, providing a precautionary assessment.

### 6.9.7 Ambient Radioactivity and Ecological Health

Table 6-9 describes key uncertainties in assessing residual effects from the NSDF Project on ecological health and how conservatism in the analysis and assumptions addressed these uncertainties.

**Table 6-9 - Uncertainties in the Ambient Radioactivity and Ecological Health Assessment**

| Parameter               | Uncertainty                                                                                                                                                                                                                 | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|-------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Waste inventory         | There is uncertainty with regard to the inventory of radionuclides that have been accumulated over the decades of operation of CRL site, as well as the projected inventory of wastes that will be generated in the future. | <ul style="list-style-type: none"> <li>Both already accumulated wastes and those that will be generated in the future will have to meet NSDF WAC.</li> <li>The PostSA explores the effect of uncertainty in the inventory, in the "Inventory Sensitivity" Sensitivity Analysis Case.</li> </ul>                                                                                                                                                                                                      |
| Source term             | There is uncertainty associated with airborne and waterborne release rates.                                                                                                                                                 | <ul style="list-style-type: none"> <li>Waterborne releases from the WWTP are assumed to contain contaminants at maximum permissible concentrations.</li> </ul>                                                                                                                                                                                                                                                                                                                                       |
| ECM performance         | There is uncertainty with regard to when protective barriers may begin to fail due to erosion or other natural events.                                                                                                      | <ul style="list-style-type: none"> <li>The ECM includes multiple protective barriers in the cover and base liner, designed to isolate the waste even in the event if one or more of the barriers were to fail.</li> <li>The ECM can be maintained and monitored during the period of institutional control. Any issues identified during this period can be mitigated.</li> <li>The PostSA considers two conservative scenarios involving premature failures of the cover and base liner.</li> </ul> |
| Waste package integrity | The current and future integrity of waste packaging is uncertain. Package failure leads to increased leachate concentrations.                                                                                               | <ul style="list-style-type: none"> <li>For pre-closure design and safety considerations, "Normal" packaged waste is assumed to have an initial failure of 5% upon placement. It is then assumed to fail at a rate of 1% per year.</li> <li>For post-closure, no credit is given for waste packages or containers. It is assumed that all waste packages have degraded and provide no barrier to the release of contaminants.</li> </ul>                                                              |

| Parameter              | Uncertainty                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |
|------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Wastewater quantity    | The wastewater volumes used in the <i>Leachate and Wastewater Characterization</i> [6-33] report are developed for the purpose of determining the long-term average wastewater volumes that are used to establish the flow-rate design capacity of the WWTP. Extreme precipitation events are not considered, as their effects are mitigated by the temporary storage capacity provided by the three Equalization Tanks.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <ul style="list-style-type: none"> <li>The pressure boundary failure analysis conservatively assumes that failure occurs when membrane filter feed and process tanks are full. The calculation is, therefore, not affected by changes in wastewater quantity.</li> <li>The WWTP seismic event analysis conservatively assumes that failure occurs when all three Equalization Tanks are full (5.6E+06 L).</li> </ul>                                                                                                                                                                                                                                                                                                                  |
| Leachate concentration | Uncertainties in the wastewater concentrations include the effects of uncertainties in the contaminant concentrations in the waste, the waste density, moisture content and the distribution coefficients. Contaminant concentrations in waste are defined by the <i>Waste Characterization</i> [6-8] report, which defines the inventories and is consistent with the PostSA inventory. The waste density and moisture content play minor roles in the uncertainty of the wastewater concentrations. Both are confined to relatively small ranges. The average waste density is assumed to be 1.5 g/cm <sup>3</sup> but may vary locally in the disposal cell, by perhaps ±20%, from this nominal value. The waste moisture content (0.2181, volumetric basis), is from the Hydrological Evaluation of Landfill Performance model discussed in the <i>Leachate and Wastewater Characterization</i> [6-33] report. Moisture content may also vary by ±20% from this value during wet and dry periods of the year. The distribution coefficients, taken from Canadian Standards Association N288.1-14 Table G-2 (CSA Group 2014), may also vary, but alternative values have not been evaluated. | <ul style="list-style-type: none"> <li>A soil to liquid partition model was used to determine leachate concentrations. Average K<sub>d</sub> (water-soil distribution coefficient) values for soil (loam) and a waste density of 1.5 g/cm<sup>3</sup> were assumed to apply homogeneously to the waste matrix. Compaction procedures and waste processing to minimize void space will ensure that this approximate waste density is maintained.</li> <li>During normal operations, higher leachate concentrations would have no effect on the public or environment since wastewater is treated at the WWTP. It would increase contaminant concentrations in the WWTP slightly, but the effect on safety would be minimal.</li> </ul> |

| Parameter                         | Uncertainty                                                                                                                                                                                                                                                                                                                   | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Environmental transport           | Contaminants released to the environment, primarily groundwater and surface water, are transported uniquely, based on their chemical form and specific hydrogeological and hydrological characteristics near the SSA. Some of these characteristics are known from nearby WMAs and recent modelling, albeit with uncertainty. | <ul style="list-style-type: none"> <li>For the scenario involving waterborne exposure to members of the public, a transit time from the ECM to Perch Creek is not credited. This is conservative given that the groundwater transit time from modelling analysis is expected to be seven years, which would be applicable to tritium, but conservative for all other radionuclides. No removal of contaminants from groundwater through sedimentation or other processes is assumed.</li> <li>The PostSA includes a sensitivity analysis case where groundwater transit time to Perch Creek is reduced to five years (from seven years in the NES).</li> </ul>           |
| Conceptual model                  | This uncertainty is associated with conceptual model for groundwater flow and potential future effects on it resulting from the climate change.                                                                                                                                                                               | <ul style="list-style-type: none"> <li>Current groundwater flow and contaminant transport in Perch Lake area are well understood due to decades of data available for the site.</li> <li>Groundwater flow model was calibrated against the available datasets based on the existing plumes emanating from WMA and LDA.</li> <li>The PostSA includes a sensitivity analysis case where groundwater transit time to Perch Creek is reduced to five years (from seven years in the Normal Evolution Scenario).</li> <li>Characterization of the site includes 25 test pits, 70 boreholes and 47 monitoring wells, among other monitoring and testing activities.</li> </ul> |
| Leaching and transport parameters | Parameter uncertainty may lead to underestimation of doses to members of the public and non-human biota                                                                                                                                                                                                                       | <ul style="list-style-type: none"> <li>The site characteristics are well understood owing to many decades of monitoring. In any case, conservative and bounding assumptions were used as described above.</li> <li>To test the effect of uncertainty in sorption rates, the PostSA includes a sensitivity analysis case that tests the uncertainty of the parameter <math>K_d</math> (water-soil distribution coefficient).</li> </ul>                                                                                                                                                                                                                                   |



| Parameter                              | Uncertainty                                                                                                                                              | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|----------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Future conditions                      | Due to the timeframe of the PostSA, there is some uncertainty with respect to future conditions at the site, for example, seismicity and climate change. | <ul style="list-style-type: none"> <li>As part of the NES, the climate is assumed to evolve according to the current scientific interpretation of anthropogenic climate change. Additionally, the PostSA examines the potential for a reduced amount of hydrologically effective rainfall, due to an increase in evapotranspiration.</li> <li>Although seismic activity is not expected to affect the safety function of the cover, liner, or berm, the PostSA considers the potential for a beyond design-basis earthquake to affect the safety function of these structures, in a number of the PostSA Disruptive Event Scenarios.</li> <li>In the NES, the PostSA assumes that erosion is balanced by other processes such as deposition. However, the PostSA also examines a case with more severe erosion, e.g., caused by wetter climate, or seismic damage.</li> </ul> |
| Performance of the facility            | This uncertainty is related to the degradation of various components of the Facility ECM, such as the cover, liner and berm.                             | <ul style="list-style-type: none"> <li>The PostSA includes Disruptive Event Scenarios that examine the effect of accelerated degradation of the cover and liner.</li> <li>Additionally, the PostSA explores the importance of both the cover and liner using two scenarios that assume either the cover or the liner is absent at the time of closure. A third scenario is also included to assess the importance of the berm.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Assessment of doses to non-human biota | There is uncertainty in the modelling parameters for atmospheric and waterborne exposure pathways.                                                       | <ul style="list-style-type: none"> <li>Conservative exposure parameters were used, consistent with the quantitative risk assessment methods described in CSA N288.6.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

| Parameter                                                          | Uncertainty                                                                      | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|--------------------------------------------------------------------|----------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Assessment of radiological risks to populations of non-human biota | There is uncertainty in the dose acceptance criteria used for non-human biota.   | <ul style="list-style-type: none"> <li>While there is a variation of dose benchmarks in various jurisdictions, care should be taken in ensuring that they are fit for use.</li> <li>In particular, a screening level of 10 <math>\mu\text{Gy/hr}</math> should be considered as "below concern" based on generic screening calculations. If this level is exceeded, then a more detailed evaluation is required above such levels (Anderson et al. 2009). As such, this is a minimum level, which is not meant to be a limiting criterion.</li> <li>Benchmarks selected for this assessment are consistent with CSA N288.6. They are appropriate for the site-specific quantitative ecological risk assessment conducted for the NSDF.</li> </ul>                                                                                                                                                                                                                                                                                                                             |
| Modelling tool uncertainty                                         | There is uncertainty associated with conceptual models built within AMBER codes. | <ul style="list-style-type: none"> <li>The assessment of long-term safety of the NSDF in the PostSA was undertaken in accordance with REGDOC-2.11.1, Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management which states:<br/>           "Due to the uncertainty of predictions made far into the future, the reliability of quantitative predictions diminishes with increasing timescale. The demonstration of safety will rely less on quantitative predictions and more on qualitative arguments as the timescale increases. Long-term quantitative predictions should therefore, not be considered as guaranteed impacts, but rather as safety indicators."</li> <li>It also states that:<br/>           "uncertainties in the modelling should be addressed by conservatism built into 1. The assessment model; 2. the scenario design; and 3. parameter choice."</li> <li>As documented within this table, modelling uncertainty is addressed with conservatism built into the model, scenario design and parameters.</li> </ul> |

| Parameter                    | Uncertainty                                                                                                                                                                                         | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                         |
|------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Cumulative effect            | There is uncertainty associated with the cumulative effect during post-closure, taking into account releases from WMAs and LDAs in the Perch Creek basin.                                           | <ul style="list-style-type: none"> <li>• CNL is developing an appropriate environmental remediation concept for contaminated areas. The decision-making process is based on radiological effects.</li> <li>• It is expected that, if there is any potential to have cumulative effects exceeding safety objectives, then contaminated land from WMAs and LDAs will be removed prior to the NSDF closure.</li> </ul>                                                  |
| Receptor occupancy           | There is uncertainty in receptor occupancy at the site (e.g., how long would a migratory bird be on the site?).                                                                                     | <ul style="list-style-type: none"> <li>• The EcoRA [6-37], conservatively assumes that all mobile receptors spend all of their time in the location of maximum predicted concentrations.</li> </ul>                                                                                                                                                                                                                                                                  |
| Receptor characteristics     | There is uncertainty with respect to receptor characteristics (e.g., body weight, intake rates for food, soil, water).                                                                              | <ul style="list-style-type: none"> <li>• The EcoRA [6-37], addresses this indirectly, through the use of generally conservative assumptions (e.g., assuming that 100% of intake of the COPC is absorbed into the organism).</li> </ul>                                                                                                                                                                                                                               |
| Environmental concentrations | Concentrations in environmental media are modelled (i.e., information is not measured).                                                                                                             | <ul style="list-style-type: none"> <li>• The EcoRA [6-37] uses maximum concentrations (predicted in the PostSA). As a result, calculated exposures are likely to be conservatively overestimated.</li> </ul>                                                                                                                                                                                                                                                         |
| Contaminant migration        | Contaminant migration through environmental media and biota are either modelled or estimated using literature or food intake calculations (i.e., information is not measured and not site-specific) | <ul style="list-style-type: none"> <li>• There is uncertainty in the transfer of contaminants between environmental media, or from the environment to biota as transfer factors and data are not site specific; however, in the absence of measured data, this approach provides the only method for estimating concentrations and for estimating transfer up the food chain. Uncertainty can be addressed by selecting conservative transfer parameters.</li> </ul> |

| Parameter             | Uncertainty                                                                                                                                                                                                           | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|-----------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Effects assessment    | Toxicity reference values and benchmark values used in the EcoRA, are based on reputable sources; however, there is inherent uncertainty associated with the extrapolation of laboratory testing to field conditions. | <ul style="list-style-type: none"> <li>Despite being obtained from reputable sources, there is uncertainty associated with TRV from literature, because they were derived from laboratory conditions and species rather than a field environment.</li> <li>In the EcoRA [6-37], toxicity information for a COPC was used regardless of its form in the test procedure, even though this may not be the same form used in the assessment.</li> </ul>                      |
| Risk characterization | When dealing with multiple COPCs, there is the potential for multi-stressor effects (e.g., interaction between contaminants).                                                                                         | <ul style="list-style-type: none"> <li>When dealing with toxic chemicals, there is potential interaction with other chemicals that may be found at the same location. It is well established that synergism, potentiation, antagonism, or additivity of toxic effects occurs in the environment. These potential interactions were not investigated as part of the EcoRA [6-37], which may result in an underestimate of the risk for some COPC combinations.</li> </ul> |

### 6.9.8 Human Health

Table 6-10 describes key uncertainties in assessing residual effects from the NSDF Project on human health and how conservatism in the analysis and assumptions addressed these uncertainties.

**Table 6-10**  
**Uncertainties in the Human Health Assessment**

| Parameter                      | Uncertainty                                                                                                                                                                                                                  | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                       |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Waste Inventory (radiological) | There is uncertainty with regards to the inventory of radionuclides that have been accumulated over the decades of operation of CRL site, as well as the projected inventory of wastes that will be generated in the future. | <ul style="list-style-type: none"> <li>Both already accumulated wastes and those that will be generated in the future will have to meet NSDF WAC [6-7].</li> <li>The effect of uncertainty in the radiological inventory is explored in 'Sensitivity Analysis Case - Inventory Sensitivity' for the post-closure phase.</li> </ul> |

| Parameter                          | Uncertainty                                                                                                                                                                                                                                                                                     | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Waste Inventory (non-radiological) | There is uncertainty with regards to the inventory of hazardous wastes (i.e., non-radionuclides) that have been accumulated over the decades of operation of the CRL site, as well as the project inventory of hazardous wastes (i.e., non-radionuclides) that will be generated in the future. | <ul style="list-style-type: none"> <li>Both already accumulated wastes and those that will be generated in the future will have to meet NSDF WAC [6-7].</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| ECM Performance                    | There is uncertainty with regards to when protective barriers may begin to fail due to erosion or other natural events.                                                                                                                                                                         | <ul style="list-style-type: none"> <li>The ECM includes multiple protective barriers in the cover and base liner, designed to isolate the waste even in the event if one or more of the barriers were to fail.</li> <li>The ECM can be maintained and monitored during the period of institutional control. Any issues identified during this period can be mitigated.</li> <li>The PostSA [6-6] considers two conservative scenarios involving premature failures of the cover and base liner.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Source term                        | There is uncertainty associated with airborne and waterborne release rates.                                                                                                                                                                                                                     | <ul style="list-style-type: none"> <li>Waterborne releases from the WWTP are assumed to contain contaminants at maximum permissible concentrations. This is a bounding assumption; in most cases concentrations will be a minor fraction of maximum permissible concentrations.</li> <li>Airborne releases from the ECM are based on empirical data for carbon-14 and tritium oxide and on a conservative model for radon-222.</li> <li>In the PostSA, water release from overtopping the berm is assumed to begin earlier than it would realistically be expected to occur, i.e., it does not account for the time required for the water level in the ECM to rise above the level of the berm.</li> <li>The generation rate of gases will heavily depend on the nature and quantity of organic and metal wastes, which are currently not well-defined for the ECM.</li> <li>Accumulation of radon-222 was calculated using an approach that typically overestimates the radon-222 concentrations found in buildings.</li> <li>Carbon-14-labelled gases are assumed to be released to the surface at the rate they are generated.</li> </ul> |

| Parameter                                                 | Uncertainty                                                                                                                                           | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |
|-----------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Human habits                                              | It is uncertain that future populations will maintain current habits, consumption rates, and that the location of population centers will not change. | <ul style="list-style-type: none"> <li>The PostSA (NES), makes conservative assumptions about future land use, using different human receptor groups, such as a resident/farmer household living on the ECM footprint, growing fruits and vegetables, and raising poultry and cattle.</li> <li>To investigate sensitivity to changes in future human habits and location of potential exposure groups, the PostSA considers scenarios involving borehole drilling, and a house with a basement on the ECM.</li> </ul>                                                                                                                                        |
| Conceptual model                                          | This uncertainty is associated with conceptual model for groundwater flow and potential future effects on it resulting from the climate change.       | <ul style="list-style-type: none"> <li>Current groundwater flow and contaminant transport in Perch Lake area are well understood due to decades of data available for the site.</li> <li>Groundwater flow model [6-35] was calibrated against the available datasets based on the existing plumes emanating from WMAs and LDAs.</li> <li>The PostSA includes a Sensitivity Analysis Case where groundwater transit time to Perch Creek is reduced to five years (from seven years in the NES).</li> <li>Characterization of the site includes 25 test pits, 70 boreholes, and 47 monitoring wells, among other monitoring and testing activities.</li> </ul> |
| Assessment of radiological doses to members of the public | There is uncertainty in modelling parameters used for the assessment of radiological dose to members of the public.                                   | <ul style="list-style-type: none"> <li>In the PostSA, assumptions for dispersion, consumption and intake rate parameters are mainly based on CSA N288.1 [6-83].</li> <li>Conservative values are chosen for occupancy and other human exposure factors in the PostSA.</li> <li>Estimated radiological doses represent a very minor fraction of the limit.</li> </ul>                                                                                                                                                                                                                                                                                         |
| Leaching and Transport parameters                         | Parameter uncertainty may lead to underestimation of radiological doses to members of the public and non-human biota.                                 | <ul style="list-style-type: none"> <li>The site characteristics are well understood, owing to many decades of monitoring.</li> <li>To test the effect of uncertainty in sorption rates, the PostSA includes a Sensitivity Analysis Case where a lower water-soil distribution coefficient (<math>K_d</math>) was assumed. A lower <math>K_d</math> would result in more rapid release and more rapid transport in groundwater.</li> </ul>                                                                                                                                                                                                                    |

| Parameter                    | Uncertainty                                                                                                                                             | Conservatism and Assumptions                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
|------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Effect of Environment on ECM | Performance of the ECM barriers could be impeded by natural events, such as floods, weathering, animal borrowing and fires destroying vegetative cover. | <ul style="list-style-type: none"> <li>To address uncertainty in the performance of the cover and liner during the post-closure phase, the PostSA examines the effect of accelerated degradation of these barriers (relative to their design life).</li> <li>Additionally, the PostSA explores the importance of both the cover and liner using two scenarios that assume either the cover or the liner is absent at the time of closure. A third scenario is also included to assess the importance of the berm.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |
| Modelling Tool uncertainty   | Uncertainty associated with conceptual models built within AMBER codes.                                                                                 | <ul style="list-style-type: none"> <li>The models used in the PostSA calculations (e.g., AMBER), have undergone model validation for the relevant pathways and exposure scenarios.</li> <li>The assessment of long-term safety of the NSDF in the PostSA was undertaken in accordance with Canadian Nuclear Safety Commission REGDOC-2.11.1, Volume III [6-84], which states:<br/><br/>           "Due to the uncertainty of predictions made far into the future, the reliability of quantitative predictions diminishes with increasing timescale. The demonstration of safety will rely less on quantitative predictions and more on qualitative arguments as the timescale increases. Long-term quantitative predictions should therefore, not be considered as guaranteed impacts, but rather as safety indicators."</li> <li>It also states that:<br/><br/>           "uncertainties in the modelling should be addressed by conservatism built into: 1. the assessment model; 2. the scenario design; and 3. parameter choice."</li> <li>As documented within this table, modelling uncertainty is addressed with conservatism built into the model, scenario design, and parameters.</li> </ul> |
| Cumulative Effect            | Uncertainty associated with the cumulative effect during post-closure, taking into account releases from WMAs and LDAs in the Perch Creek basin.        | <ul style="list-style-type: none"> <li>Canadian Nuclear Laboratories is developing an appropriate environmental remediation concept for contaminated areas. The decision-making process is based on radiological effects.</li> <li>It is expected that, if there is any potential to have cumulative effects exceeding safety objectives, then contaminated land from WMAs and LDAs will be removed prior to the NSDF closure.</li> </ul>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

## 6.10 Future Work to Manage Uncertainty

Future work to manage uncertainties includes:

- A geologic verification program will be implemented at the NSDF site during the construction phase. This program aims to reduce the uncertainty with respect to the current understanding of geological characteristics and features at the NSDF site, particularly the NSDF SSA, where these characteristics, and geological features have the most effect to the long-term performance of the Facility. During the construction phase, the upper bedrock and its geologic features will be exposed, thus providing direct access to conduct surface geological surveys. The geologic verification program will comprise of additional field and laboratory testing. The scope will assess the presence, orientation and characteristics of key geological features within NSDF SSA (e.g., Feature #7 and Feature #17). The field investigation will include activities such as: surficial geological survey, geological core logging, photographic and acoustic televiewer. The investigation will focus at the locations and depths where the key features will likely be observable. Further details about the on-going monitoring plan are described in Section 3.1.4.5.
- Perch Lake water quality under winter conditions will be monitored to confirm that the impacts on Perch Lake and East Swamp for the projected phosphorous loading are minimal.
- The groundwater quantity and quality will be part of the operational control monitoring for the NSDF. This will address the uncertainty regarding the expected water table levels under the ECM footprint and vicinity after blasting and uncertainties in the water table level fluctuations. A number of monitoring wells are available at the NSDF site (see Section 3.1 of the Safety Case). Additional monitoring wells may be required to perform this monitoring.
- Canadian Nuclear Laboratories will continue to improve knowledge of the waste inventory and near field sorption coefficients during the operation phase, since this is the most efficient way to reduce uncertainty in the dose calculations.
- The gas vents installed as part of the final cover system are assumed to be sealed before the end of institutional control. If this is not the case, there is a chance that the continued exchange of air between the atmosphere and the gas within the repository might lead to relatively oxidizing conditions in the unsaturated zone within the NSDF. This could have an impact on contaminant release rates; thus, this is a potential area of study for future iterations of the PostSA and Safety Case.
- Biochemical conditions are a source of uncertainty in the current environment and PostSA modeling and this uncertainty will be assessed in the future using monitoring results.
- Exact knowledge of the composition of each waste layer in the ECM could result in more refined PostSA models.
- The PostSA references the latest acceptable CSA and ICRP dose coefficients until new ones are accepted by the CSA and ICRP. Future iterations of the PostSA may be able to take credit for improved dose conversion factors and demonstrate that the expected radiological consequence (dose) is actually lower than originally calculated.
- Canadian Nuclear Laboratories will consider a research and development plan to study the performance of the NSDF engineered barrier system, taking into consideration the full lifecycle and information and data that CNL will need at the time of closure.



## 6.11 Conclusion

The uncertainties present in the NSDF safety assessments are primarily due to the long periods of time that are considered, i.e., up to 10 000 years for the PostSA. It is difficult to state, with confidence, that a particular event will or will not occur, or if a particular modelling input will remain accurate for 10 000 years.

The primary method of managing and addressing uncertainties in the PostSA is to identify the key modelling parameters that impact the radiological consequence (dose) assessment, and to perform sensitivity analysis on these parameters. With the NSDF, the key uncertainties in the PostSA modelling are:

- The actual emplaced radiological inventory at the time of closure.
- The duration of institutional controls.
- How quickly contaminants move through the groundwater and the environment.
- The degradation rate of the engineered barriers.
- The effect of climate change.

For the key uncertainties, Sensitivity Analyses were performed to determine the effect of each parameter on the final outcome. In all cases the results of Sensitivity Analysis remained below acceptance criteria.

For other uncertainties in the modelling, conservative assumptions are used to increase confidence that the assessment is bounding, and demonstrates pessimistic outcomes.

An important conservatism relates to the HDPE geomembrane service life. Although the comprehensive testing program concludes that the HDPE geomembrane (used once in the final cover and twice in the base liner) could perform for over 2000 years, the PostSA assumes that the geomembrane degrades significantly by the end of the specified design life of 550 years. The uncertainty in the barrier design life is addressed by making deliberately conservative modelling choices to achieve conservative radiological consequences (dose).

The discussion of natural analogues demonstrates that it is feasible for an earthen mound to remain fully covered and structurally sound for thousands of years. The natural analogue discussion also demonstrates that humans are able to recognize human-made structures, and do not necessarily demolish or mass-excavate them. Earthen mounds constructed thousands of years ago used only basic construction methodologies and natural materials. The NSDF will be constructed with modern engineering practices, with combinations of engineered and natural barriers. A modern facility is expected to last far longer than earthen mounds constructed thousands of years ago.

Canadian Nuclear Laboratories examined recently constructed facilities and gathered lessons learned and operating experience from them. Several design and optimizations were considered as a result of the benchmarking activities.

Canadian Nuclear Laboratories also used the international nuclear community to provide third-party review on key documentation, to help guide the development of the analyses, and to provide confidence that the analyses were using the best methods and available modelling techniques.

Moving forward, uncertainties will be managed by monitoring the Facility's performance during construction, closure, and post-closure periods. Observations, site investigations, and environmental sampling results will indicate if the Facility is performing as intended, and if the assumptions used in the modelling process are consistent with reality. Safety assessments may be updated to reflect current conditions and, if required, to further reduce uncertainty.

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## 7. LIMITS, CONTROLS AND CONDITIONS

The Limits, Controls and Conditions for the NSDF have been determined from the design documentation, safety analyses performed, in the operations SAR, PostSA and EcoRA, and the requirements of CNL's management system. The limiting conditions, including systems important to safety, are aimed at minimizing the exposure of personnel, the public and the environment to radiological and hazardous materials at all stages of the Project.

The limits, controls and conditions are a set of rules that set parameter limits, functional capability and performance levels of equipment and personnel for the safe construction, operation and closure of the NSDF. These include safety limits, safety system settings and limiting conditions for safe operational requirements during all phases of the NSDF Project. The post-closure activities are primarily related to inspection and monitoring of the NSDF ECM and physical security equipment needed to monitor the Facility during the ICP.

Near Surface Disposal Facility activities during construction, operations, closure, decommissioning and the ICP, shall be subject to CNL's management system and CNSC Regulations.

### 7.1 Construction and Commissioning

The NSDF CQA Plan [7-1], identifies the SSCs that require inspection and testing during construction to ensure the quality of the NSDF SSCs. The acceptance criteria for each construction inspection/test is documented in the NSDF CQA Plan [7-1], and will be documented in task specific procedures, inspection and test plans.

The construction of the ECM has inspection and testing requirements [7-2] and [7-1], to ensure the quality of the ECM SSCs. The ECM SSCs that require inspection and testing are CCL, HDPE, GMB, GCL, geogrid, geotextile, and the leachate collection and removal system [7-2].

The NSDF Commissioning Plan [7-2], establishes methods for ensuring accountability in addition to the preparation, review and approval and revision control of the components of NSDF commissioning. The pre-commissioning and commissioning activities will follow the documentation hierarchy in accordance with CNL's Commissioning Program [7-3] and [7-4].

The construction limits, controls and conditions for the NSDF Project are:

- Workers on the NSDF site, shall complete the CRL generic contractor orientation and awareness training and the NSDF Project specific environmental awareness training [7-5].
- Operations will be restricted or shut down during sustained wind speeds of 40 km/h as registered by the on-site wind gauge, or if visible dust plumes are observed on site [7-6].
- The posted speed limit for vehicles on haul roads is 20 km/h [7-6].
- Waste delivery vehicles and ECM construction vehicles shall be provided with on board fire suppression systems [7-7].
- Temporary silt fencing (e.g., sheeting, fencing, hay-bales), adjacent to wetlands, shall be installed prior to May 1 around the construction footprint in areas located in potential critical habitat to prevent the turtle's entry during construction. Inspection of silt fencing and turtle fencing shall be conducted periodically (e.g., weekly) and particularly after heavy rainfalls. No work using heavy equipment activities disturbing the

ground within the 30 m wetland setback is authorized during the turtle active season (between May 1 and September 30).

- The three SWMPs will be temporarily configured for construction. The flood control orifice will be smaller than the one required for normal operation to extend the retention time in the pond. The inlet elevation to the flood control inlet will also need to be increased using temporary sandbags to provide the necessary storage volumes and drawdown times. Once construction is completed, the temporary orifices and inlets will be replaced with the necessary structures required for normal operations.

## 7.2 Pre-Closure Phase

The OLCs in the NSDF SAR [7-8], have been derived following Preparation of OLCs [7-9]. An OLC provides the linkage between safety-significant parameters and associated operational parameters that must be adhered to, and adherence to OLCs ensures that the Safe Operating Envelope is maintained [7-9]. In addition, adherence to the OLCs will ensure that the Facility, the Facility Staff, other on-site personnel, members of the public (off-site), and the environment are not exposed to unacceptable levels of risk.

### 7.2.1 Safety Limits

The ECM radiological inventory at closure shall not exceed the specific radionuclide activity (Bq) limits in the Licensed Inventory at closure in Table 7-1 [7-8].

**Table 7-1**  
**NSDF Engineered Containment Mound Licensed Inventory at Closure [7-8]**

| Radionuclide  | Maximum Activity (Bq) at Closure |
|---------------|----------------------------------|
| Ag-108m       | 2.62E+10                         |
| Am-241        | 9.74E+10                         |
| Am-243        | 5.24E+07                         |
| C-14          | 1.70E+12                         |
| Cl-36         | 3.97E+09                         |
| Co-60         | 1.47E+16                         |
| Cs-135        | 5.19E+08                         |
| Cs-137        | 3.17E+12                         |
| H-3           | 2.79E+14                         |
| I-129         | 1.75E+10                         |
| Mo-93         | 1.47E+05                         |
| Nb-94         | 2.34E+10                         |
| Ni-59         | 1.21E+09                         |
| Ni-63         | 2.59E+11                         |
| Np-237        | 1.74E+07                         |
| Pu-239/Pu-240 | 5.06E+10                         |
| Pu-241        | 5.84E+11                         |
| Pu-242        | 6.32E+07                         |
| Ra-226        | 3.61E+10                         |
| Se-79         | 9.26E+07                         |
| Sn-126        | 1.24E+08                         |
| Sr-90         | 3.35E+12                         |
| Tc-99         | 3.16E+11                         |



| Radionuclide | Maximum Activity (Bq) at Closure |
|--------------|----------------------------------|
| Th-230       | 5.30E+09                         |
| Th-232       | 2.70E+10                         |
| U-233        | 2.74E+08                         |
| U-234        | 6.88E+10                         |
| U-235        | 2.96E+09                         |
| U-238        | 7.57E+10                         |
| Zr-93        | 4.92E+11                         |

### 7.2.2 Criticality Safety Controls

The following OLCs are criticality limiting conditions for the safe operation of the NSDF [7-8] and [7-11]:

- Operations with Fissionable Materials shall be carried out such that the following Upper Subcritical Limits are not exceeded, under both normal and credible abnormal conditions.
  - 80% of the minimum critical mass, or
  - $k_{\text{eff}} + 2\sigma \leq k_c - |\Delta k_c| - |\Delta k_m|$   
 Where:  
 $k_c$  is the mean  $k_{\text{eff}}$ , which results from the calculation of benchmark criticality experiments. The difference between the experimentally measured value of  $k_{\text{eff}}$  and  $k_c$  is defined as bias.  
 $\Delta k_c$  is a margin for  $k_c$  bias and bias uncertainty.  
 The bias (or  $k_c$ ) and the  $\Delta k_c$  are the results of the validation process.  
 $\Delta k_m$  is the 50 mk administrative margin.
- All operations involving Fissionable Materials shall comply with the limits and restrictions defined in the Summary of Fissionable Materials, Limits and Restrictions Section of the NSDF Criticality Safety Document [7-11]. Table 7-2 shows the Special Fissionable Materials (SFMs) Mass Fraction limits for waste placements [7-11]. Table 7-3 shows the SFMs total inventory limits in the NSDF [7-11].

**Table 7-2**  
**Limits for Special Fissionable Materials in Waste Placement [7-11]**

| Radionuclide in Special Fissionable Materials <sup>(1)</sup> | Limit for Sum-of-Fractions Rule (mass fraction)     |
|--------------------------------------------------------------|-----------------------------------------------------|
| <sup>235</sup> U (enrichments above natural, 0.71 wt%)       | 0.35 g <sup>235</sup> U/kg waste <sup>(1)</sup>     |
| <sup>233</sup> U                                             | 0.3 g <sup>233</sup> U/kg waste <sup>(1)</sup>      |
| <sup>239</sup> Pu                                            | 0.14 g <sup>239</sup> Pu/kg waste <sup>(1)(2)</sup> |

Note 1: For combinations of SFM types, the sum-of-fractions rule shall be satisfied.

Note 2: <sup>240</sup>Pu and <sup>241</sup>Pu shall be counted as <sup>239</sup>Pu.

**Table 7-3**  
**Total Special Fissionable Materials Inventory Limits in the NSDF ECM [7-11]**

| Special Fissionable Materials Type | Total Special Fissionable Materials Inventory Limit <sup>(1)</sup> (g) |
|------------------------------------|------------------------------------------------------------------------|
| <sup>235</sup> U <sup>(2)</sup>    | 3.70x10 <sup>4</sup>                                                   |
| <sup>233</sup> U                   | 0.75                                                                   |
| <sup>239</sup> Pu <sup>(3)</sup>   | 22                                                                     |

Note 1: Equivalent mass limits calculated from activity values listed in Table 13 of the NSDF Waste Acceptance Criteria [7-12]

Note 2: Includes the activities of depleted and natural uranium.

Note 3: <sup>240</sup>Pu and <sup>241</sup>Pu shall be counted as <sup>239</sup>Pu.

### 7.2.3 Limiting Conditions for Safe Operation

The general limiting conditions for the safe operation of the NSDF Facilities are:

1. The NSDF perimeter fence and posted warning signs, shall be maintained with the gates locked when unattended, to resist intrusion by unauthorized personnel [7-8].
2. The disposal of waste and waste operations, shall be such that the dose rate at the NSDF perimeter fence shall not exceed 10 µSv/h, and the dose at Plant Road shall not exceed 0.5 µSv/h [7-8].
3. The Facility is operated primarily on Class IV Power. Should a loss of Class IV Power occur, all waste handling activities that require electrically-operated systems important to safety, shall be halted until Class IV Power has been restored [7-8].
4. Actuation of fixed radiation alarms and any other related alarms shall be investigated and actions taken as per established procedures prior to allowing related operations to proceed. Operations shall be allowed to proceed only when the cause(s) are known and appropriate corrective actions have been taken. If causes cannot be determined, or corrective actions cannot be completed promptly, normal operations shall not resume without authorization of the Facility Authority, after having determined that the resumption of normal operations will have no adverse effect on safety, radiological risk, the environment, or security. The authorization of the Facility Authority shall be documented [7-8].
5. The dose rate limits and the means of handling and transferring that shall be applied to the bulk and packaged waste at the NSDF are presented in Table 7-4. [7-8].

**Table 7-4**  
**Dose Rate Limits and Means of Handling and Transferring**

| Radiation Type          | Dose Rates                                                                                         | Means of Handling and Transferring                                                                                                            |
|-------------------------|----------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| Total gamma and neutron | ≤0.5 mSv/h near contact <u>and</u> ≤0.01 mSv/h at a distance of 1 metre.                           | Manual or mechanical means.                                                                                                                   |
| Total gamma and neutron | >0.5 mSv/h to ≤2 mSv/h near contact <u>and</u> >0.01 mSv/h to ≤0.1 mSv/h at a distance of 1 metre. | Mechanical means.                                                                                                                             |
| Total gamma and neutron | >2 mSv/h near contact <u>or</u> >0.1 mSv/h at a distance of 1 metre.                               | Handling and transferring is subject to RP Program controls, Infrequently Performed Operations [7-31] and assessment approval by the NSDF FA. |
| Beta                    | <10 mSv/h near contact                                                                             | Based on total gamma and neutron dose rates.                                                                                                  |

### 7.2.3.1 Engineered Containment Mound

The limiting conditions for the safe operation of the NSDF ECM are:

1. Except as authorized by the Facility Authority on a case-by-case basis, only wastes meeting the current WAC as defined in Near Surface Disposal Facility WAC [7-12], may be placed in the ECM [7-8].
2. Acceptance of waste that is non-compliant with the requirements and limits of the current WAC as defined in the NSDF WAC [7-12], shall be authorized on a case by case basis by the Facility Authority, and shall not in any circumstances result in contravening the safety goals and design targets for normal operations or design targets for accidents as presented in Section 3 of the NSDF SAR [7-8]. The Facility Authority authorization of the acceptance of non-compliant waste and the analysis to support that authorization shall be documented. The acceptance of non-compliant waste shall be documented in the Annual Compliance Report [7-8].
3. All shipments of waste received shall be accompanied by a completed Radioactive Waste Data Sheet and supporting documentation as required [7-8].
4. All waste packages received shall have a Waste or Package Identification label/sticker attached to the package [7-8].
5. All waste shipping/transportation containers and waste packages received shall have a total maximum surface contamination on the outer surface, averaged over 300 cm<sup>2</sup>, and must be less than 3.7 Bq/cm<sup>2</sup> beta/gamma emitters and less than 0.37 Bq/cm<sup>2</sup> alpha emitters [7-8].
6. Only one cell shall be open for the placement and disposal of waste [7-8]. An adjacent cell may be open for supporting activities: TSWRPA and contact water management [7-8].
7. Maximum open cell area is 15 000 m<sup>2</sup> plus 6 000 m<sup>2</sup> (area of TSWRPA) [7-8].
8. The maximum volume of bulk and packaged waste stored in the TSWRPA shall be 800 m<sup>3</sup> and the maximum storage duration shall be one year. No uncontained waste is stored in the TSWRPA. All waste is either in its transportation container or disposal container, or covered with daily cover. The only processing that is performed is staging of waste or container preparation for grouting in the ECM [7-8].
9. Waste packages identified with greater than 10% void space shall be grouted [7-8].
10. Dewatered residuals generated by the WWTP shall be disposed of in the ECM [7-8].
11. The location of wastes placed in the disposal cell and characteristic information about the waste, shall be recorded [7-8].
12. Conditions to prevent and minimize contact water and leachate (for both placed waste and waste in temporary storage) include, but are not limited to [7-8]:
  - 1) Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face.
  - 2) Interim cover is applied to: a) waste disposal areas that will remain inactive for more than 30 days; and b) waste disposal areas that have reached the design waste fill grade. The interim cover is used to promote non-contact surface water run-off.

3) The surface of each waste lift is graded at a minimum 2% slope to promote run-off and minimize infiltration of surface water into the waste.

13. All Type 6 wastes shall be accepted through the Infrequently Performed Operations [7-31] process [7-8].
14. All disused sources being considered for disposal at NSDF shall be evaluated through the Infrequently Performed Operations [7-31] process [7-8].

### **7.2.3.2 Waste Water Treatment Plant**

The specific limiting conditions for the safe operation of the WWTP are:

1. The WWTP, Building 1551 active ventilation and exhaust ventilation systems shall be operational when the building is occupied [7-8]. Upon loss of active ventilation and or exhaust ventilation systems, normal operations in the associated rooms shall be suspended until the active ventilation and exhaust ventilation systems are returned to service and operating within design parameters [7-8].
2. Tank volume in the Equalization Tanks of 4710 m<sup>3</sup> shall be available for the DBA, back-to-back 100 year storm event or AOO precipitation events [7-8]. If this tank capacity cannot be maintained, the Facility shall develop a plan to restore capacity as soon as possible [7-8].
3. The effluent released shall meet the NSDF Effluent Discharge Targets [7-13]. Table 7-5 and Table 7-6, provide the effluent discharge targets for radionuclides and non-radiological constituents, respectively [7-13].
4. Filter press enclosure ventilation shall be 20 air changes per hour when occupied [7-8].
5. Valves V-019, V-020, V-057, and V-058 on the bypass line are normally closed and shall be locked closed [7-8]. The valves can be unlocked with Facility Manager or Facility Authority approval [7-8].
6. The WWTP shall only process wastewater generated by the NSDF [7-8].
7. The Hydrogen Sulphide monitors and alarms shall be functional when the sulphuric acid lockable valve is unlocked and sodium sulphide is valved in [7-8].
8. In the event the WWTP was to experience a prolonged outage of greater than 30 days, placements of waste in the ECM would be halted and an interim cover would be installed over the open waste surfaces [7-8].
9. The WWTP workers shall confirm active ventilation and exhaust ventilation systems are functioning before commencing the transfer of GAC into the IX vessel [7-8].
10. The tritium activity concentration in the wastewater entering the WWTP for processing shall meet the tritium effluent discharge target of 2.3E+05 Bq/L [7-8].

**Table 7-5**  
**Effluent Discharge Targets for Radionuclides [7-13]**

| <b>Radionuclide</b> | <b>Discharge Target (Bq/L)</b> |
|---------------------|--------------------------------|
| Ag-108m             | 60                             |
| Am-241              | 0.7                            |
| Am-243              | 0.7                            |
| C-14                | 200                            |
| Cl-36               | 100                            |

|                              |                 |
|------------------------------|-----------------|
| Co-60                        | 40              |
| Cs-135                       | 70              |
| Cs-137                       | 10              |
| H-3                          | 360 000         |
| I-129                        | 1               |
| Mo-93                        | 40              |
| Nb-94                        | 80              |
| Ni-59                        | 2 000           |
| Ni-63                        | 900             |
| Np-237                       | 1               |
| Pu-239                       | 0.6             |
| Pu-241                       | 30              |
| Pu-242                       | 0.6             |
| Ra-226                       | 0.5             |
| Se-79                        | 50              |
| Sn-126                       | 30              |
| Sr-90                        | 5               |
| Tc-99                        | 200             |
| Th-230                       | 0.7             |
| Th-232                       | 0.6             |
| U-233                        | 3               |
| U-234                        | 3               |
| U-235                        | 3               |
| U-238                        | 3 <sup>a</sup>  |
| Zr-93                        | 100             |
| Gross alpha                  | 0.2             |
| Gross beta (based on Sr-90)  | 5               |
| Gross gamma (based on Co-60) | 40 <sup>b</sup> |

<sup>a</sup> The U-238 limit is for drinking water protection from radiological effects; a more restrictive limit of 0.06 Bq/L (5 µg/L) is required for protection of aquatic life from chemical toxicity of uranium.

<sup>b</sup> The gross gamma limit applies to any gamma-emitting radionuclide not listed in Table 7-5.

**Table 7-6**  
**Effluent Discharge Targets for Non-Radiological Constituents [7-13]**

| Non-Radiological Constituent | Discharge Target (mg/L) <sup>a</sup> |
|------------------------------|--------------------------------------|
| 1,1,2,2-Tetrachloroethane    | 0.07                                 |
| 1,1,2-Trichloroethane        | 0.8                                  |
| 1,4-Dichlorobenzene          | 0.004                                |
| Acetone                      | 1.5                                  |
| Aluminum                     | <b>0.05</b>                          |
| Ammonia                      | 0.02                                 |
| Anthracene                   | 8.0E-07                              |
| Antimony                     | 0.02                                 |
| Arsenic                      | 0.005                                |
| Barium                       | <b>0.004</b>                         |
| Benzene                      | 0.1                                  |

|                                     |                          |
|-------------------------------------|--------------------------|
| Benzo(a)pyrene                      | 1.5E-05                  |
| Beryllium                           | 0.011                    |
| Bis(2-ethylhexyl) phthalate         | 6.0E-04                  |
| Boron                               | 0.2                      |
| Cadmium                             | <b>9.0E-05</b>           |
| Calcium                             | 116                      |
| Carbon tetrachloride                | 0.0133                   |
| Chloride                            | 120                      |
| Chlorobenzene                       | 0.0013                   |
| Chloroform                          | 0.0018                   |
| Chromium (III)                      | 0.0089                   |
| Chromium (VI)                       | 0.001                    |
| Chrysene                            | 1.0E-07                  |
| Cobalt                              | 9.0E-04                  |
| Copper                              | <b>0.002</b>             |
| Dioxin                              | 1.0E-08                  |
| Ethylene dibromide                  | 0.005                    |
| Fluoranthene                        | 8.0E-07                  |
| Fluorene                            | 2.0E-04                  |
| Fluoride (aqueous)                  | 0.12                     |
| Furan                               | 1.0E-08 <sup>b</sup>     |
| Iron                                | <b>0.3</b>               |
| Lead                                | <b>0.001</b>             |
| Magnesium                           | 82                       |
| Manganese                           | 0.12                     |
| Mercury (aqueous)                   | 2.6E-05                  |
| Methylene chloride                  | 0.0981                   |
| Molybdenum                          | 0.04                     |
| Nickel                              | 0.025                    |
| Nitrate                             | 13                       |
| Nitrite                             | 0.06 (as Nitrogen)       |
| Petroleum hydrocarbons, C6 - C10    | 0.15                     |
| Phenol                              | 0.004                    |
| Phenolic compounds, non-chlorinated | 0.004 <sup>c</sup>       |
| Phosphorus                          | <b>0.01</b> <sup>d</sup> |
| PCB                                 | 1.0E-06                  |
| Potassium                           | 53                       |
| Selenium                            | <b>0.001</b>             |
| Silver                              | <b>1.0E-04</b>           |
| Sodium                              | 680                      |
| Sulphate                            | 128                      |
| Tetrachloroethylene                 | 0.05                     |
| Thallium                            | 3.0E-04                  |
| Tin                                 | 0.073                    |
| Trichloroethylene                   | 0.02                     |
| Uranium                             | 0.005 <sup>e</sup>       |
| Vanadium                            | 0.006                    |

|                                |                |
|--------------------------------|----------------|
| Zinc                           | <b>0.007</b>   |
| pH, standard units             | <b>6.5 - 9</b> |
| CBOD5                          | 25             |
| COD                            | 125            |
| Dissolved oxygen, >15°C - 20°C | ≥6             |
| Dissolved oxygen, <15°C - 20°C | ≥9.5           |

<sup>a</sup> The **bolded** values indicate constituents where historic background concentrations in Perch Lake watershed exceed the discharge targets listed in this Table.

<sup>b</sup> The dioxin limit is used for furans because furans have similar, or slightly lower, toxicity than dioxins and the mechanism of toxicity is the same as dioxins, namely disruption of protein synthesis by binding to the aryl hydrocarbon receptor.

<sup>c</sup> Since no specific non-chlorinated phenols were identified in CNL's non-radioactive inventory, the limit for phenol is considered adequate to represent this class of compounds.

<sup>d</sup> The phosphorus discharge target is an investigation level triggering analysis on impacts if exceeded. An analysis has been completed indicating minimal impacts on Perch Lake and East Swamp for the projected phosphorus loading [7-14]. The results of the analysis will be verified by monitoring Perch Lake water quality under winter conditions [7-14].

<sup>e</sup> Uranium discharge target based on chemical toxicity to aquatic life.

### 7.2.3.3 Vehicle Decontamination Facility

The specific limiting condition for the safe operation of the VDF is:

1. The Carbon Monoxide monitor and alarm shall be functional when vehicles are present in the VDF [7-8].

### 7.2.3.4 Fire Prevention and Detection

The specific limiting conditions for the fire prevention and detection are [7-8]:

1. The installed fire detection systems shall be operational [7-8].
2. If any of the installed fire detection systems are unavailable, compensatory measures as proposed by the Fire Protection Program and approved by the Facility Manager shall be put in place [7-8]. Compensatory measures could include routine patrols of the area, use of a fire watch or provision of an alternate water supply depending on the nature of the unavailability [7-8].
3. Actuation of smoke/heat detectors shall be investigated promptly. Normal operations shall be allowed to proceed only when the cause(s) are known and corrective actions have been taken. If causes cannot be determined or corrective actions cannot be completed immediately, normal operations shall not resume without a formal risk review and authorization by the FA and Fire Protection Program Authority or Designate [7-8]. The authorization of the FA and Fire Protection Program Authority or Designate shall be documented [7-8].
4. Waste delivery vehicles and ECM heavy equipment used for waste placement and compaction shall be provided with on-board fire suppression systems [7-7]. To control the spread and severity of fire and minimize operator injury, the on board extinguishing systems shall be certified to FM Global FM 5970 standards [7-7].

### 7.2.4 Waste Inventory Controls

The NSDF Licensed Inventory at placement and closure is presented in Table 3-22 [7-8]. As discussed in Section 7.2.1, Table 7-1, the Licensed Inventory at closure is a safety limit for the safe operation of the NSDF [7-8]. Table 3-23 provides the list of key non-radiological COPC, and the lower and maximum estimated leachable quantities [7-15]. Table 3-24 provides the estimated quantity of metals disposed of in the NSDF at

closure [7-15]. Table 3-25 provides the estimated quantity of organic materials disposed of in the NSDF at closure [7-15]. The control for meeting the inventory for non-radiological contaminants is the TCLP results as compared to Schedule 4, Leachate Quality Criteria of Ontario Regulation 347, General – Waste Management [7-32].

The ECM waste inventory is recorded, monitored and evaluated during the operations phase to ensure that the waste inventory at placement and at closure does not exceed the Licensed Inventory in Table 3-22 and Table 7-1[7-8]. In addition the waste inventory is assessed to ensure that the non-radiological inventory meets the values in Table 3-23, Table 3-24, and Table 3-25.

### **7.2.5 Waste Placement Controls**

The following are waste placement controls to protect and maintain the base/sidewall liner system, LCS and final cover system:

- The initial waste layer in each cell will consist of an approximately 1 m thick select waste layer of homogenous Type 1 soil and soil-like waste that is free of large stones/boulders or other foreign materials, and relatively free draining (e.g., free of silts and clays). The select waste layer provides protection to the LCS and underlying composite base/sidewall liner components during subsequent waste placements. [7-16].
- The placement of the initial operational lift in the disposal cell is adjacent to the sidewalls to protect against shear failure in the sidewall liner system to provide buttressing for side-slope stability [7-16].
- The maximum pressure over the base liner system geosynthetic materials is 35 kpa [7-16]. Placement of select waste over the base liner system (geosynthetics) shall meet the 35 kpa requirement [7-16]. Low-ground-pressure equipment for construction, operations, and maintenance may be used until the initial 1 m select waste lift is in place to meet the 35 kpa pressure requirement over the geosynthetic materials [7-16].
- Placement of debris, large bulky items, or packaged waste is not permitted within approximately 10 m of the sidewall slopes or within 1 m of the LCS and final cover system [7-16].
- To prevent possible damage to the collection layer or other components of the composite base/sidewall liner, no equipment is permitted to operate directly on the surface of the LCS layer [7-16].
- The surface of the waste is graded at approximately 2% to provide surface water run-off and minimize infiltration of surface water into the waste [7-16].
- Waste packages placed in the ECM will have a maximum of 10% void space within the package to prevent collapse [7-16].



### **7.2.6 Dust Controls**

The following dust controls methods will be implemented during NSDF operations [7-6]:

- Limit the material/waste fall distance.
- Limit the size of the disposal cell working face.
- Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face.
- Dust suppression of the inactive surfaces of the ECM and surrounding support areas.
- Restrict or shut down operations during high wind conditions. Operations will be restricted or shut down during sustained wind speeds of 40 km/h as registered by the on-site wind gauge, or if visible dust plumes are observed on site.
- Restrict or limit vehicle access to the ECM and NSDF site.
- Water is applied to roads to minimize dust generation on NSDF haul roads and ECM access roads using a water truck or other method as needed.
- Water (or approved chemical agents), is applied to the stored waste to mitigate dust emissions. A tarp or fabric cover may be used or the material may be stored within a sheltered area to prevent dust generation.

### **7.2.7 Monitoring and Surveillance**

Monitoring and inspections shall be conducted as described in Section 9 of the NSDF SAR [7-8] and in conformance with approved procedures. Records from Inspection and Maintenance activities shall be maintained and findings/actions from these activities shall be formally tracked [7-8]. A summary of the key monitoring activities to be performed during the pre-closure phase are presented in Table 7-7, [7-8] and [7-17].

**Table 7-7**  
**Summary of Key Pre-closure Phase Monitoring Activities at the Near Surface Disposal Facility**

| <b>Monitoring Description</b>                                                                                                                 | <b>Operations (50 years)</b>                                                                                                                                                                                                                                                                        | <b>Closure (30 years)</b>                                                                                                                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Meteorological Data Collection*<br>Precipitation, Temperature, Evaporation, Transpiration, Wind Speed, Wind Direction, Atmospheric, Stability | Data acquired on a monthly basis to determine water balance                                                                                                                                                                                                                                         | Data acquired on an annual basis to track water balance and determine local changes to hydrogeologic and climatological processes.                                                                    |
| <b>Stability and Structural Performance Monitoring</b>                                                                                        |                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                       |
| Settlement/Subsidence Monitoring                                                                                                              | Settlement plates will be installed on top of the final cover as the cover is constructed. In addition, interim settlement plates will be installed on the backfill between the final lifts to observe settlement during operations.                                                                | Permanent settlement plates installed on top of the final cover will continue to be monitored annually for subsidence to the final cover system.                                                      |
| Vertical alignment monitoring                                                                                                                 | Interim monument pins will be installed at the top of the lifts. These will then be surveyed monthly to establish a baseline and monitor potential vertical displacement. Variations outside of acceptable limits will invoke remediation.                                                          | The vertical alignment monitoring will not be required once the disposal cells are closed. The monitoring pins will be abandoned in place and vertical alignment monitoring will cease after closure. |
| <b>Surface Surveillance/Visual Monitoring</b>                                                                                                 |                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                       |
| Visual Inspections                                                                                                                            | Visual Inspections will be performed semi-annually and after severe weather events to ensure haul roads, ditches, fence lines and other areas are clean, sound, and functional.                                                                                                                     | Visual inspections will continue on an annual basis and following severe weather events to ensure fence lines are clean and functional and erosion is minimized.                                      |
| Drainage/Diversion Channels                                                                                                                   | Particular attention will be focused on drainage channels and diversion ditches to ensure that stormwater flows away from the disposal cells, that outfalls are kept clean and free flowing, and that riprap and other corrective actions are added in evidence of scouring or erosion in channels. | Visual inspections will occur once every two years or following severe weather events.                                                                                                                |

| Monitoring Description     | Operations (50 years)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Closure (30 years)                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|----------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| General Visual Inspections | Visual inspections of the facilities will ensure that required routine maintenance is scheduled and performed. Maintenance will be conducted to remove deep-rooted vegetation from undesired areas, clean up litter and other debris on site, remove burrowing animals from the site, inspect fence lines, ensure proper operation of gates, and visually inspect monitoring points for proper operation. The LFG passive venting system will be inspected. Photographs of pertinent features will be documented. These will occur monthly. | Visual inspection of the disposal cells will be performed to ensure settlement/subsidence is not causing localized grade reversal or depressions in the final cover, litter is removed, burrowing animals are not present, and perimeter fence lines are intact and properly maintained. The LFG passive venting system will be inspected. A review of historic photographs of pertinent features or problems will be conducted to assist in the inspection. These will occur quarterly.                                                                     |
| Infiltration Monitoring    | Infiltration measurements will be conducted on completed cells with final cover to ensure that the cover is operating correctly. Infiltration monitoring will consist of neutron moisture probes being placed in the cover system to measure water content and suction pressures in the cover. In addition, meteorological data will be acquired on the cover surface to provide an estimate of the amount of water that could potentially infiltrate into the cover system.                                                                | Moisture probes will be removed or abandoned in place during closure of the Facility and infiltration will no longer be monitored if there is adequate confidence in the long-term infiltration rate. It is anticipated that over the 50 year period of operations adjustments to the cover will be made as required from the data collected during operations that will ensure the cover functions as required. Records of meteorological data will be reviewed on an annual basis to ensure that the cover is not overloaded in any post-operational year. |
| <b>Leachate Monitoring</b> |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| Leachate Collection Piping | Leachate collection sumps are constructed at the lowest elevation to ensure any leachate is collected at this point. During operations leachate will be collected from the cells and conveyed to the Equalization Tanks for treatment.                                                                                                                                                                                                                                                                                                      | The leachate collection piping will be monitored on a monthly basis to verify the proper performance of the cover system. When and if leachate is detected in the disposal unit, it will be analyzed for radionuclides and disposed of appropriately. If necessary, further investigation will be conducted to pinpoint the location of potential problems.                                                                                                                                                                                                  |

### 7.2.8 Administrative Requirements

The minimum staffing requirements during operating periods (e.g., scheduled working hours) in the NSDF are:

1. For licensed activities governed by approved procedures, work plans, etc., the staffing requirements are given in the appropriate procedure [7-8].

### 7.2.9 Environmental Controls

The NSDF design supports the CRL environmental management system, including an integrated environmental monitoring system that includes side-wide groundwater monitoring and that conforms to the CNSC regulatory document REGDOC-2.9.1 Environmental Protection Policies, Programs and Procedures [7-18], and the requirements set by CSA standards: N288.4-10, Environmental Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills [7-19], N288.5, Effluent Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills [7-20] and N288.7-15 Groundwater Protection Programs at Class 1 Nuclear Facilities [7-21].

The CNL Environmental Protection Program establishes sampling and monitoring of liquid discharges and gaseous effluents to the environment. Data is collected, monitored, and reported as required by the Environmental Protection Program. The management and monitoring of emissions and the environment at the NSDF follows company-wide requirements [7-22] for management and monitoring of emissions as well as project specific requirements [7-17] for monitoring and reporting including:

- Effluent monitoring of airborne radiological emissions.
- Effluent monitoring of radiological liquid emissions.
- Estimation of airborne non-radiological emissions.
- Effluent monitoring of non-radiological liquid emissions.
- Environmental monitoring of radiation levels in environmental media at the CRL site and surrounding communities.

The environmental controls to ensure protection of human health and the environment include:

- Tritium concentrations in Perch Creek are not to exceed 7 000 Bq/L, the Canadian Drinking Water Guideline for Tritium [7-13].
- Monitor Perch Lake water quality in the spring and fall for chlorophyll-*a*, for one year to determine the present trophic status and provide a baseline for the NSDF operation [7-14]. Chlorophyll-*a* provides an indication of whether the phosphorus loading is increasing phytoplankton or macrophyte biomass [7-14].
- Monitor, every five years, Perch Lake water quality for chlorophyll-*a*, and winter oxygen [7-14].
- Monitor, every three - five years, Perch Lake water quality for benthic community indices [7-14].
- Fugitive dust controls will be implemented for dusts generated from NSDF operation activities, including heavy equipment use, vehicle traffic, and waste placement in accordance with the Dust Management Plan [7-6].
- On a weekly basis, LFG readings are taken directly above the ECM surface in locations along the top of the perimeter slope, along the edge of the active waste disposal area, and above the active waste placement

working surface [7-23]. Measurements are compared against LFG assessment limits, consistent with Ontario Regulation 232/98 requirements [7-23].

### 7.3 Closure and Decommissioning

The closure phase includes the following activities:

- Installation of any remaining components of the final cover of the ECM.
- Decommissioning of infrastructure and support facilities.
- Remediation and grading of the NSDF Project site.
- Continued operation of the WWTP and discharge of treated effluent.
- On-going, long-term performance monitoring, surveillance and inspection activities.

The decommissioning strategy for the NSDF is documented in Preliminary Decommissioning Plan (PDP) [7-24]. Prior to the commencement of decommissioning, the work will be planned and documented in the Detailed Decommissioning Plan(s) and associated documents including work plans, decommissioning waste management plan, and licence applications. The NSDF will follow the licensing process to obtain a licence to decommission.

The NSDF infrastructure elements to be decommissioned include [7-24]:

1. **ECM:** The ECM final cover construction and landscaping will occur at closure of the ECM (cease in operations). The LCS is the only ECM component system to be decommissioned during the closure activities.
2. **WWTP and Equalization Tanks:** Decommissioning of the WWTP and Equalization Tanks will be performed after the leachate quantity no longer requires this Facility for treatment or the leachate is sent for treatment at an alternate Facility. The decision regarding when the WWTP is no longer required, will be based on leachate generation performance trend data following closure of the ECM, availability of other leachate management/treatment systems, capital costs, and life-cycle operation costs and maintenance costs associated with the alternatives. Decommissioning of the WWTP and Equalization Tanks will be performed after the ECM LCS is decommissioned.
3. **Support facilities and site infrastructure:** Support facilities and site infrastructure to be decommissioned include the VDF, weigh scale, Administration Office, OSC, entrance Kiosks, PWPS, FWPS, exfiltration gallery, contact water pump stations, power distribution building, fueling station, tie-ins to CNL site infrastructure, and septic systems including sewage lift station and leaching beds. Decommissioning of support facilities may be performed in a phased approach, based on structures no longer being required to support the closure activities.

#### 7.3.1 Planned End State

At the completion of decommissioning, final surveys of residual radioactive and hazardous materials shall be performed and documented to demonstrate that the final end state for remaining equipment, structures, and the site has been achieved in accordance with the criteria specified in the final decommissioning plan.

The land use designation for the NSDF Project site is as a waste disposal facility. Upon closure, controls will be in place to limit land usage, including recognition on the property title or deed to ensure the appropriate zoning restrictions and including buffer or attenuation zones.

As the enduring Federal entity, and owner of the assets and liabilities of CNL, AECL is committed to controlling and restricting the land use of the NSDF footprint for as long as necessary. While other areas of the CRL site may be re-used, the NSDF footprint will be restricted as a waste disposal Facility.

#### **7.4 Post-Closure Phase**

The post-closure phase is anticipated to contain two discrete periods: institutional control of about 300 years, and post-institutional control. During institutional control, monitoring and surveillance activities will verify the integrity of the disposal facility system, while environmental monitoring activities will verify that the predicted performance continues to demonstrate compliance with the EA predictions.

The NSDF Project will be maintained during the ICP to meet the following performance requirements [7-25]:

- Prevent unacceptable dispersal of radioactive materials through environmental pathways (e.g., protecting groundwater from leachate).
- Detect release of radioactivity early.
- Confirm the final cover system can withstand damage from degradation over the design life.
- Confirm the vegetated topsoil of final cover system does not erode at an unacceptable rate.
- Maintain the final cover at an appropriate slope to mitigate the effects of settlement and achieve positive drainage off the ECM surface to limit infiltration, erosion, sediment transport and maintain cover stability.
- Confirm that safety is provided by passive means (i.e., no active intervention necessary), during the post-closure phase.
- Execute applicable environmental requirements with regard to monitoring, and surface water management systems and drainage features.
- Provide records for facility closure and for regulatory review as required.

As the post-closure phase progresses, environmental sampling is expected to be reduced with the exception of the groundwater monitoring, which is required to provide data to support long-term safety and environmental effects evaluation. After Facility closure, the primary pathway for unintended radionuclide releases from the ECM to the environment would be through the groundwater pathway. The GWMP will be continued during the initial period after Facility closure, but may be gradually be reduced dependent on the radionuclide or chemical constituent migrations identified.

##### **7.4.1 Limiting Conditions and Controls**

The NSDF post-closure limiting conditions and controls during institutional control include:

- Only authorized personnel are permitted in the disposal facility footprint [7-25].
- The vegetated topsoil of final cover system shall not exceed an erosion rate of 5 tonnes/acre/year [7-25].
- Deep-rooted and woody vegetation including trees shall be prevented from growing on the cover [7-25].
- Accumulation of sediment in storm water pathways, including culverts, must be removed to ensure appropriate capacity and resist obstruction of flow [7-25].
- Identified areas of erosion on the final cover will be regraded and revegetated to design slopes [7-25].
- Physical inspection of all storm water features is required after a severe precipitation event, which is defined as exceeding 30 mm in 1 hour [7-25].

- If a flowing seep is found, CNL management must report the incident to AECL within 24 hours [7-25].

#### **7.4.2 Monitoring and Surveillance**

Monitoring and inspections shall be conducted as described in Section 9 of the NSDF SAR [7-8] and in conformance with approved procedures. Note that the NSDF SAR will be maintained during the post-closure phase.

A summary of major post-closure monitoring and surveillance activities to be performed during institutional control are presented in Table 7-8 [7-8].

**Table 7-8**  
**Summary of Major Institutional Control Monitoring Activities at the Near Surface Disposal Facility**

| <b>Monitoring Description</b>                                                                                                                 | <b>Institutional Control (300 years)</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                           |
|-----------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Meteorological Data Collection*<br>Precipitation, Temperature, Evaporation, Transpiration, Wind Speed, Wind Direction, Atmospheric, Stability | Data acquired on an annual basis to track water balance and determine local changes to hydrogeologic and climatological processes.                                                                                                                                                                                                                                                                                                                                                                 |
| Groundwater monitoring                                                                                                                        | Groundwater monitoring on a semi-annual basis (spring and fall).                                                                                                                                                                                                                                                                                                                                                                                                                                   |
| <b>Stability and Structural Performance Monitoring</b>                                                                                        |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Settlement/Subsidence Monitoring                                                                                                              | Permanent settlement plates installed on top of the final cover will continue to be monitored every two years.                                                                                                                                                                                                                                                                                                                                                                                     |
| Vertical alignment monitoring                                                                                                                 | Not required after closure.                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
| <b>Surface Surveillance/Visual Monitoring</b>                                                                                                 |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |
| Visual Inspections                                                                                                                            | Visual inspections will occur once every two years or following severe weather events and inspect surfaces for erosion.                                                                                                                                                                                                                                                                                                                                                                            |
| Drainage/Diversion Channels                                                                                                                   | Visual inspections will occur once every two years or following severe weather events.                                                                                                                                                                                                                                                                                                                                                                                                             |
| General Visual Inspections                                                                                                                    | Visual inspection of the final cover/disposal cells and perimeter berm will be performed to ensure settlement/subsidence is not causing grade reversal or depressions in the final cover, burrowing animals are not present, and perimeter fence are intact and properly maintained. The LFG passive venting system will be inspected.<br>The final cover is inspected for erosion, standing water on the surface, and abnormal vegetation conditions. These inspections will occur semi-annually. |
| Infiltration Monitoring                                                                                                                       | Records of meteorological parameters will be reviewed on an annual basis to ensure that the final cover is not overloaded in any post-operational year.                                                                                                                                                                                                                                                                                                                                            |
| <b>Leachate Monitoring</b>                                                                                                                    |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |

| Monitoring Description     | Institutional Control (300 years)                                                                                                                                                                                                                                                                                     |
|----------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Leachate Collection Piping | Continued quarterly monitoring of the leachate collection piping and system will ensure the Facility is functioning properly. The monitoring frequency may be reduced in subsequent years based on previous results. Inspection and monitoring of the LCS and LDS will be performed as long as leachate is generated. |

### 7.4.3 Institutional Controls

Institutional controls are anticipated to be required when transitioning from the end of the closure phase to the post-closure phase. Institutional controls are mechanisms designed to appropriately limit access to or uses of land and facilities, to protect cultural and natural resources, to maintain the physical security of facilities and to prevent or limit inadvertent human and environmental exposure to residual contaminants. Institutional controls include administrative and legal controls, and may include certain physical controls (e.g., fences and gates).

Institutional controls are important in helping to protect EBS by providing a means to ensure that the barriers remain effective, are not showing signs of degradation, and continue to limit the potential for being vandalized or damaged by outside elements (natural or human) in any way. The NSDF Project is designed to promote safety through passive means during post-closure but is complemented by active measures taken by CNL, such as maintenance, security and surveillance. The NSDF Project site physical security features including signage, markers, fencing and gate are controls against unauthorized access to the Facility. The perimeter fence (chain-link fence) will deter intruders and animals from site access. A control gate located on the north side of the NSDF Project site allows personnel access for required monitoring, surveillance and maintenance.

Institutional controls also include methods to preserve knowledge and to inform current and future generations of potential hazards and risks. Such administrative or legal controls help to reduce the potential for human exposure to contamination. The land use designation for the NSDF Project site is as a waste disposal facility. Upon closure, controls will be in place to limit land usage including recognition on the property title or deed to ensure the appropriate zoning restrictions and including buffer or attenuation zones. As the enduring Federal entity, and owner of the assets and liabilities of CNL, AECL is committed to controlling and restricting the land use of the NSDF footprint for as long as necessary. The term “as long as necessary” is meant to communicate that the enforcement of institutional control on the property is not intended to end, and will continue for as long as legally required by either federal or provincial regulations. While other areas of the CRL site may be re-used, the NSDF Project site will continue to be restricted as a waste disposal facility.

Institutional controls work by limiting land or resource use by providing information to modify or guide human behavior at the site. The above are preliminary recommendations of institutional controls for the NSDF Project, however, these will be reassessed at the time of final closure of NSDF Project and will be updated as necessary during, and at the end of the ICP. The institutional controls will address changes in jurisdiction of authority and changes in other requirements that may occur as they relate to final closure and post-closure care of the NSDF Project.

Within Canada examples of radioactive material under institutional control can be taken from the closure of decommissioned uranium mine and/or mill sites. The CNSC and the Province of Saskatchewan have recently



established an understanding regarding the transition from licensee-controlled lands to provincially-controlled lands in terms of institution controls [7-26].

In Saskatchewan, the licensee requesting transfer of sites from CNSC oversight to provincial oversight under Institutional Control Program must provide the province with sufficient funds to conduct long-term monitoring and maintenance and financial assurance to address unforeseen events [7-26]. A condition of acceptance by the province to transfer properties into the Institutional Control Program is that the site receive a release from any and all Government of Canada issued licences, including those issued by the CNSC pursuant to the Nuclear Safety and Control Act., thus reverting total custodial responsibility back to the provincial government.

While Saskatchewan is the only Canadian province or territorial jurisdiction with an established Institutional Control Program, it serves as an example of how a future Institutional Control Program for NSDF could be implemented on a government owned site. When NSDF approaches closure, a case-specific review of the applicable legislation and the arrangements would be put forward by CNL, as the licensee. Based on the results of that review, CNSC staff would recommend the appropriate regulatory approach for the Commission consideration.

## **7.5 Long-term Maintenance of Safety Assessments**

The NSDF Safety Assessments, Safety Case, SAR [7-8] and Post SA [7-27], will be periodically reviewed and updated (as required), approximately every five years, over the lifetime of the Facility.

The scoping review of the safety assessments will include [7-28]:

- Physical and configuration changes to the Facility including design changes and modifications.
- Modifications to the Facility processes and operations.
- Operating experience.
- Waste inventory.
- Environmental monitoring data.
- Organizational and administrative changes.
- Verification of assumptions (applicable to the PostSA and Safety Case).
- Changes to regulatory documentation.
- Changes to international guidance documentation.

At subsequent stages in the Facility's lifecycle, as-built information and operational data will be used, when found necessary, to refine the model of the disposal system for assessment purposes. As with the site model, the model of the disposal system will evolve to become more realistic, and less conservative, based on real data.

## **7.6 Long-term Maintenance of Records**

Storing and handling information is a controlled activity at CNL, and currently Information Management is responsible for ensuring information is usable and retained. Information Management maintains processes to ensure the authenticity and integrity of records to meet long-term information requirements. A specific type of information is identified as a document or record and it is stored and retained in the CNL Company Repository, under records management controls through its lifecycle in accordance with Records

Management [7-29]. Records are specific information created, received and maintained as evidence of business activities to meet legal obligations.

When a Class I nuclear facility is decommissioned, the following permanent records are required to be retained:

- Progress achieved in meeting the schedule for decommissioning.
- Implementation and results of decommissioning.
- How and where nuclear or hazardous waste is managed, stored, disposed of or transferred.
- The status of each worker's training, qualifications, and re-qualification including the results of all tests and examinations completed in accordance with the site license.

Records that are classed as permanent are required to be kept for 100 years after the expiry date of the license to abandon issued in respect of the Class I Nuclear Facility, or as specified by regulatory authorities, [7-29]. Once the license to abandon is received, then assigned retention is reviewed.

## 7.7 Staff Training

Training requirements will be determined as part of the NSDF Staffing and Training Plan, developed according to Program Description Document Training [7-30]. The primary function of the Training & Development Program, is to ensure that employees are adequately and efficiently trained to safely and competently perform their roles and responsibilities [7-30]. Canadian Nuclear Laboratories has developed a Systematic Approach to Training (SAT) process that provides a standardized approach to staff training and qualification and ensures that CNL is in compliance with conditions in the applicable license [7-30]. The purpose of the SAT process is to provide a structured, documented and auditable set of processes that, when implemented, will provide management with the assurance that personnel are trained, competent and qualified for the work they are assigned to do [7-30].

The total number of NSDF staff during operations is anticipated to be 55 to 65 persons. Specific training is required for all personnel to operate and maintain equipment within each NSDF Facility, which includes continuing training appropriate to their positions and qualifications. Facility-specific training is provided to support staff to enable them to perform assigned tasks effectively and safely. The Facility Manager is responsible for the development and implementation of the training program and for its effectiveness. Recruitment and training for the NSDF staff follows CNL procedures. Personnel, selected to operate the NSDF, are qualified when the training program has been successfully completed and the individuals have demonstrated the skills and ability to perform the job.

The training program focuses on three main areas for any Nuclear Facility and associated support staff:

- **Fundamentals** - To provide the theoretical knowledge required to understand technical concepts, the principles of equipment operation, and the policies and procedures for controlling nuclear materials at CNL.
- **Safety Training** - To provide the knowledge and skills in the areas of RP and industrial safety as appropriate to the hazards and conditions that are encountered in a specific job position.
- **Facility Specific** - To provide familiarization with NSDF operation policies and procedures, the systems important to safety, criticality and emergency procedures, and the knowledge and skills required to operate the NSDF Facility.

## 7.8 References

- [7-1] AECOM, *Construction Quality Assurance Plan*, 232-508244-QAP-001, Revision 2, 2019 September.
- [7-2] AECOM, *Commissioning Plan*, 232-505250-PLA-001, Revision 1, 2018 December.
- [7-3] *Commissioning*, 900-505250-PDD-001, Revision 1, 2019 January.
- [7-4] *Commissioning*, 900-505250-PRD-001, Revision 0, 2017 March.
- [7-5] AECOM, *NSDF Environmental Protection Plan*, 232-509200-PLA-001, Revision 1, 2018 November.
- [7-6] AECOM, *Dust Management Plan*, 232-03700-PLA-001, Revision 1, 2018 August.
- [7-7] AECOM, *Fire Hazard Analysis (FHA)*, 232-503230-FHA-001, Revision 2, 2019 March.
- [7-8] NSDF Safety Analysis Report, 232-508770-SAR-002, Revision 2, 2020 October.
- [7-9] *Preparation of Operational Limits and Conditions*, 900-508770-FID-003, Revision 0, 2018 October.
- [7-10] NSDF *Reference Inventory Report*, 232-508600-REPT-003, Revision 2, 2019 September.
- [7-11] Calian, *Criticality Safety Document*, 232-203230-CSD-001, Revision 7, 2020 August.
- [7-12] Near Surface Disposal Facility Waste Acceptance Criteria, 232-508600-WAC-003, Revision 2, 2020 September.
- [7-13] *Near Surface Disposal Facility Effluent Discharge Targets*, 232-106499-REPT-002, Revision 0, 2019 October.
- [7-14] Increased Loading of Phosphorus to Perch Lake from NSDF Operations, 153-121221-021-000-0006, ESB-18-024, 2018 November 12.
- [7-15] *Near Surface Disposal Facility (NSDF) Non-Radiological Inventory of Constituents of Potential Concern (COPC)*, 232-508600-TN-007, Revision 3, 2019 August.
- [7-16] AECOM, *Waste Placement and Compaction Plan*, B1550-508600-PLA-001, Revision 2, 2019 October.
- [7-17] AECOM, *Monitoring and Reporting Plan*, 232-508220-PLA-002, Revision 0, 2017 May.
- [7-18] CNSC, Environmental Protection: *Environmental Principles Assessments and Protection Measures*, REGDOC-2.9.1, 2017.
- [7-19] CSA, CSA N288.4-10, *Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills*, 2<sup>nd</sup> Edition, 2015.
- [7-20] CSA, CSA N288.5, *Effluent Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills*, 2011 January.
- [7-21] CSA, CSA N288.7-15, *Groundwater Protection Programs at Class I Nuclear Facilities and Uranium Mines and Mills*, 1<sup>st</sup> Edition, 2015.
- [7-22] *Environmental Protection*, 900-509200-PRD-001, Revision 2, 2018 May.
- [7-23] AECOM, *Landfill Gas Management Plan*, 232-508600-PLA-003, Revision 1, 2018 August.
- [7-24] AECOM, *Preliminary Decommissioning Plan*, 232-508300-PLA-001, Revision 1, 2018 September.
- [7-25] AECOM, *Post-Closure Care Plan*, 232-508220-PLA-004, Revision 0, 2017 April.
- [7-26] Overview of the Institutional Control Program for Decommissioning Mine and/or Mills Sites in Saskatchewan. CMD: 18-M38. e-Doc 5582892. 2018 September.

- [7-27] Arcadis & Quintessa, *Post-Closure Safety Assessment 3rd Iterations to the NSDF Project*, 232-509240-ASD-004, Revision 2, 2020 December.
- [7-28] Functional Instruction Document Scoping Review of a Safety Analysis Report, 900-508770-FID-012, Revision 0, 2019 July.
- [7-29] *Creation, Capture and Use of Information Assets*, 900-511300-STD-003, Revision 1, 2019 February.
- [7-30] *Training*, 900-510200-PDD-001, Revision 3, 2020 March.
- [7-31] *Infrequently Performed Operations*, 900-508200-MCP-008, Revision 1, 2019 November.
- [7-32] Ontario Environmental Protection Act, *General – Waste Management*, R.R.O. 1990, Regulation 347.

## 8. INTEGRATION OF SAFETY ARGUMENTS

This Safety Case has collated the available evidence to demonstrate that the data, assumptions and models have been tested and that a systematic assessment has been performed. Areas of uncertainty have been identified and assessed so that the limitations of the data and hence, the limitations of the models used, are fully understood. The quality of the assessment is reliant on the development of the scenarios using realistic arguments and specific evidence related to the NSDF. Where there is uncertainty in the data or the models, conservative assumptions have been made. Further confidence in the models is provided by the use of commercially available software that has been tested and validated in a wider range of international projects. The analyses performed has also shown that the NSDF meets the acceptance criteria specified in Section 2.10.

The integration of safety arguments addresses:

- Radiological and non-radiological impacts.
- Overall safety of the disposal facility.
- Overall compliance with relevant legislation and regulatory requirements.

The Post-Closure Safety Assessment (PostSA) [8-1] has demonstrated that radiological doses and chemical exposures are significantly below the acceptance criteria for all scenarios in addition to the NES. For each scenario, appropriate conservatism have been used in numerical models where uncertainties were present. Where assumptions have been made, they have undergone a review process to ensure that they are valid, justified, and appropriate for the scenario being studied.

The key safety arguments are:

- The waste inventory disposed of in the NSDF is LLW only. This has the following implications:
  - Radiological consequence to humans and biota as a result of the NSDF are very low, and meet the dose acceptance criteria for both the expected normal evolution of the Facility, and for less probable events.
  - The total radioactivity decays quickly because LLW contains many short-lived radioisotopes. As a result, the total radioactivity of the Facility is greatly reduced in the first 100 years, and the radioactivity concentration begins to approach natural background concentrations.
  - Non-radiological contaminants and hazardous constituents are limited through compliance with the land disposal requirements of Ontario Regulation 347.
- The Facility is designed for the waste inventory and the physical characteristics of the site:
  - Performance of the high density polyethylene (HDPE) geomembrane (GMB) demonstrated by the GMB testing program show that the models and assumptions used are conservative.
  - The disposal system design utilizes engineering best practices to contain and isolate the waste. The natural and synthetic barrier systems isolate short-lived radionuclides, which allows for substantial decay of these wastes.
  - The disposal system includes multi-barrier liner and cover systems. The synthetic materials, such as the HDPE GMB, have a design life of 550 years, and an expected service life of up to 2 000 years. The natural materials, such as sand, rock, and the 750 mm of compacted clay, are expected to perform their containment and retardation functions for thousands of years.

- 
- The design and safety analyses for the NSDF Project have been performed by qualified and experienced individuals comprised of both independent contractor staff, as well as internal CNL staff. Many of the critical design elements and analyses were peer-reviewed by independent third-parties to ensure quality and accuracy of the results.
  - The proposed site is appropriate for the NSDF:
    - The surrounding area has been impacted by previous waste management practices. As a result, decades of study has been performed on the Perch Lake basin, giving a comprehensive characterization of the site, including how contaminants migrate in the environment, and hydrogeological & geotechnical properties of the host environment.
    - The design is robust and will survive significant seismic events for which there is evidence have never occurred within the region.
    - The site benefits from the existing programs and management systems of CNL, such as security, emergency response, and environmental protection.
  - The NSDF Project is compliant with relevant legislation and regulatory requirements:
    - Key documents are submitted to the CNSC staff for review and acceptance.
    - Appendix B provides a Concordance Table mapping the relevant regulatory requirements and international guidance to NSDF Project documentation.
  - The inputs and models used in the PostSA are conservative and overestimate the risk to the public and the environment.
    - 100% of Reference Inventory is assumed to be present in the Facility.
    - Institutional controls are assumed to fail, which allows for human intrusion into the Facility.
    - Receptor characteristics are deliberately conservative (i.e., occupancy factors, local fraction of food consumption, etc.).
    - Barriers are assumed to degrade at conservative rates.
    - No credit is taken for the packaging and grouting of specific waste streams.
  - The NSDF supports environmental sustainability, reduces environmental risk & liability, and is protective of the Ottawa River.
    - The NSDF allows for the remediation of contaminated areas of the CRL site, reducing the radioactivity currently exposed to the environment.
    - The NSDF places legacy wastes which currently do not have containment, and other LLW streams into a modern disposal facility, reducing monitoring and maintenance to a single location.
    - Water which makes contact with waste is treated before release, ensuring that no significant quantities of radioactive material enter the Ottawa River.
  - The Facility will contain and isolate the waste for hundreds of years into the future, and measures are in place to reduce the probability and limit any consequences of human intrusion to within the dose acceptance criteria of 1 mSv/a:
    - Land-use restrictions provide confidence that the Facility footprint will continue to be monitored into the institutional control period and beyond.

- The intrusion barrier in the final cover, perimeter fencing, and warning signs are provided to deter potential human intruders into the Facility.
- The natural resource potential of the area in and around the disposal Facility is low. Therefore, the likelihood of human intrusion associated with the exploration and development of natural resources is also low.
- The waste acceptance criteria and total facility inventory limits have been established to limit the consequences of human intrusion if control over the site is lost in the post-closure phase.
- Natural and anthropogenic analogues (described in Section 6), demonstrate that primitive methods of constructing earthen mounds have been used to build structures that have stood for thousands of years.

## **8.1 Key Evidence Supporting the Safety Arguments**

The following sections describe some of the key evidence in support of the NSDF Project and the safety arguments above.

### **8.1.1 Low-Level Waste is Appropriate for a Near Surface Disposal Facility**

The NSDF will contain only low level radioactive wastes. Canadian Nuclear Laboratories is using the IAEA and CSA definition of LLW in the development of the WAC (See Section 3 for more information on the waste inventory and WAC).

The majority of the radioactive wastes contained in the NSDF are relatively short-lived, such as cobalt-60 (half-life of 5.26 years) and tritium (half-life of 12.3 years) which will decay to less than 0.1% of initial amounts within about 55 and 120 years after placement, respectively. Other relatively short-lived radionuclides include cesium-137 (half-life 30.17 years) and strontium-90 (half-life of 28.8 years) which will have decayed to less than 0.1 % of initial amounts in about 300 years. Overall, the radioactivity of the wastes are reduced by about 2 000 times in the first 100 years, which brings the radioactivity concentration of the NSDF below the concentration of some naturally occurring ore bodies in the area.

After the initial rapid decay of the shorter-lived radionuclides, the radioactivity concentration begins to approach the natural background concentrations of the local soils. The design life of the Facility is 500 years after closure, for a total of about 550 years. By the time the Facility begins to experience degradation of barriers, the radioactivity concentration will have decayed even closer to background levels (see Figure 8-1).

While Figure 8-1 demonstrates absolute radioactivity of the Facility over time, there is no indication of the risk posed by the material. The measure of “radioactivity” only accounts for the quantity of material and how many decays are occurring per second. An additional exercise was performed which compared the relative “radiotoxicity” of the waste material, as compared to the radiotoxicity of local ore bodies of the Pembroke-Renfrew area. The term “radiotoxicity” in this context is referring to how much potential risk, or dose, can be caused to humans through direct exposure, usually through ingestion of the material itself. Figure 8-2 below shows that the relative radiotoxicity of the NSDF material is comparable to local surficial ore bodies at the time of placement, and quickly becomes far less radiotoxic in only a matter of years after closure. More discussion and details of the calculation can be found in Section 2.3.1.1. The exercise in radiotoxicity also supports the design life of 550 years, as the Facility becomes far less radiotoxic than naturally occurring ore bodies very quickly after closure.

The design life is not necessarily equal to the “service life”, which refers to the reasonable expectations of how long a specific barrier or system can be expected to perform its function. The primary barrier material, the high-density polyethylene geomembrane (HDPE GMB), is expected to remain an effective barrier for up to 2 000 years (See Section 5 for GMB testing and selection). In addition to the HDPE GMB which exists as three separate layers (once in the final cover, twice in the base liner), the ultimate barrier is the compacted clay liner (CCL), which is completely a natural material and is expected to perform its function for many thousands of years.

The LLW results in low level hazards, especially after the rapid decay in the first 100 years. The PostSA [8-1] evaluates radiological consequences (dose) from a variety of scenarios. The scenarios with specific dose acceptance criteria are the NES (0.3 mSv/a), Sensitivity Analyses (0.3 mSv/a), and Disruptive Events (1 mSv/a), and What-If? scenarios (1 mSv/a). The results of the PostSA indicate that the calculated dose is less than the dose acceptance criteria in all cases, which demonstrates that the waste is appropriate for the design and location of the Facility.

Radiological consequences to a resident living on top of the waste facility after the institutional control period (ICP) are calculated to be 0.015 mSv per year. This is less than 1% of the natural background dose of about 2 mSv per year experienced by all Canadians, and far below the regulatory dose.

A summary of the evidence demonstrating that a near-surface facility containing only LLW is appropriate is presented in Figure 8-3.

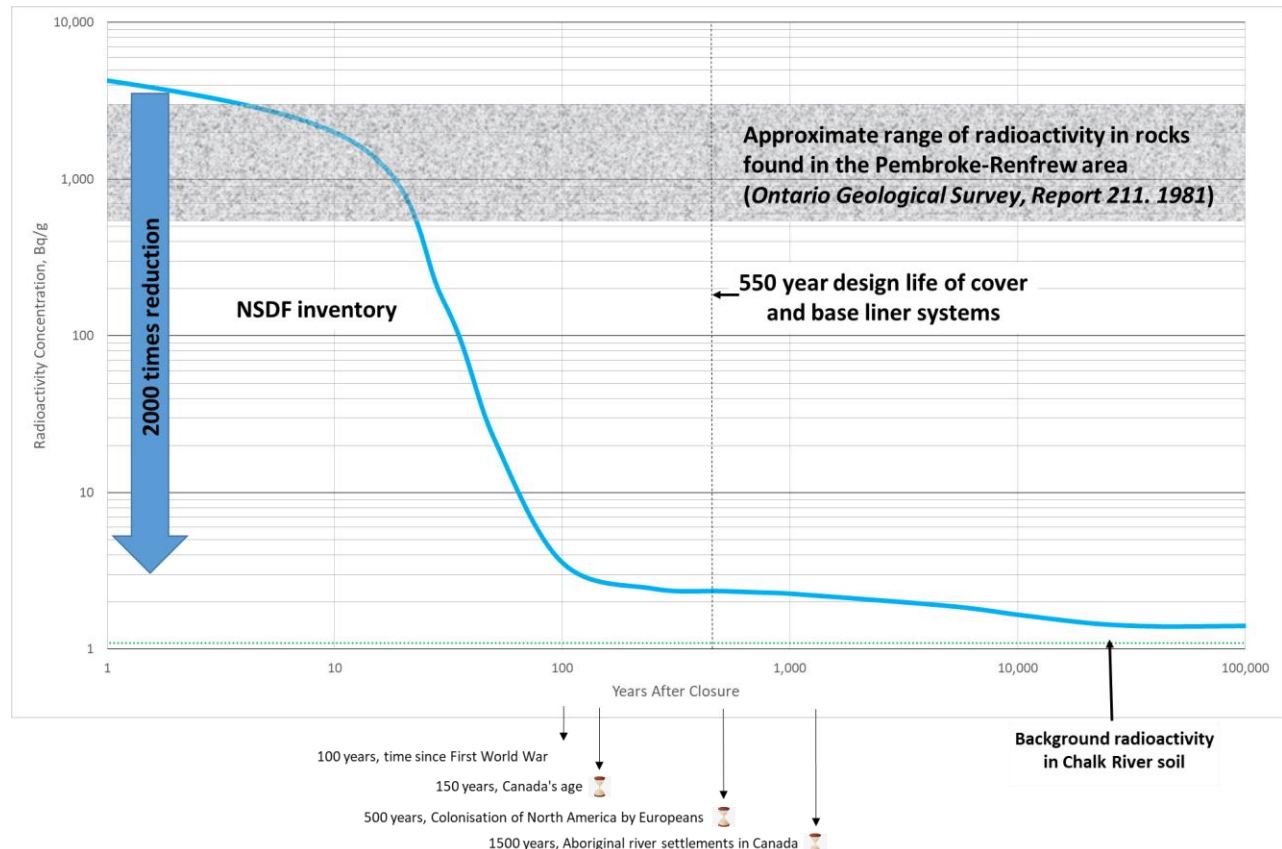


**Figure 8-1 NSDF Inventory Decay Over Time**



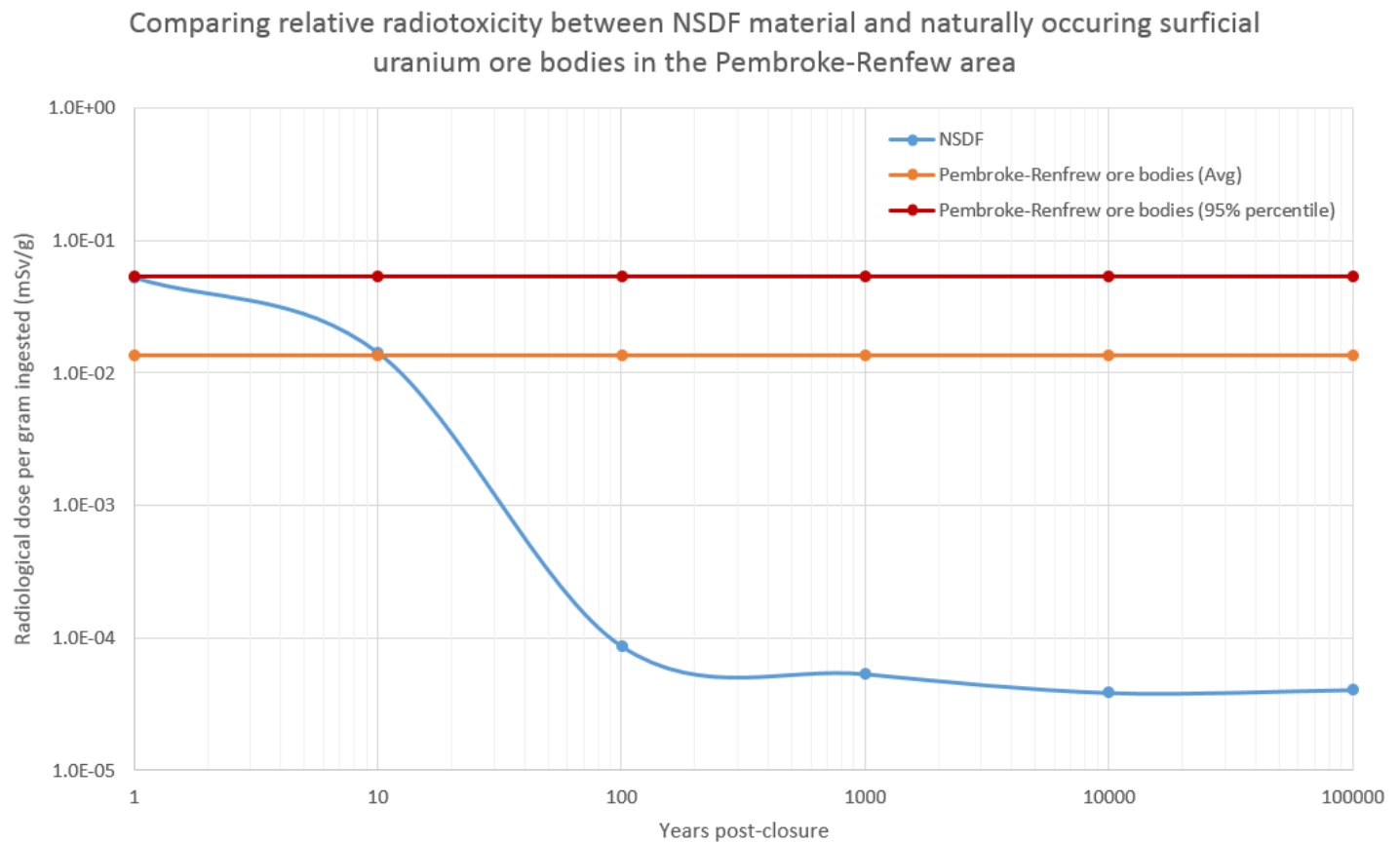


Figure 8-2 NSDF Relative radiotoxicity compared to natural ore bodies

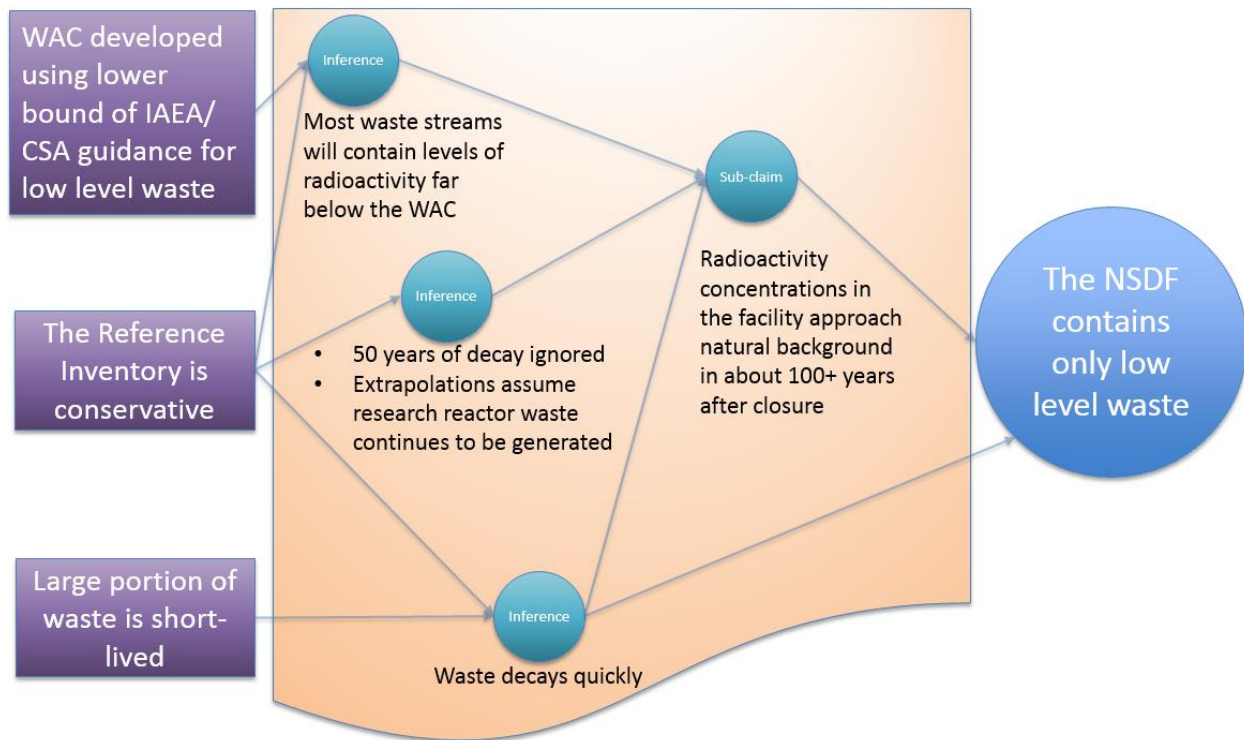


**Figure 8-3 Evidence Summary Supporting that NSDF Contains only LLW**

### 8.1.2 The Ottawa River will be Protected

A primary objective of the NSDF is to prevent radioactive materials from entering the environment, and by extension the Ottawa River. During the operations phase of the NSDF, the waste is contained, and there are no uncontrolled releases from the NSDF to the Ottawa River.

Precipitation falling on the NSDF site is separated and managed as non-contact and contact water. Contact and non-contact water will be separated from the leachate collection system (LCS) by installing a 1 mm geomembrane (sacrificial liner) over the entire ECM floor (Phase 1 & 2) and perimeter berm sideslopes prior to the start of operations. For Phase 1, the liner is installed above the completed base liner system. The exception in Phase 1 is in the active waste cell where the liner is not installed to allow leachate to enter the LCS. For Phase 2, the liner is installed on the unfinished but graded ECM floor.

The spread of contamination and migration of radionuclides is managed during the operations phase through a number of design aspects. During waste placement operations, all efforts are made to minimize the contact of precipitation with the waste, therefore limiting leachate production. Operations of the NSDF are limited to one cell at a time to limit the surface area of waste that is exposed to the environment (i.e., precipitation) at any given time. As a cell is constructed, interim covers are placed over waste to limit infiltration of precipitation and promote non-contact surface water run-off. As each disposal cell is completed the final cover system is installed over the filled disposal cell. Other operational practices to limit contact with precipitation include grading and compaction of the waste fill to promote surface water run-off.

Ways to optimize (i.e., minimize) wastewater quantity were considered. The NSDF radionuclide concentration limits apply a graded approach to control leachate radionuclide concentrations during placement of waste. There will be a small portion of waste which will be required to utilize robust packaging to prevent the spread of contamination. Specifically, leachate controlled waste packages are intended to provide short-term

barriers for wastes with higher radionuclides concentrations during the time the disposal cell is not covered with the final cover system (approximately 5-10 years). Thus more mobile radionuclides, such as tritium, are kept isolated from the environment to minimize liquid effluent releases during the operations phase.

Any water that makes contact with (or is suspect of contacting), the contaminated waste is collected in the leachate collection system (LCS) and or the contact water collection ponds, and treated in the WWTP to remove contaminants, prior to controlled release into the environment. All treated effluent will meet the effluent discharge targets which are established to be protective of human and non-human biota health, and thus are providing protection to the Ottawa River. This is determined by ensuring that predicted concentrations for the Ottawa River for each of the radionuclides that screened into the assessment are well below No Effect Concentrations based on 400  $\mu\text{Gy/hr}$  radiation benchmark used in the assessment. Accordingly, radiation doses to Aquatic Biota in the Ottawa River are also predicted to be well below the Province of Quebec criteria of 10  $\mu\text{Gy/hr}$ .

The design of the leachate collection and leak detection system (LDS) includes the use of collection headers downgradient of the ECM. Specific areas of the ECM drain to specific headers and collection sumps. By monitoring which collection sumps are experiencing increased or unexpected flows of leachate, it is possible to locate the general area of the ECM that is causing the higher leachate generation rates caused by potential liner damage. Therefore, it is possible to perform remedial actions on the affected portion of the liner system and mitigate the high flow of leachate.

Even during periods of very high precipitation, the WWTP and associated leachate treatment systems have been designed for the back-to-back, 1-in-100-year storms. The influent equalization system is designed to contain contact water flow at the maximum 48-hour condition that would be produced from the largest cell of the ECM during back-to-back 100 year, 24-hour storm events including peak monthly rain and accumulated snowmelt (4 710  $\text{m}^3$ ). The Equalization Tanks have a capacity of 1 900  $\text{m}^3$  each, with a total working capacity of 5 700  $\text{m}^3$ . The Equalization Tanks' capacity for operations is 990  $\text{m}^3$ , based on a total working capacity of 5 700  $\text{m}^3$  and the design basis event rainfall event is 4 710  $\text{m}^3$ . Furthermore, the NSDF water collection and conveyance systems are typically designed to resist erosion, safely convey flows, and maintain structural integrity during peak flows generated from various design storms up to a PMP storm event.

During the post-closure phase of the NSDF, the concentration of radionuclides in the ECM has decayed significantly, and is now closer to natural background concentration levels. The non-radiological contaminants remain at acceptably low levels, given the use of Ontario Regulation 347 in the operations and WAC of the Facility. The evolution of the Facility has been modelled, and concentrations of radionuclides in the environment, including the Ottawa River, have been calculated. The results indicate that concentrations meet environmental quality standards for the protection of biota and human health. In addition, two receptors were added to the PostSA which demonstrate that the Ottawa River, and users of the Ottawa River, are protected. Receptors were placed downstream of the NSDF, at Sheenboro Quebec, and at Ottawa/Gatineau. Doses to these receptors are a million times lower than the public dose limit, and concentrations of both radiological and non-radiological contaminants are 100 000 times lower than the environmental quality standards.

Figure 8-4 below, illustrates the evidence in support of the safety argument that the Ottawa River will be protected.

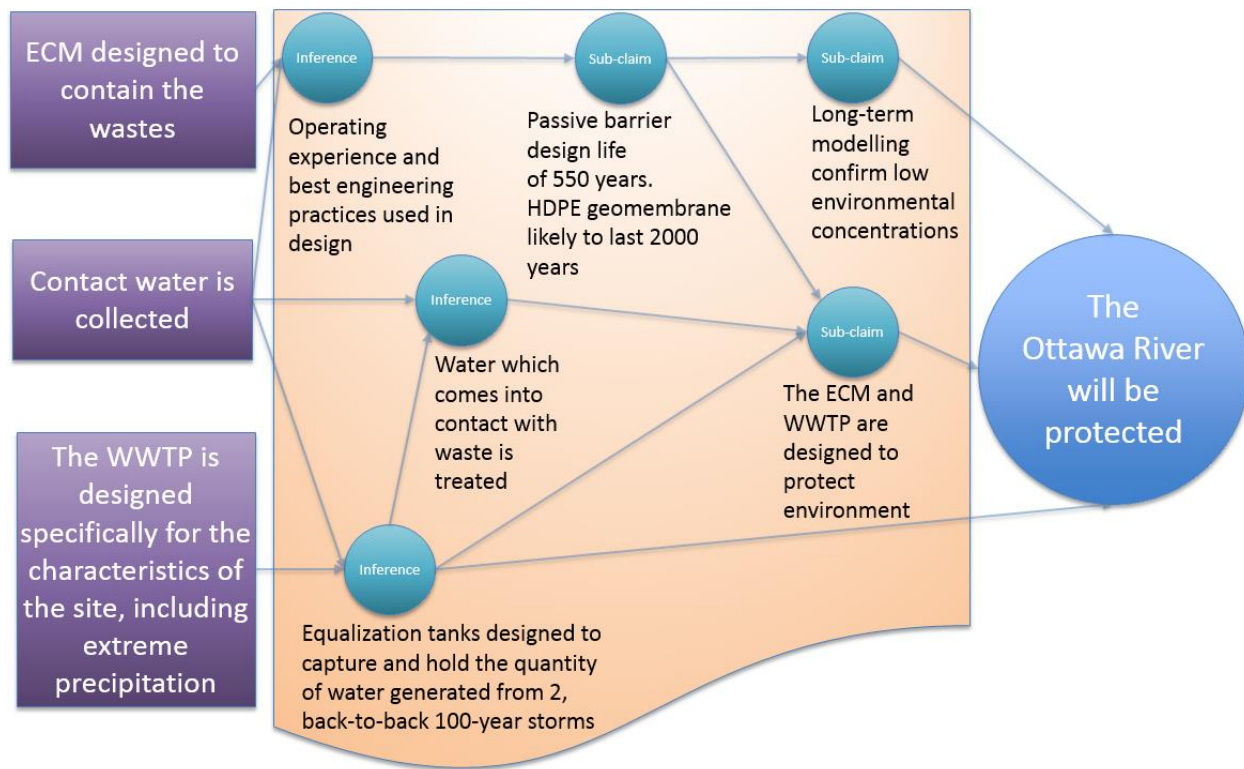


**Figure 8-4 Evidence Summary for Protection of the Ottawa River**

### 8.1.3 The NSDF Supports Environmental Sustainability

The NSDF is a long-term solution for LLW which supports environmental sustainability. The current practice of storage-with-surveillance can be costly and perpetual. Wastes are currently stored at multiple sites in multiple buildings or management areas. Each site or area requires monitoring and maintenance to ensure that wastes remain safely contained. The continuation of the current waste management practices guarantees a burden to future generations and goes against intergenerational equity principles – that is, the responsibility for continuous monitoring and maintenance is passed on to those who did not create or directly benefit from the wastes. The NSDF allows CNL to meet Natural Resource Canada’s Radioactive Waste Policy Framework, which specifies that waste producers are responsible for the entire lifecycle of radioactive waste materials. Some of the wastes destined for the NSDF were created as early as the 1940s, and now is the appropriate time to develop a permanent solution.

The NSDF allows for the consolidation of many LLW streams into an engineered disposal facility that contains and isolates the waste from the environment for centuries or more. The consolidation of the wastes in a disposal facility greatly reduces the resources and cost required for maintenance and monitoring, compared to on-going storage.

Comprehensive and detailed long-term modelling of the NSDF (found in the PostSA [8-1]), demonstrates that the risk posed by the Facility to future generations is minimal, and meets all acceptance criteria for dose, environmental releases, and environmental concentrations. There are no significant adverse effects expected from the NSDF, and it is therefore, a responsible disposal solution for LLW.

Figure 8-5 illustrates the key evidence to support the safety argument that the NSDF provides environmental sustainability.

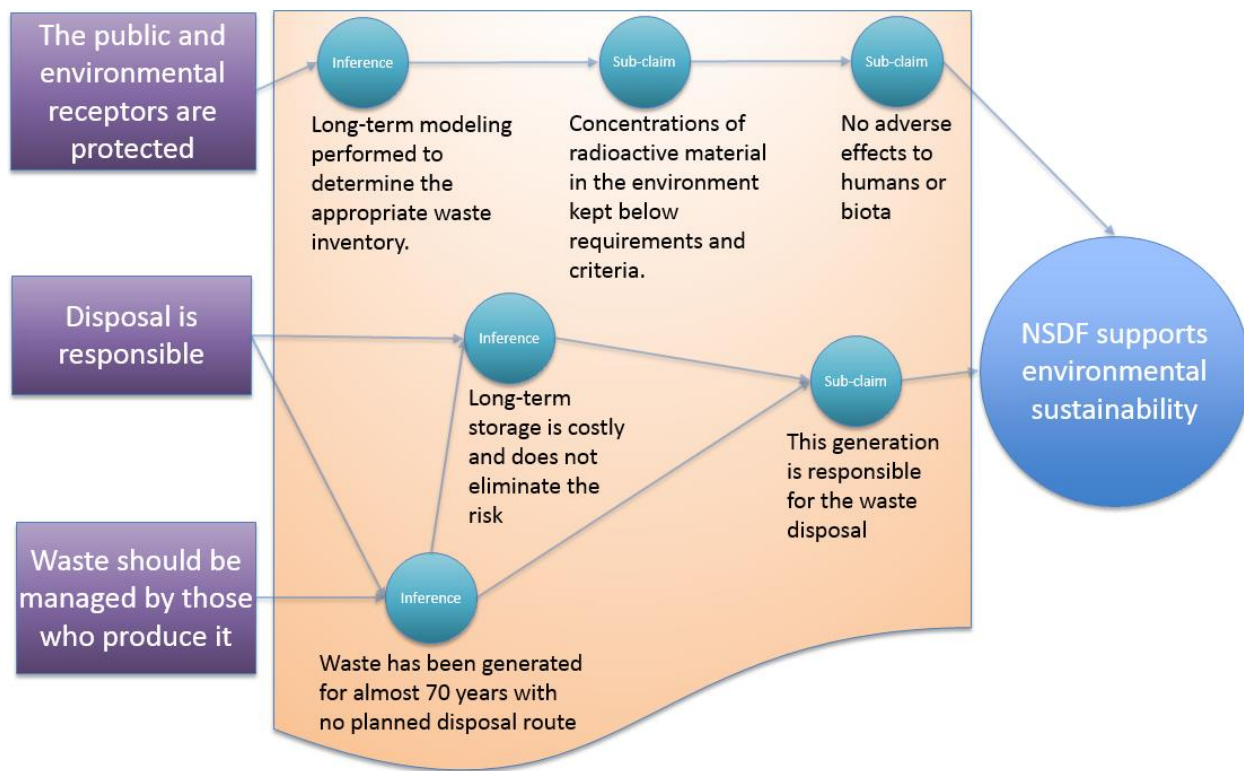


**Figure 8-5 Evidence Summary Supporting that NSDF Provides Environmental Sustainability**

#### 8.1.4 NSDF Reduces Environmental Risk and Liability

The NSDF is a key enabling facility required for the clean-up and restoration of CNL sites. There is currently LLW stored at CNL sites in a variety of forms. Some of the LLW are stored outdoors in above-ground storage, in containers providing protection to the environment. Other waste streams are kept indoors in storage buildings. However, a large portion of waste currently exists as contaminated soils in areas of the CRL site. These contaminated areas exist as a result of past waste management practices that took place in the early days of the nuclear industry, starting in the 1940s and 1950s, including:

- Solid wastes were buried below grade in facilities such as unlined sand trenches.
- Liquid wastes were pumped to areas to be dispersed into the sand and soil.
- Contaminated soil generated by the remediation efforts at Port Hope and surrounding area in the 1980s, stored in an unlined landfill type facility, exposed to the environment.

The wastes stored in the above ground facilities currently do not pose an environmental hazard, as they are structurally contained, however, these facilities have design lives of about 50 years. Some of the current buried wastes stored outdoors are exposed to the environment and contaminants are leaching into the sands and soils surrounding them.

The NSDF is a solution for buried waste and contaminated lands that are currently not protected from the environment on CNL sites. Canadian Nuclear Laboratories intends to transfer the contents of many of these sites into the NSDF, provided that the waste streams meet the WAC. Determination of which sites will be remediated will follow CNL's environmental remediation process, subject to separate licensing decisions by the CNSC. Wastes placed in the ECM are controlled and contained, and any precipitation that makes contact



is collected and treated, which is a large improvement to the current situation. The introduction of the NSDF protects the environment by reducing the source term of radionuclides available for leaching.

The NSDF is the primary enabling facility for the remediation and clean-up of the CRL site. Without the NSDF, the buried wastes and contaminated lands currently contaminating portions of the environment cannot be moved because of the limited storage capacity available. The plumes of radioactivity travelling from the waste areas are being monitored and managed, and do not pose a risk to the environment or human health at this time or immediate future. However, in the long term, these radionuclide plumes will travel further, and have the potential to become a long-term hazard if not remediated. The NSDF allows CNL to meet its commitment to the protection of the environment.

Figure 8-6 summarizes and illustrates the evidence supporting the safety arguments that the NSDF reduces environmental risk and liability at CNL sites (e.g., CRL and Whiteshell Laboratories).

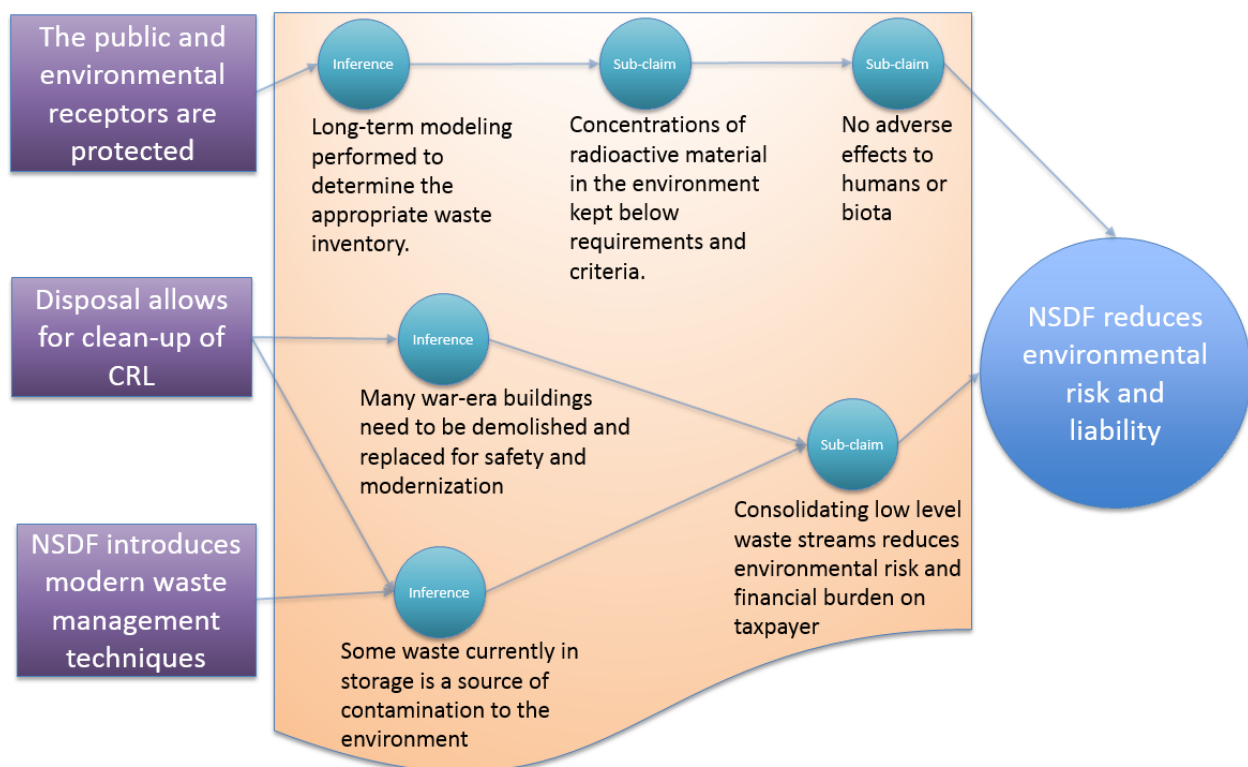


**Figure 8-6 Evidence Summary Supporting that NSDF Reduces Environmental Risk and Liability**

### 8.1.5 NSDF Design is Appropriate for the Site Characteristics

The location of the NSDF is appropriate for its function as a LLW disposal site.

On a larger scale, the CRL site is located in a well understood and comparatively low to moderate seismic zone (See Section 3 for more information on the site characteristics). The CRL site is considered to be in the Canadian Shield, a stable rock formation.

On a more local scale, the proposed ECM is to be constructed on or near the bedrock. Structures founded on bedrock are in general seismically resistant because the motion is not amplified as much as the ones founded on overburden.

The local seismic characteristics were used to design the ECM. The ECM and perimeter berm have been designed to maintain their containment functions for up to a 1-in-10 000 year seismic event during the design life of the facility. As a result of the seismic assessment, optimizations were made during the design phase to mitigate the potential for liquefaction. A process known as “remove and replace”, is used to stabilize the base of the perimeter berm. The native sandy soil is being removed and replaced by compacted engineered granular fill material, which allows for water to drain out of it more effectively. More information on the PSHA and other seismic analyses can be found in Section 3. For comparison, the NSDF seismic design uses a peak ground acceleration value of 0.55 g, and the peak ground acceleration at Fukushima during the seismic event was 0.56 g. The NSDF is designed to withstand a magnitude of earthquake that has not been observed in this area of the Earth, because Ontario is not on a major tectonic plate border.

Additional analysis was performed to determine the effects of an even larger seismic event on the integrity of the ECM [8-2]. The analysis used a beyond design basis seismic event with a return period of 1-in-50 000 years. The results of the analysis indicate that there would be displacement in the berm and cover ranging from about 1 m to up to 4.8 m. From Figure 8-1 and Figure 8-2, it is clear that the radioactivity concentration, and therefore the potential hazard posed by the facility, does not significantly change after about 100 years post-closure of the facility. Furthermore, the effects of large displacements and loss of containment in the ECM are evaluated in the PostSA and explained in Section 4.1 of this report. Specifically, the results of the Series of Landslides and Mass Evacuation scenarios (summarized in Table 4-3) demonstrate that even with the loss of the berm or loss of containment, the dose rates still meet the acceptance criteria.

The NSDF site is in the Perch Lake Basin, an extremely well understood and characterized area. Due to early waste management practices, portions of the Perch Lake Basin have been impacted with groundwater plumes of radioactivity. The area has been used to study the mobility of radionuclides in groundwater and the overburden.

The site is located far above the maximum calculated Ottawa River flood levels for the area. Specifically, the lower point of the ECM is at 163 metres above sea level (mASL), while the maximum flood level due to upstream dam breaks is calculated to be about 122 mASL. Therefore, flooding of the Ottawa River cannot adversely affect the integrity of the NSDF or its barriers. In addition, the Facility is designed to handle the volume of precipitation associated with two, back-to-back storms with a return frequency of 100 years, as discussed in Section 8.1.4.

In the post-closure phase, the site characteristics and how they affect the design were considered as part of the features, events, processes (FEPs) screening process. The FEPs are screened and assessed on an individual basis, which help guide the development of the scenarios in the PostSA [8-1]. The intent of the FEPs screening is to ensure that all features, events or processes related to a disposal facility are considered. The effect of the local environment on the NSDF Project are considered through the FEPs process.

The PostSA models the hypothetical release from the Facility, hundreds of years into the future when degradation of the barriers is plausible, and continues the assessment for 10 000 years. The release rate of contaminants exiting the Facility lead to acceptable environmental concentrations and radiological consequence to both the public receptors and non-human biota. The release rates are low because of a

combination of the natural and synthetic barriers, coupled with the natural attenuation of the geosphere and surrounding environment.

The effects of failed engineered barrier systems were assessed in the PostSA in the Defence in Depth scenarios. The results indicate that a failed barrier does not significantly increase dose or risk to the public or the environment. Sections 4 and 6 discuss the Defence in Depth scenarios in more detail.

Figure 8-7 illustrates the evidence supporting the safety argument that the NSDF design is appropriate for the site characteristics.

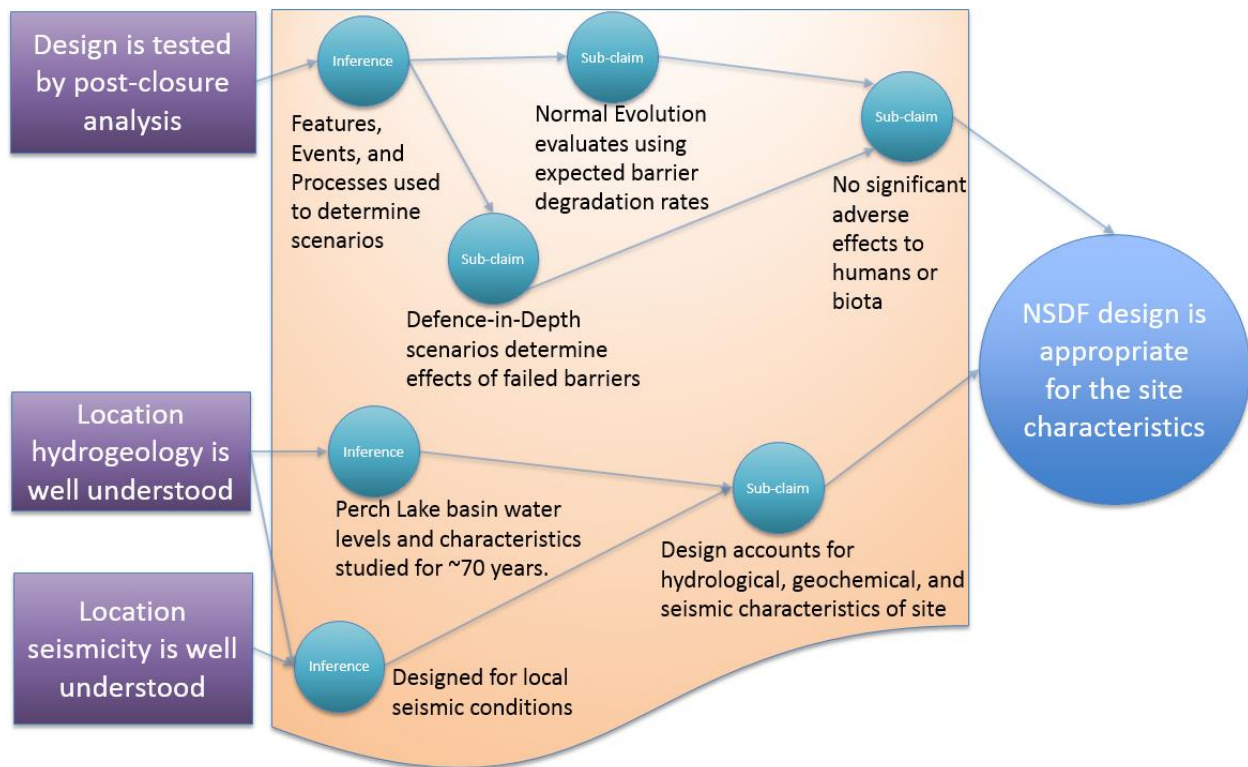


**Figure 8-7 Argument Summary Supporting that NSDF Design is Appropriate for the Site Characteristics**

### 8.1.6 The Waste is Contained by Multiple Barriers

The waste disposed in the NSDF is contained by a multi-barrier liner and cover system designed to perform multiple safety functions for at least 550 years. The NSDF safety functions are containment, isolation, retardation, monitoring and control. Passive safety engineered features that provide containment include the final cover system, base liner system, and the perimeter berm. The NSDF design relies on passive systems to ensure long-term safety. The safety functions fulfilled by the passive systems are containment, isolation and retardation. The NSDF design, based on multiple safety functions, ensures that safety is not dependent on a single safety function.

Waste containment and isolation is achieved through the Facility's design, based on multiple barriers providing defence-in-depth and controlling the Facility's operational releases to the environment. The layers of protection for containment and isolation include structure design/materials, and Facility inspections, supported by radiation protection monitoring and the groundwater monitoring program.



The NSDF will achieve containment through multiple passive barriers between the waste and the environment. Isolation of radionuclides is achieved by enveloping the waste between multiple engineered barrier systems, and by maintaining land-use restrictions on the site to make inadvertent human intrusion less likely.

Defence in depth against migration of the contaminants from the Facility will be achieved through multiple passive barriers: the waste form and packages, double composite GMB liner system with compacted clay, the composite GMB cover system, and the perimeter berm. The engineered barriers that restrict the contaminant migration from the NSDF are:

- Base liner system: A double composite GMB liner system supported by 750 mm of compacted clay. The system contains contaminants in the ECM.
- Final cover system: Minimizes infiltration of precipitation in the NSDF, thus limiting the mobilization of soluble contaminants.
- Perimeter berm: maintains the structural integrity of the Facility.
- Waste form: The majority of the wastes are compacted soil and building debris. The compaction of the wastes limits the waste porosity, thus limiting the infiltration of water, which limits the contaminant mobility.
- Waste packages: Some wastes will be contained in packages, many of which filled with grout or concrete to meet void space requirements, which has the additional benefit of reducing contaminant mobility.

The isolation of contaminants in the long term will be achieved by institutional controls:

- Physical barriers and security to limit access to the site and reduce probability of human intrusion.
- Enforcement of land-use restrictions placed on the property deed.

The containment and isolation features are described in more detail below.

### **Final cover system**

The final cover system contains multiple layers of independent barriers comprised of both natural and synthetic materials, using the best available technology and materials available. Cover systems like the one used in the NSDF have been deployed at other similar facilities around the world. The components are described in detail in Section 3, and presented below in Figure 8-8.

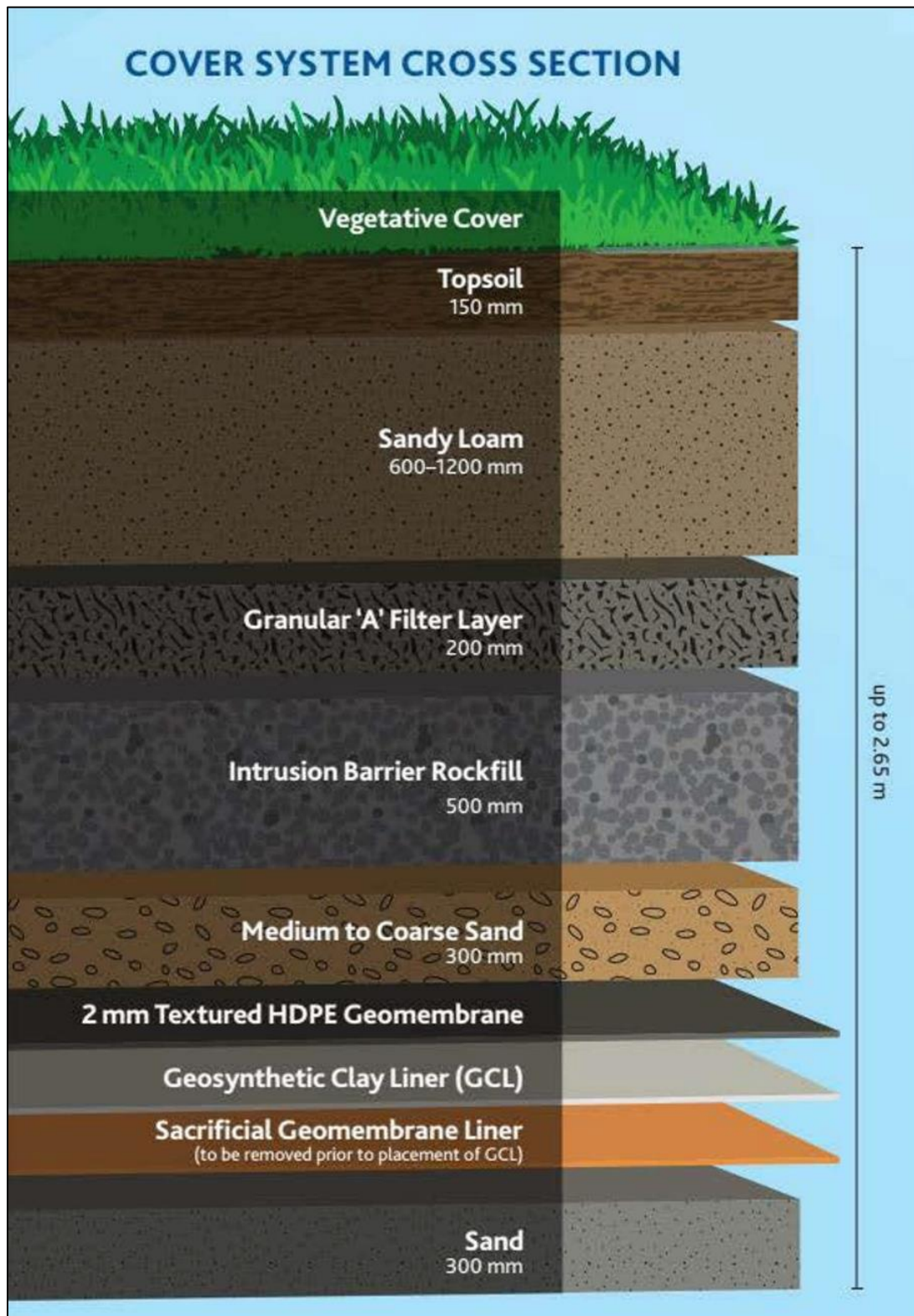


Figure 8-8 Final Cover – Material Layers

The final cover is designed to direct precipitation away from the waste and minimize infiltration into the waste. The HDPE GMB is a non-porous material, meaning water cannot penetrate through it. The HDPE GMB is supported by a layer of geosynthetic clay liner (GCL). The clay liner serves two purposes: as a barrier to water infiltration, and also as a repairing mechanism for the HDPE GMB. If the HDPE becomes pierced, or degrades to the point where water is able to pass through it, water will then come into contact with the GCL. The clay in the GCL expands when in contact with water, thus “sealing” the damage to the GMB.

The other important barrier in the cover system is the Intrusion Barrier, which is a layer of rock aggregate fill and has several purposes. The primary purpose is to deter wildlife from digging holes into the waste. The intrusion barrier may also deter or even prevent the roots of large trees from penetrating into the waste. By keeping tree roots shallow, the potential damage to the cover system from a felled tree being uprooted is significantly reduced.

After institutional controls are lost, it is reasonable to suggest that borehole activities or exploratory digging/excavation may take place on the site. The layer of crushed rock in the intrusion barrier is intended to communicate that the area is clearly man-made, and not natural in origin, as only solid rock is expected to be found under the overburden. This may encourage the intruder to stop digging, or seek out more information about the area and its history.

The layers of material above the HDPE GMB all contribute to the protection of the GMB. The approximately 2 metres of material create a barrier between the HDPE and the environment. The cover materials protect the HDPE from potential forest fire conditions, and from the potential of freeze/thaw cycling in the winter/spring. The barrier layers together form a system designed to mitigate water infiltration into the ECM for the duration of its design life, but likely for much longer.

### **Base Liner System**

The base liner system is made of multiple layers of natural and synthetic materials, described in detail in Section 3. Like the final cover system, the liner is designed with the best available technology, and similar designs exist in other surface disposal facilities. Figure 8-9 below presents a cross-section of the base liner system.

The base liner’s primary purpose is to contain and isolate the waste from the geosphere. The secondary purpose of the liner system is to collect leachate and to detect leaks in the primary liner during the operations phase of the Project.

Like the cover, the liner system contains multiple layers of natural and synthetic materials designed to maintain the integrity of the primary hydrological barriers; the HDPE GMBs. The liner system contains two HDPE liner systems, both supported by GCLs, separated by sand and stone layers. The liner is constructed with this double-layer to provide additional confidence that the system as a whole will perform as designed over the duration of the design life of the ECM. In addition to the double-HDPE GMB liner system, the final barrier separating the waste from the environment is 750 mm of compacted clay. Clay is a natural material with no specific “design life” and is expected to perform as a hydraulic barrier for thousands of years.

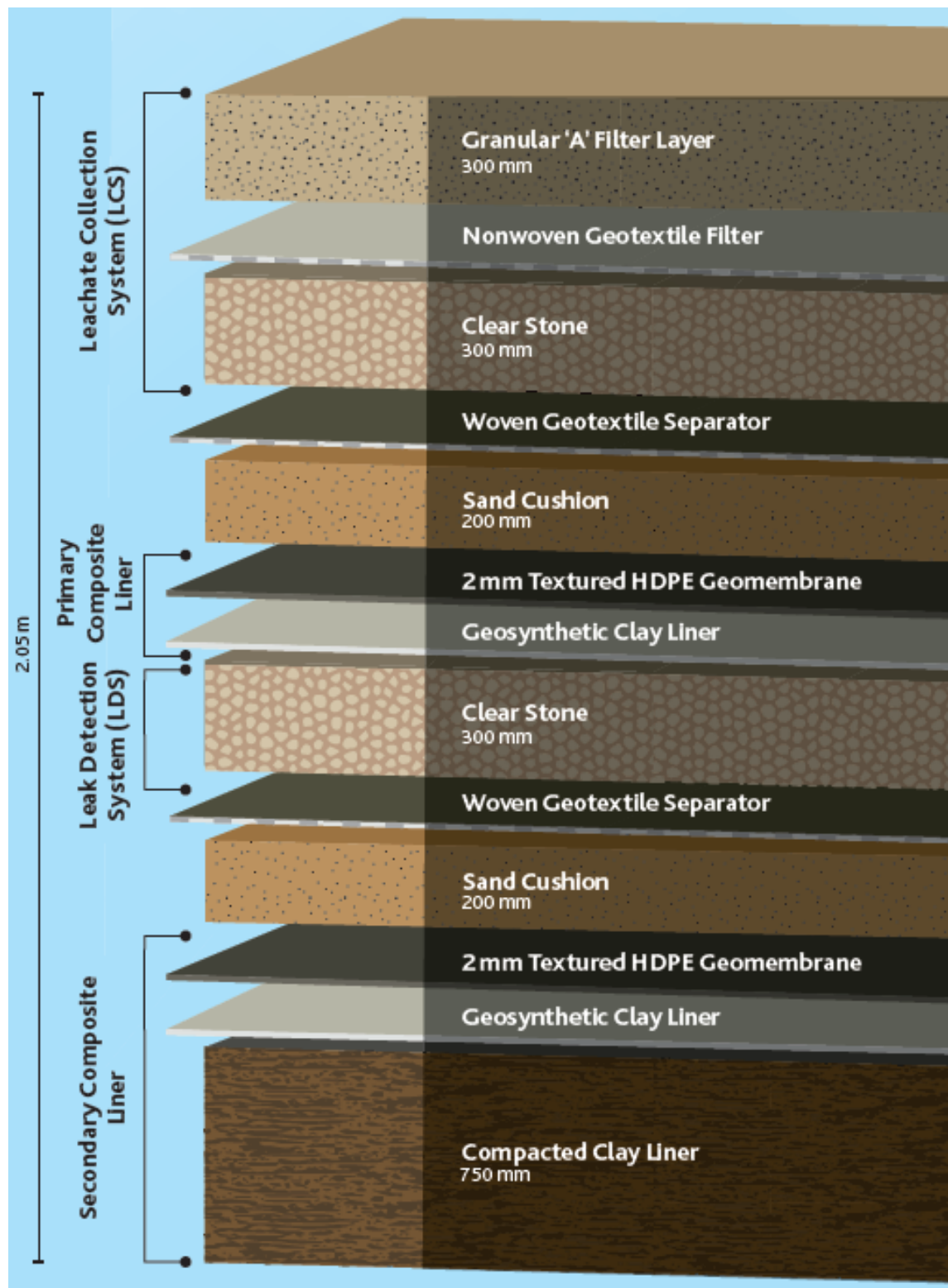


Figure 8-9 Base Liner System Components

## Perimeter Berm

The ECM is surrounded by a perimeter berm. The primary functions of the perimeter berm are to provide structural integrity for the ECM, and to provide isolation and containment of the waste. The berm crest is designed to provide vehicle access required for performing operations and monitoring at the ECM. The berm provides a physical barrier to divert stormwater from impinging on the ECM containment area, and is formed of earthen materials and geosynthetic materials. Exterior berm sideslopes are inclined at a ratio of 3 horizontal to 1 vertical unit, and the berm has a width of 7 m at the top (crest). The surface (face) of the exterior portion of the berm is covered with rock to provide erosion protection. The height of the berm varies from about 2 m minimum to about 15 m maximum. The inside face of the berm is covered with the various liner system layers, while the outer face is covered with the intrusion barrier rockfill over an HDPE GMB liner, geotextile cushion, and geogrid. The top of the berm is covered with a layer of Granular 'A' material, an HDPE GMB, and a geotextile cushion.

Together, the final cover system, base liner system, and perimeter berm work as a system of multiple barriers to contain the waste and isolate it from the environment, which includes limiting water infiltration into the Facility. Each of the final cover, base liner, and perimeter berm are constructed of multiple layers intended to protect the HDPE GMB, and to provide additional confidence that the barriers will withstand the natural evolution of the Facility, including erosion.

## Waste Form and Packages

The majority of the waste intended for disposal into the NSDF will be bulk, unpackaged materials. This material can be compacted to reduce porosity, and therefore, reduce the water infiltration rate.

There will be a small portion of waste which will be placed in robust packaging to provide containment and isolate the waste from precipitation, preventing the spread of contamination. Specifically, leachate controlled waste packages are intended to provide short-term barriers for wastes with higher radionuclides concentrations during the time the disposal cell is not covered with the final cover system (approximately 5-10 years). Thus, more mobile radionuclides, such as tritium, are kept isolated from the environment to minimize liquid effluent releases during the operations phase.

The packaging of wastes may slow down the release of some radionuclides from the ECM into the environment in the long-term. However, the containment functions of the waste packages have not been included in the PostSA. This is a deliberate and conservative modelling assumption. The PostSA assumes that all waste in the ECM is available for leaching immediately on contact with water, therefore, no credit is taken for the presence of packaging materials.

The engineered barriers are not subject to common-cause failure. Failure due to a large seismic event is a potential common-cause failure mode. Section 3 describes the seismic analysis performed for the ECM in great detail, and concludes that the ECM is designed to withstand the 1-in-10 000 year seismic event. Subsidence would be another common-cause failure mode in a mound-type of facility. The compaction requirements for waste placement work together with planned and procedural waste placement processes, to ensure that subsidence in the facility is limited. In the case where the final cover system becomes damaged, repair and maintenance can be performed during the institutional control period.

Figure 8-10 presents a summary of the evidence supporting the safety argument that the waste is contained by multiple barriers.

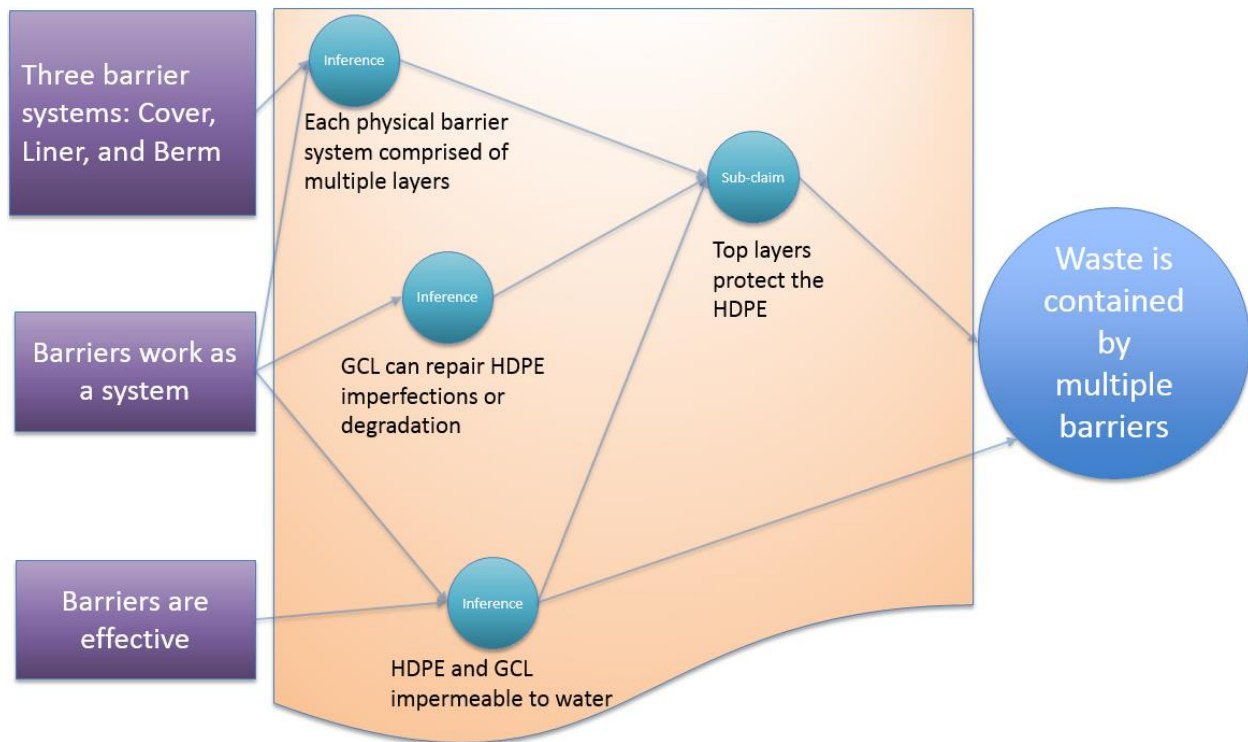


**Figure 8-10 Evidence Summary Supporting that the Waste is Contained by Multiple Barriers**

### **8.1.7 The Inputs and Models used in the PostSA are Conservative and Overestimate the impact to the Public and Environment**

The adequacy and appropriateness of the disposal facility design, host environment, and waste inventory is determined primarily in the PostSA [8-1] which assesses how the ECM is likely to perform in the long-term, and the risks associated with it. The PostSA draws from design documents, environmental analyses, safety assessments, site characterization, FEPs screening, and other radioactive waste disposal facility assessments, to create the long-term models which form the basis of the analysis. This section discusses the conservatism deliberately introduced into the PostSA, to ensure that the final dose results and final environmental concentrations are also conservative, and therefore, provide a safety margin.

#### **Waste Inventory**

The NSDF contains only LLW, and the Reference Inventory [8-3] has been calculated to be very conservative. A detailed discussion of the waste inventory is presented in Section 3. Many waste streams proposed for the NSDF contain very low levels of radioactivity. The NSDF could be filled to the 1 000 000 m<sup>3</sup> volume capacity before the radioactivity limit at closure is reached.

In addition to the use of a conservative radioactive inventory, the PostSA does not adjust the inventory to account for leachate treatment and removal during the operations phase. During the operations phase, some wastes will come into contact with precipitation which creates leachate. This leachate is collected by the WWTP for treatment before release to the environment. The WWTP is designed to treat water to specific guidelines and targets, but it is not possible to remove 100% of contaminants. There will be controlled releases of radioactivity to the environment that meet the effluent discharge targets. Although radioactivity will be leaving the Facility, there is no credit taken for the reduction of inventory in the PostSA. The PostSA



uses the radioactive inventory at closure, and assumes that no radionuclides leave the Facility during operations through decay and migration.

The PostSA uses the Reference Inventory as a source term (input) in all of its assessments. However, as a result of the third iteration of the PostSA, a recommendation to reduce the Pu-239 and I-129 inventories by 58% was made to meet the 1 mSv/y dose acceptance criteria in the shallow well scenario. Canadian Nuclear Laboratories has made this recommended reduction to its Licensed Inventory. As a result, the PostSA has assessed an inventory slightly larger than the Licensed Inventory, and therefore the dose calculations and results are conservative. Discussion on the Licensed Inventory can be found in Section 5.7.

### **Institutional Control and Land Use**

The PostSA uses a 300 year period of institutional control for the Normal Evolution Scenario (NES), most Disruptive Events, and other lower probability scenarios. In the models, receptors are assumed to reside on or near the Facility at exactly 300 years after closure. The assumption is that societal memory of the Facility has been lost, and that the Federal Government is no longer able to restrict the land-use of the Facility footprint. These assumptions are conservative because the highest radiological dose and risk are typically in early years after closure, because radiological decay decreases the hazard with time.

It is a reasonable assumption that the Federal Government of Canada will continue to exist for many decades and centuries into the future. Institutional controls, such as land-use restrictions, are the responsibility of the Federal Government of Canada as the CRL site owner thus are also reasonably expected to continue for many decades and centuries into the future. The continued existence of an established federal government provides confidence that human intrusion onto the NSDF site will be unlikely.

Furthermore, CNL has gained a commitment from AECL that the NSDF footprint will be treated as a disposal facility, and thus, have land-use restrictions placed upon NSDF, for as long as required.

To remain conservative and ensure that the dose calculations represent the worst-case conditions, the PostSA uses 300 years as the assumed period of institutional control and restricted land-use.

### **Barrier Design Life and Expected Service Life**

The primary barrier against water infiltration into the ECM is the HDPE GMB, supported by the GCL. Through the GMB testing and selection process, it was established that the selected GMB material can meet the 550 year design life, and could perform its function for up to 2 000 years (See Section 5 for more details on the GMB testing program and its results).

To remain conservative, the PostSA assumes the following on the performance of the final cover:

- The infiltration rate is initially 0.3 mm/y.
- The logarithm of the infiltration rate increases linearly, to 200 mm/y at 650 years.
- At the design life of 550 years, the infiltration rate is 74 mm/y.

The results of the GMB testing program are not credited in the PostSA. The PostSA conservatively uses assumptions on infiltration rates and extrapolations to the design life to calculate how much water enters the ECM. With proper quality assurance and quality control procedures during GMB installation, it is likely that the GMB will outperform the 550 year design life. The assumptions used in the modelling process ensure that a conservative outcome is achieved.

Similar conservative modelling assumptions have been used for the base liner. The liner's primary barriers are two sets of GMB systems, supported by a final CCL. The PostSA assumes that the GMB layers have failed at the end of their 550 year design lives. This means that after 550 years post-closure, the only barrier taken into account in the liner system is the compacted clay. As a result, the leakage rate of leachate through the base liner and into the geosphere is overestimated, and therefore, environmental concentrations are likely to be conservatively high.

The rate at which water is able to infiltrate the Facility through the cover, and the rate at which water is able to leak through the liner, are very important parameters in the PostSA. The infiltration rate, minus the leakage rate, influences how quickly a "bathtub" scenario can occur. The bathtubbing scenario occurs when the water level in the Facility rises, eventually causing "overtopping", which refers to leachate escaping over the berm, at the lowest point in the Facility. The time at which overtopping occurs has important implications on the results of the PostSA, specifically on the concentrations of radioactivity in the environment, and as well as the resulting dose to the biota and human receptors. As mentioned previously, the cover is modelled to have mostly failed in 550 years, causing the bathtubbing effect shortly thereafter. Since the radioactivity in the Facility continues to decrease with time due to radiological decay, the longer the cover performs, the less radioactivity is available to reach the environment. With that said, the radioactivity concentration in the facility after 550 years is low, and is comparable to the natural background concentrations.

### **Human Intrusion**

For the purposes of the NSDF and the PostSA, human intrusion refers to the act of physically coming into contact with the waste materials, inadvertently. The Normal Evolution Scenario assumes that a receptor lives on top of the ECM, but does not necessarily come into direct contact with the waste materials.

Human intrusion scenarios were assessed in previous iterations of the PostSA and related scoping calculations. The final PostSA considers the following scenarios involving human intrusion into the waste material:

- Borehole drilling
- Construction of a house with a basement

For the human intrusion events considered, all include deliberate conservatisms to ensure that the dose is overestimated.

#### ***Borehole Driller***

In the borehole driller scenario, the borehole penetrates a series of packages containing wastes at the upper limit of the WAC for packaged waste. This is a very conservative modelling assumption because:

- Waste packages are intended to be placed in 1 or 2-dimensional arrays, not stacked several high in one location. This is both for radiological protection measures during the ECM operations, but also for compaction requirements. It is desirable to surround packages with soil-like wastes as much as possible to fill voids around packages and to create a compactable layer. Therefore, the idea that a borehole would penetrate vertically through multiple packages is very unlikely.
- Waste packages exhibiting radioactivity concentrations near the WAC limits may be subject to grouting/concrete filling, both to reduce the external dose rate, and to fill voids in the container. It is very likely that a borehole auger will be rejected by the solid concrete package, causing the operator to either stop or re-evaluate the situation. This may prevent or deter the borehole driller from coming into contact with any packages lower into the ECM.



***House with a Basement***

In this scenario, the resident excavates 2.5 metres into the top of the ECM to construct a house with a basement. The result is that all cover materials, and the first 0.45 m of waste are excavated. The resulting cover materials and waste materials are mixed together and used in the garden to grow vegetables, which are consumed by the resident. This scenario is conservative because:

- The multiple layers and barriers of the cover system should indicate to a digger that they are intruding on something man-made. Perhaps the soil and sand layers are nothing to cause alarm, but the HDPE layer should quickly indicate an artificial installation.
- Even if the HDPE has degraded to a point where it is not recognizable, the cover includes a 0.5 metre layer of rock aggregate fill, known as the Intrusion Barrier. Its primary purpose is to deter burrowing animals and the roots of vegetation. However, this particular layer should stand-out in an excavation project as something unnatural and unexpected at that depth.

Human Intrusion scenarios were assessed for both the expected 300 year institutional control period, as well as for 100 year period to demonstrate that the dose is acceptable even without the full duration. The peak dose in the House with a Basement scenario 100 years after closure is 0.04 mSv/y, which is only 4% of the 1 mSv/y dose acceptance criteria. This demonstrates that the NSDF is not dependant on a long institutional control period.

***What-If?***

In addition to the human intrusion scenarios described above, a “What-If?” scenario was included to assess the effects of a deliberately conservative and bounding case. In this scenario, the resident uses a shallow well drilled directly into the contaminant plume and use this water for domestic use as well as to provide water for cattle. This scenario introduces several conservatisms, including:

- Shallow wells are not common practice. The median well depth between Rolphton and Pembroke is 38.3 m [8-4], whereas the ECM is about 18 metres at its peak height.
- The water source is assumed not to mix with any fresh groundwater. That is, the well is sourced only from leachate.

Due to the very low probability of this event, the scenario is classified as a “What-If?”. The purpose of the scenario is to test extreme limits and assumptions about the system. Using the Reference Inventory, the receptor in this scenario received a dose greater than the 1 mSv/y public dose limit. The PostSA identified that the vast majority of the dose was as a result of Pu-239 and I-129 exposure. To meet the 1 mSv/y public dose limit in this unlikely scenario, CNL has made the decision to decrease the Pu-239 and I-129 inventories by 58%, leading to the creation of the final “Licensed Inventory”, further described in Section 5.7.

**Comparison between the design & planning basis, and what is modelled**

The above sections have discussed some of the conservatisms used in the PostSA [8-1] modelling. Table 8-1 provides a comparison between the design, modelling assumptions, and a statement on conservatism.

**Table 8-1**  
**Conservatisms in the PostSA Modelling**

| Design or planning basis                                                                                                                                                                                                                                                                                                                                                                                 | Modelled in the PostSA                                                                                                                                                                                                                            | Why is this a conservative modelling assumption?                                                                                                                                                                                                                                                                                                                                                                                                                                             |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| The Reference Inventory is an upper limit of radioactivity in the Facility.                                                                                                                                                                                                                                                                                                                              | <p>It is assumed that 100% of the Reference Inventory is present in the Facility at closure.</p> <p>In addition, a Sensitivity Case is explored using the 10 times the Reference Inventory.</p>                                                   | <p>It is possible that the Facility will fill up in physical volume before it fills from radioactivity limits. It is unlikely to contain exactly 100% of all radionuclides in the Reference Inventory. This makes the use of the Reference Inventory a bounding and conservative assumption.</p> <p>The maximum inventory limit is referred to as the Licensed Inventory, which is less than the Reference Inventory. As a result, the inventory assessed in the PostSA is conservative.</p> |
| <p>The footprint of the Facility is designated as a Disposal Facility. The land is not intended for re-use in the foreseeable future. AECL is committed to enforcing the land-use restriction for as long as required/possible.</p> <p>Institutional Controls are in place to restrict the use of the Facility footprint.</p> <p>As a result, there should not be a human intruder or site resident.</p> | <p>The land-use restriction on the Facility (and all other Institutional Controls) are assumed to be lost at 300 years post-closure.</p> <p>The resulting assumption allows for a human to intrude on the property and establish a residence.</p> | <p>The CRL site is unlikely to be abandoned or released for unrestricted use in the foreseeable future.</p>                                                                                                                                                                                                                                                                                                                                                                                  |
|                                                                                                                                                                                                                                                                                                                                                                                                          | <p>The resident who lives on the facility footprint is also a farmer, and uses the land to grow crops and graze livestock. The resident consumes a portion of his own crop yields.</p>                                                            | <p>Use of a Farmer instead of simply a Resident increases the potential exposure to radionuclides due to the uptake in the soil and crops, as well as uptake into the livestock (cows and chickens).</p>                                                                                                                                                                                                                                                                                     |
|                                                                                                                                                                                                                                                                                                                                                                                                          | <p>All receptor characteristics (food/water intake, breathing rates, etc.) as well as the transfer factors and equations used to determine the rate at which contaminants move through the environment to</p>                                     | <p>CSA standards are intentionally developed to be conservative. Their use is an additional layer of conservative inputs into an assessment.</p> <p>Certain receptor characteristics, such as the occupancy factor, are deliberately chosen to remain</p>                                                                                                                                                                                                                                    |

| Design or planning basis                                                                       | Modelled in the PostSA                                                                                                                                                                                                                                                  | Why is this a conservative modelling assumption?                                                                                                                                                                                                                                                                                                     |
|------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                                                                                                | livestock, are taken from CSA N288.1-14.<br><br>Occupancy factors assume that the farmer never leaves the facility site.                                                                                                                                                | conservative. For example, it is assumed that the farmer never leaves the property, therefore maximising the potential dose.                                                                                                                                                                                                                         |
| Some wastes will be contained in steel liners or other forms of leachate-controlled packaging. | Except for a single scenario which specifically examines the effect of the packages as an additional barrier, no scenarios take credit for the presence of packages.                                                                                                    | Robust packaging can slow the release of radionuclides from the waste. Ignoring this effect could overestimate the rate at which radionuclides migrate through the waste, and is therefore conservative.                                                                                                                                             |
| The engineered barriers have a design life of 550 years.                                       | The HDPE GMB is assumed to have some leakage rate, and almost fully degrades at 550 years after construction.<br><br>The liner system contains two separate HDPE layers separated by other barrier material. Both HDPE layers are modelled to degrade at the same rate. | The HDPE GMB testing program concludes that several of the candidate materials are likely to maintain their integrity for well over the 550 years, up to 2 000 years.<br><br>The double HDPE liner is unlikely to degrade at the same rate, with the secondary HDPE degrading at a slower rate given that it is protected by other barrier material. |

### 8.1.8 Post-Closure Safety Assessment Results and Discussion

The PostSA results demonstrate that the facility meets dose acceptance criteria for all applicable scenarios. This section discusses the implications of some of the results of the PostSA. For a comprehensive discussion of the results, see Section 6 of the PostSA report [8-1].

#### **Mass Excavation**

The PostSA examines a scenario where the entire waste and barrier mass is excavated, mixed, and deposited on the surface, 300 years after the closure of the Facility. A resident/farmer builds a house directly on the mix of waste and barrier materials. The scenario is modelled similarly to the NES, except there is more direct exposure to the waste, and the waste is more readily available to the environmental pathways.

The peak dose from this scenario is 0.43 mSv/y to the adult farmer, and meets the public dose acceptance criteria of 1 mSv/y.

The low radiological consequence of this scenario confirms that the waste material itself is a low hazard, especially after the significant decay experienced in the first couple hundreds of years.

By placing the waste into an ECM with multiple barriers separating the waste from the environment, the hazard is greatly reduced. Comparison with the NES demonstrates that the barriers are responsible for reducing the dose by a factor of about 30 times.

### ***Establishment of a Buffer Zone***

A key assumption of the NES is that land-use restrictions and institutional controls are lost, such that the resident is able to construct a house directly on the ECM.

The PostSA examines a scenario where the receptor respects the land-use restrictions, and instead builds a residence where Perch Creek and the Ottawa River meet.

Because the receptor is living on the Ottawa River banks, it is assumed that a portion of their fish come from the Ottawa River. They also use the Ottawa River as a primary source of drinking water.

The peak radiological consequence to a resident living on the Ottawa River banks is 0.0017 mSv/y. Compared to the NES, the dose is reduced by a factor of about nine, simply by adhering to the land-use restrictions imposed on the site. For perspective, this dose is less than 0.1% of the natural annual Canadian background dose experienced by everyone, which is about 2 mSv/y.

### ***The Bathtub Effect***

Both the final cover and base liner systems of the ECM contain multiple layers of synthetic and natural materials intended to contain and isolate the waste for many hundreds of years, at which point the hazard has significantly decreased through radioactive decay.

The final cover is exposed to the environment, i.e., weathering and erosion. The base liner system is not subject to the same erosion effects because it is located many metres below grade. By this fact alone it is expected that the final cover will erode much faster than the base liner system. As the final cover degrades, water is allowed to infiltrate into the waste. The base liner system, supported by a compacted clay liner, is still functioning, and will not allow this water to exit the Facility. At some point, the water level in the ECM will rise enough to overtop the perimeter berm, allowing water which has come into contact with waste to exit the ECM. This is known as the “bathtub” effect.

The bathtub effect is a natural evolution of the ECM, and is included in the PostSA modelling. Although the ECM eventually enters this state, it is important to put the consequences of this evolution into context. With the conservative assumptions made in the PostSA regarding the cover degradation rate, this bathtub effect is expected to occur at about 450 years after the closure of the Facility, and remain in this condition for several thousand years while the liner system performs as an effective barrier. By the time this effect begins, the waste has already decayed to only 0.026% of its original radioactivity. In other words, 99.97% of the radioactivity in the Facility has decayed. In addition, the radiotoxicity of the waste material is far below that found in natural surficial ore bodies in the local area, as demonstrated in Section 2.3.1.1 and Figure 8-2.

The bathtub effect may cause some water-soluble material to migrate from the ECM, but the hazard has been significantly reduced to near background levels of radioactivity concentration.

### ***Radioactivity in the Environment***

The PostSA calculates and assesses the concentration of radioactive material in the environment as a result of the NSDF’s natural evolution for hundreds and thousands of years, as barriers degrade and contaminants migrate from the ECM. Figure 8-11 below shows the modeled migration of contaminants from the Facility to

the environment throughout the assessment timeframe and beyond. Figure 8-11 also shows that the vast majority (over 99%) of the wastes are contained in the ECM while radioactive decay is occurring. Over time, the conservative modelling performed in the PostSA shows that some contaminants migrate through the engineered barrier systems and into the environment. Contaminants that leave the modelled system are considered to be in biosphere “sinks”. A good example would be trace quantities of tritium that enter the atmosphere – quantities so low and so dilute that they would be almost unmeasurable a few kilometers from the point of release.

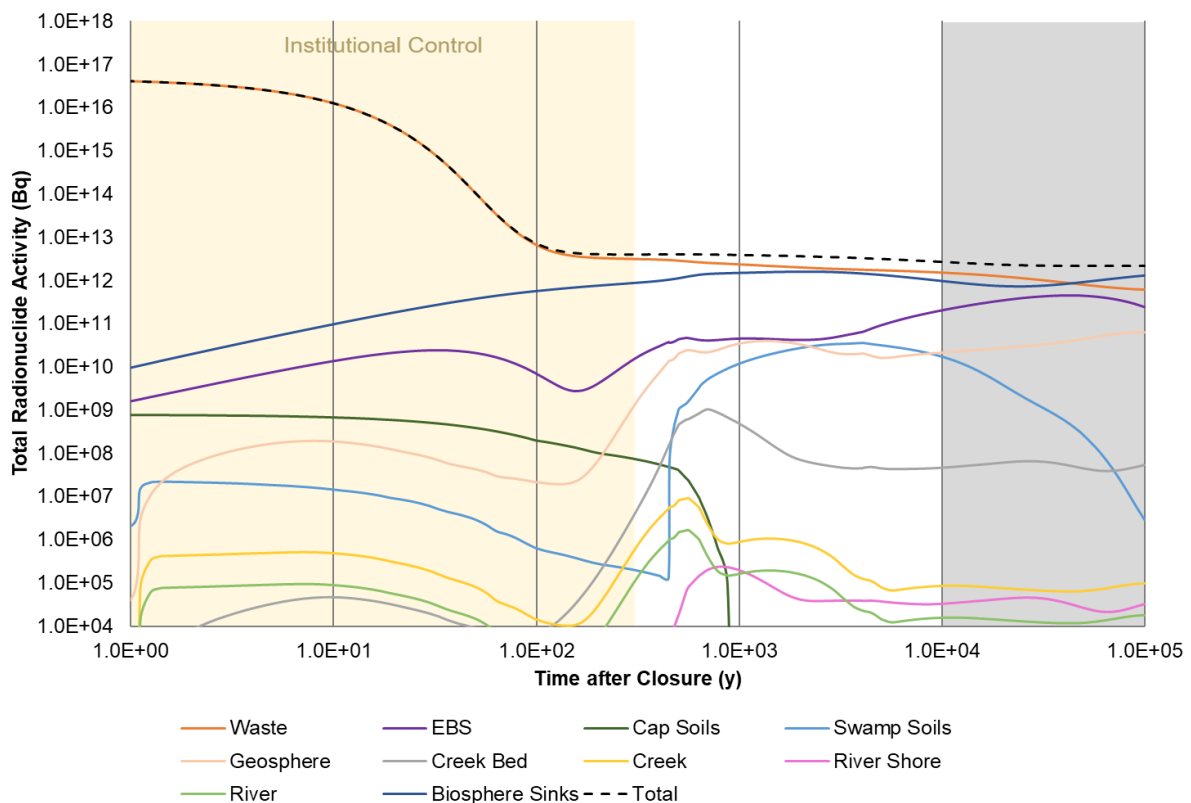


**Figure 8-11 Radioactivity Migration with Time**

### 8.1.9 Radiological Inventory and Decay at times of Interest

As discussed above in Section 8.1.1, the NSDF only contains LLW. This section presents details about the waste inventory as it changes with time, and the data at specific points of interest.

These times of interest are related to how the PostSA model is built, and the assumptions that are used. The timeframes of particular interest in the PostSA are:

- Year 2100 – Closure
- Year 2200 – Early end of institutional control (Sensitivity Analysis)
- Year 2400 – Normal Evolution assumed end of institutional control
- Year 2570 – End of NSDF barrier design life of 550 years total from start of construction
- Year 12,000 – End of assessment timeframe, as discussed in Section 4.

The Radiological Inventory presented in Section 3.3 presents the significant 30 radionuclides, chosen using a variety of screening factors such as known quantities in the waste streams, half-life, potential radiological consequences, radiotoxicity, and ability to migrate through the environment. Table 8-2 below provides the total radioactivity values in the ECM taking ingrowth and decay into consideration.

**Table 8-2**  
**Total Radioactivity (Bq) in ECM at Different Timeframes of Interest**

|   |                           | <b>0 y</b> | <b>100 y</b> | <b>300 y</b> | <b>450 y</b> | <b>550 y</b> | <b>4100 y</b> | <b>Notes</b>                                                                                                                        |
|---|---------------------------|------------|--------------|--------------|--------------|--------------|---------------|-------------------------------------------------------------------------------------------------------------------------------------|
| A | Decayed Inventory         | 100%       | 0.032%       | 0.022%       | 0.022%       | 0.022%       | 0.018%        | Inventory at time t, following decay and ingrowth                                                                                   |
| B | Inside ECM                | 100%       | 0.028%       | 0.016%       | 0.016%       | 0.014%       | 0.008%        | Inventory inside the ECM at time t, following decay and ingrowth (Note A=B+C)                                                       |
| C | Outside ECM               | 0%         | 0.004%       | 0.006%       | 0.007%       | 0.008%       | 0.010%        | Inventory outside the ECM at time t, following decay and ingrowth (Note A=B+C)                                                      |
| D | Cumulative Released       | 0%         | 0.005%       | 0.007%       | 0.008%       | 0.010%       | 0.015%        | The cumulative activity released in water and gas, this does not include decay / ingrowth in the geosphere / biosphere post-release |
| E | Decayed in ECM (100%-D-B) | 0%         | 99.967%      | 99.977%      | 99.976%      | 99.976%      | 99.977%       | The initial inventory that has decayed in the ECM                                                                                   |
| F | Decayed outside ECM (D-C) | 0%         | 0.0011%      | 0.0012%      | 0.0013%      | 0.0014%      | 0.0051%       | The initial inventory that has decayed outside the ECM                                                                              |

After only 100 years, the radioactivity has reduced to only 0.03% of the original, which is a reduction of over 2300 times. This sharp reduction in radioactivity occurs because many of the common radionuclides (e.g., cobalt-60, tritium, strontium-90, and cesium-137), have relatively short half-lives, and decay away quickly.

The reduction in inventory is even more pronounced when we reach the end of the assumed institutional control period of 300 years after closure. At this time, the radioactivity has decayed to about 0.02% of the initial values. The PostSA calculates dose to receptors during the NES at this timeframe, including a resident/farmer who lives directly on top of the waste footprint.

By the end of the design life of the geomembrane (GMB), the radioactivity has decreased to only 0.02% of the initial activity. At this point in the PostSA, the rate of water accumulation in the ECM greatly increases, eventually causing a “bathtub” effect which allows for contaminated water to exit the ECM. The time at which “bathtubbing” occurs, is greatly dependent on the integrity of the GMB. While the PostSA assumes that the GMB degrades at 550 years, the actual service life of the material could be up to 2 000 years according to the GMB testing program.

When the ECM has been closed for 4100 years, the radioactivity has decayed 0.018% of the original values. At this point, the radiological inventory is dominated by longer-lived radionuclides. Although the reduction in inventory due to decay is no longer occurring at a fast pace, the concentration of radionuclides has long since approached the natural background concentrations of the local area.

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**8.1.10 Building Confidence with Defence in Depth**

Defence-in-depth is a term used to describe how safety is achieved through multiple barriers working together. The failure or unavailability of a single barrier should not result in unsafe conditions. While Section 8.1.6 above discusses the multiple physical barriers, this section discusses all barriers, including engineered, natural, and administrative.

The NSDF includes multiple barriers to ensure safe operation and limit the releases to the environment. The engineered barriers along with the natural barrier work together to form a strong robust disposal system. Engineered barriers refer to materials or procedures designed specifically for the NSDF. Natural barriers refer to materials or naturally occurring processes that are part of the disposal system. Administrative barriers refer to processes or procedures which contribute to the overall safety of the NSDF.

The following figures illustrate some of the main barriers in the disposal system (Figure 8-12), the pre-closure phase (Figure 8-13) and the post-closure phase (Figure 8-14). The colours in the figures represent:

- Red for administrative barriers.
- Green for natural barriers.
- Blue for engineered barriers.

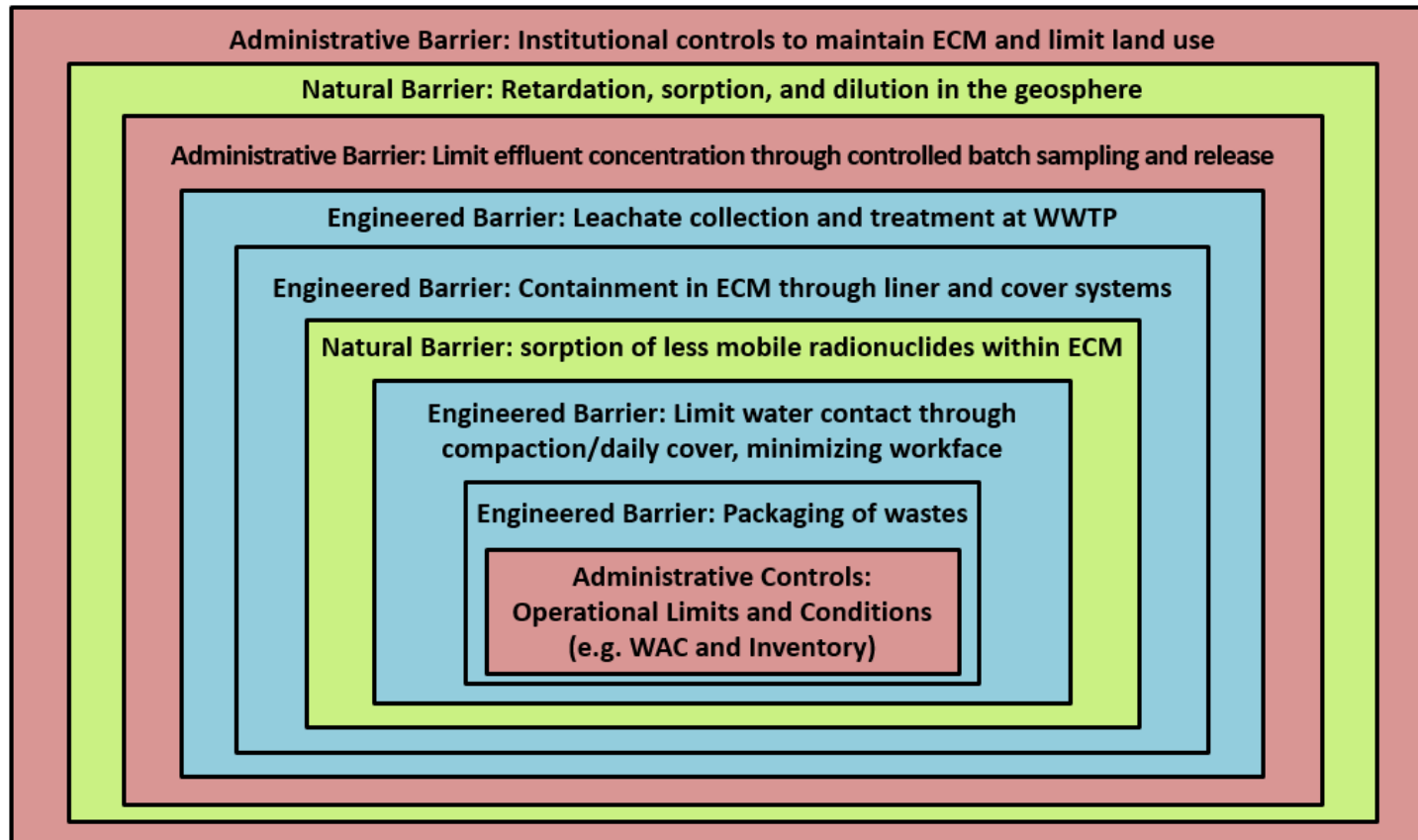


Figure 8-12 Multiple Barriers of the NSDF System



|                                                                                                             |
|-------------------------------------------------------------------------------------------------------------|
| Administrative Barrier: CRL property is restricted to the public                                            |
| Administrative Barrier: Limit effluent concentration through controlled batch sampling and release          |
| Engineered Barrier: Active drain system in WWTP                                                             |
| Engineered Barrier: Leachate treatment system, secondary containment                                        |
| Engineered Barrier: Leachate treatment system, primary containment                                          |
| Engineered Barrier: Leachate collection system                                                              |
| Administrative Barrier: Quality Assurance and Quality Control measures on all liner and cover installations |
| Natural Barrier: (Cover) – Intrusion barrier, rock and soil layers                                          |
| Engineered Barrier: (Cover) – High Density Polyethylene geomembrane                                         |
| Engineered Barrier: (Cover) – Geosynthetic clay liner                                                       |
| Engineered Barrier: sorption of less mobile radionuclides within waste forms                                |
| Natural Barrier: (Liner) – Rock and sand layers                                                             |
| Engineered Barrier: (Liner) – Primary High Density Polyethylene geomembrane                                 |
| Engineered Barrier: (Liner) – Primary Geosynthetic clay liner                                               |
| Natural Barrier: (Liner) – Rock and sand layers                                                             |
| Engineered Barrier: (Liner) – Secondary High Density Polyethylene geomembrane                               |
| Engineered Barrier: (Liner) – Secondary Geosynthetic clay liner                                             |
| Natural Barrier: (Liner) – Compacted Clay                                                                   |
| Engineered Barrier: Limit water contact through compaction/daily cover, minimizing workface                 |
| Engineered Barrier: Packaging of some wastes                                                                |
| Administrative Barrier: Operational Limits and Conditions (e.g. WAC and Inventory Limits)                   |

**Figure 8-13 Pre-Closure Phase – Multiple Barriers**

|                                                                                                                    |
|--------------------------------------------------------------------------------------------------------------------|
| Administrative Barrier: Land-use restrictions placed on property deed                                              |
| Natural Barrier: Contaminant transit time from ECM to Perch Creek                                                  |
| Natural Barrier: Retardation provided by the biosphere                                                             |
| Administrative Barrier: Passive Institutional Controls, including fences, markers and monoliths to deter intrusion |
| Administrative Barrier: Active Institutional controls, including periodic maintenance, monitoring, and surveying   |
| Administrative Barrier: Quality Assurance and Quality Control measures on all liner and cover installations        |
| Natural Barrier: (Cover) – Intrusion barrier, rock and soil layers                                                 |
| Engineered Barrier: (Cover) – High Density Polyethylene geomembrane                                                |
| Engineered Barrier: (Cover) – Geosynthetic clay liner                                                              |
| Engineered Barrier: sorption of less mobile radionuclides within waste forms                                       |
| Natural Barrier: (Liner) – Rock and sand layers                                                                    |
| Engineered Barrier: (Liner) – Primary High Density Polyethylene geomembrane                                        |
| Engineered Barrier: (Cover) – Primary Geosynthetic clay liner                                                      |
| Natural Barrier: (Liner) – Rock and sand layers                                                                    |
| Engineered Barrier: (Liner) – Secondary High Density Polyethylene geomembrane                                      |
| Engineered Barrier: (Cover) – Secondary Geosynthetic clay liner                                                    |
| Natural Barrier: (Liner) – Compacted Clay                                                                          |
| Administrative Barrier: Low radiological inventory due to compliance with WAC and Inventory Limits                 |

**Figure 8-14 Post-Closure Phase – Multiple Barriers**

### 8.1.11 Dose Acceptance Criteria

The safety assessments performed in the support of the NSDF Project demonstrate that all dose acceptance criteria have been met. Table 8-3 below, provides a summary and comparison of the dose acceptance criteria and safety assessment results.

**Table 8-3**  
**Comparison of Dose and Dose Acceptance Criteria**

| Scenario Description                                  | Dose Acceptance Criteria | Highest Calculated dose to receptor | Criteria met? | % of Criteria |
|-------------------------------------------------------|--------------------------|-------------------------------------|---------------|---------------|
| Normal operations – dose to public                    | 1 mSv/y                  | << 0.1 mSv/y                        | ✓             | << 1%         |
| Normal operations – dose to worker                    | 20 mSv/y                 | 10.4 mSv                            | ✓             | 52%           |
| Design Basis Accident – dose to public                | 0.5 - 20 mSv             | 0.02 mSv                            | ✓             | 0.1%          |
| Design Basis Accident – dose to worker                | 5 – 50 mSv               | 2.4 mSv                             | ✓             | 5%            |
| Normal Evolution Scenario – dose to critical receptor | 0.3 mSv/y                | 0.015 mSv                           | ✓             | 5%            |
| Disruptive Events – dose to critical receptor         | 1 mSv/y                  | 0.14 mSv                            | ✓             | 14%           |

The table above demonstrates that the NSDF safety assessments calculated dose rates are within the dose acceptance criteria with sufficient safety margin. It is important to note the major conservatisms incorporated into the calculation of dose, particularly in the Post-Closure phase of the Project. When a dose is calculated for the Normal Evolution Scenario, it's easy to simply compare it to the dose acceptance criteria, and make a claim that the value is only 5% of the criteria, for example. However, the conservative assumptions that have been incorporated into the calculation should be acknowledged when discussing the radiological consequence for the scenario or the event. The complete way of reporting a dose should recognize the layers of conservatism inherent in the calculations. For example:

The calculated maximum dose to the critical receptor in the Normal Evolution Scenario is 0.015 mSv/y, assuming that:

- The Facility contains 100% of the Reference Inventory (conservative, as the facility only contains the Licensed Inventory, which is smaller than the Reference Inventory).
- The Federal Government of Canada is no longer able to enforce land-use restrictions on the Facility footprint after 300 years post-closure.
- Societal memory has failed, i.e., people forget that the site was a nuclear research establishment and choose to build a house on the footprint.
- Physical barriers, such as fences, do not deter the receptor from building a residence.
- The resident is also a farmer and consumes his or her own crops and livestock. The livestock graze in the area directly adjacent to NSDF, where a contaminant plume could migrate.
- All of the conservative assumptions about the receptor's food and water intakes are accurate, and the residents spend 100% of their time on the NSDF site.
- The high-density polyethylene geomembrane and geosynthetic clay liner barrier system only performs for its design life and then immediately degrades.

### **8.1.11.1 Safety Margin as Applied to Radiation Dose Limits**

When dose limits are expected to be met in the nuclear industry, the common practice is to be within the limits with a sufficient “safety margin”. The intent of the safety margin is to provide confidence in the results, and to account for uncertainties in the assumptions and inputs used during the dose calculations.

The next sections will put the doses assessed in this report, and the safety margin on doses, into context.

#### **Natural Background Doses**

Before a discussion of relative health effects, it’s important to understand the relative magnitude of the doses discussed in this Safety Case. The Normal Evolution Scenario of the PostSA calculates doses to the critical receptor at about 0.015 mSv [8-1].

The average effective dose from natural background radiation is about 2 mSv per year in Canada, and 2.4 mSv per year worldwide [8-5]. About half of this dose is from the inhalation of radon gas from the earth’s crust, the other portions are from ingestion of food, exposure from radiation in the ground/environment, and from cosmic radiation. All of these sources are completely natural. Everyone is exposed to a baseline of natural background radiation for their entire lives.

The background dose rate can vary greatly, depending on physical location on Earth and the local geology. For example, background doses in Northern Iran can be as high as 260 mSv per year [8-6].

Studies that examine populations in high background radiation areas find that there is no statistical difference in cancer rates between people living in these high background areas compared to low background areas [8-7], [8-6].

This suggests that there is little difference between the health effects of 2 mSv per year and up to 260 mSv per year. The important factor here is that the background doses are occurring slowly and at a constant rate.

#### **Deriving Dose Limits**

The risks from radiation and subsequent dose limits are largely derived from atomic bomb survivor studies, where the incidence of disease was plotted against radiation dose received [8-8]. These were high doses delivered instantaneously.

Where data existed, the relationship between dose and cancer was linear, meaning that when radiation dose increased, cancer risk increased.

However, at lower doses closer to background levels, it was difficult to distinguish between cancer induced from the atomic bomb, versus the normal rate of cancer for the general population. Essentially, at low doses, cancer risk in atomic bomb survivors versus general public appears to be similar.

Due to the linear response observed at high doses, it was very conservatively assumed that all low doses also increase cancer risk incrementally. This is known as the Linear-Non-Threshold model, and is the most conservative of all proposed dose-risk models. As a result, it is assumed that any amount of radiation dose has the potential to increase cancer risk, and the guidelines put forth by international bodies such as the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency reflect this assumption when recommending limits on public dose exposure. The Canadian Nuclear Safety Commission has adopted these recommendations in their regulations.

The lowest dose associated with an increase cancer risk has been observed to be 100 mSv [8-8].

In an effort to ensure that this dose is not reached, the dose limit to the public is very conservatively set at 1 mSv/y. This is a safety margin of 100 times.

### **Dose and Risk**

The ICRP have studied the relationship between effective dose in humans and the development of cancer [8-9]. For every Sievert (1 000 mSv), it is estimated that mortality rate from cancer increases by 5% (assuming the linear, non-threshold hypothesis). In other words, the risk of fatality from exposure to ionizing radiation is conservatively estimated at 5% per Sievert.

Consequently, the Canadian background dose of 2 mSv/y (or 0.002 Sieverts) per year has an associated risk of: 0.002 Sv per year multiplied by 5% per Sv = 0.01%.

The calculated dose to the receptor living on the NSDF at the end of the institutional control period is 0.015 mSv/y. Expressed as risk, this is equivalent to 0.0008%.

Expressed as risk percent:

|                                                           |          |
|-----------------------------------------------------------|----------|
| Risk from natural background radiation per year (Canada): | 0.01%    |
| Risk from living on top of the NSDF:                      | 0.00008% |
| Total risk to the individual (Canada background + NSDF):  | 0.01008% |

Special mention for perspective:

|                                                             |       |
|-------------------------------------------------------------|-------|
| Risk from natural background radiation per year (Winnipeg): | 0.02% |
|-------------------------------------------------------------|-------|

The difference in risk between a person exposed to the natural background radiation, versus a person exposed to both the natural background radiation in addition to the NSDF, is insignificant, and is completely lost as noise if uncertainties were included. It's worth noting that residents of Winnipeg have almost twice the risk of the resident who lives on the NSDF, as result of Winnipeg's higher natural background dose.

Figure 8-15 provides a visual perspective on the dose rates we are discussing in the Safety Case. Discussions about "safety margin" on the dose rate occur in a range of dose rates that is insignificant compared to the natural background, and especially when compared to doses that may be linked to adverse health effects.

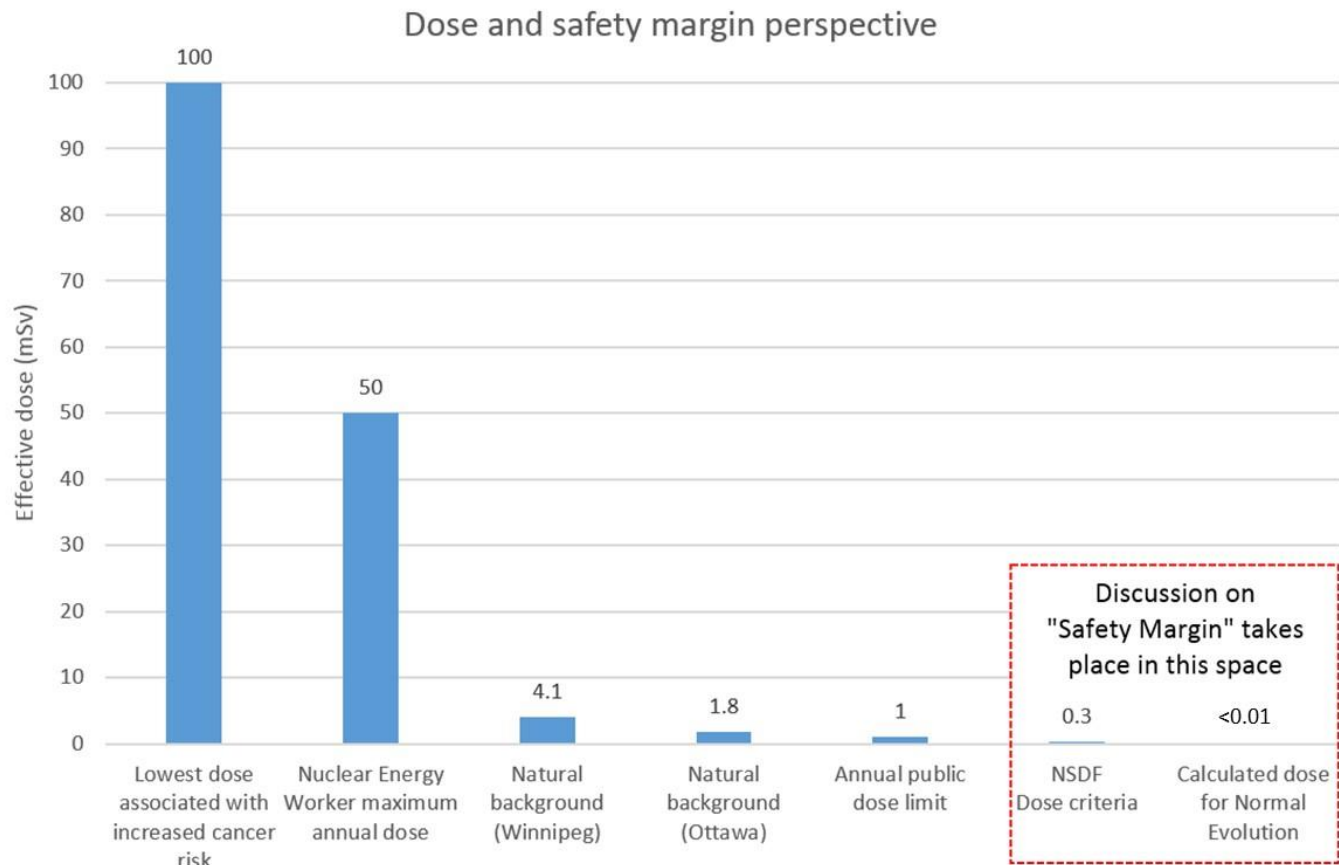


**Figure 8-15 Comparison of Various Doses and Perspective on Safety Margin Discussion**

**8.1.11.2 Safety Margin Discussion Summary**

The method in which that the international nuclear industry sets public dose limits is very conservatively calculated.

The use of data from high, instantaneous doses to individuals and deriving yearly dose limits introduces many conservatisms directly at the beginning of the process. This derivation makes no concession for the body’s natural defence mechanisms against low doses of radiation received over long periods of time.

A discussion on “safety margin” on a dose acceptance criteria of 0.3 mSv/y is redundant, as the derivation of the 0.3 mSv/y dose acceptance criteria contains layers of safety margin built into it, specifically instantaneous dose versus dose over a long period of time, and the hypothesis that low doses contribute to risk.

Having said that, the ALARA principle is and always will be a very important pillar of CNL. Maintaining doses ALARA is the driving force behind many of the design optimizations and inventory reductions that the NSDF Project has performed since project initiation. The purpose of the above section was to provide perspective and comparison into the topic.

## 8.2 Other Topics

This section addresses some miscellaneous arguments related to the NSDF Project, but not necessarily key messages related to safety. Some of these topics are discussed in response to feedback received from Project reviewers, stakeholders, and the public.

### 8.2.1 Waste Storage Capacity

The Project has received comments from both the public and other reviewers regarding the relationship between the capacity of the NSDF and the forecasted waste volumes. There can be two scenarios – either there is less than 1 000 000 m<sup>3</sup> of LLW, or there is more than 1 000 000 m<sup>3</sup>.

If there is less than 1 000 000 m<sup>3</sup> of LLW, the cover system design will be modified, and the Facility can be closed ahead of schedule, only partially filled, with no adverse effect on safety. These changes would be considered major changes, and would be subject to CNL's Engineering Change Control processes, and possibly regulatory approvals.

If there is more than 1 000 000 m<sup>3</sup> of LLW, then the NSDF will be filled to its 1 000 000 m<sup>3</sup> capacity, and the surplus wastes will require a different disposal or storage route which will be determined at a much later date. While the proposed NSDF site is adequate for the 1 000 000 m<sup>3</sup> design, the site does not permit significant expansion, due to the presence of the Hydro One transmission lines to the north-west, the top of the ridge to the north-east, and the marshlands to the south-west.

Whether CNL creates 1 000 000 m<sup>3</sup> of LLW in the future is highly dependent on the status of the CRL in several decades from now. The amount of work performed at CRL is highly dependent on the state of the nuclear industry in Canada and internationally, and is difficult to predict.

Regardless of if the NSDF is partially filled, or filled to capacity, the safety case and supporting safety assessments will be updated to reflect the planned Facility state.

### 8.2.2 Overall Confidence in the Results

Section 6 discusses uncertainty and confidence in the modelling and calculations of both the pre-closure and post-closure safety assessments. This section presents additional information with respect to model development and confidence in the results.

For the PostSA, there are several checks that were performed to increase confidence that the results were reasonable and accurate. A few examples are listed below.

- PostSA models are developed based on industry best practices and peer-reviewed standards and regulations. Input data such as dose coefficients, transfer factors, and distribution coefficients are sourced from the most applicable scientifically accepted standards, including the IAEA, the ICRP, and the CSA.
- Previous iterations of the PostSA modelling was performed in a program called RESRAD, where the current modelling is performed in AMBER. The results of the RESRAD modelling are generally consistent with that of the AMBER modelling, indicating that the AMBER model is performing as intended.
- The inputs and model building are being developed by Arcadis Canada, a team with experience with similar assessments, specifically the PostSA for the Nuclear Waste Management Organization's Deep Geologic Repository.
- The implementation of the AMBER model is being performed by the developers and owners of the code, Quintessa. This strengthens confidence that the code is being implemented properly.

- The AMBER code is validated and verified, detailed in the Validation and Verification report [8-10]. In addition, an earlier version of AMBER has been approved for use by CNL's internal Code Management program, indicating that AMBER has been through validation and QA procedures consistent with CNL's licence conditions.
- The inputs used in the model are conservative and likely overestimate the radiological consequence and environmental concentrations of contaminants. Examples of the conservatisms are presented in Section 8.1.7.
- The scenarios chosen for analysis in the PostSA are deliberately conservative. The Defence-in-Depth and "What-If?" scenarios are deliberately extreme cases to demonstrate that safety is achieved even at the boundaries of what is feasible.
- Subject matter experts involved in the development and review of the models also reviewed the output data to determine the results were consistent with expectations. The radionuclides that are expected to contribute the most to dose are present in expected quantities. Contaminants that more readily dissolve into water are shown to migrate into the environment at a faster rate than other, less mobile contaminants. This indicates that the model is performing as intended.
- The PostSA has been subjected to a peer review team comprised of subject matter experts from the US Department of Energy and United Kingdom nuclear industry, summarized in Section 6.
- As discussed in Section 6.4.2.1, a comparison of the NSDF AMBER model was performed in RESRAD-OFFSITE. The results were comparable, within an order of magnitude, providing confidence that the AMBER model is correctly representing the inventory, environmental transport, and pathways of contaminants.

As discussed above, there are many methods in which the PostSA results have been assessed. Canadian Nuclear Laboratories is confident that the PostSA was developed under appropriate QA programs, and that the results of the PostSA are conservative, and reflect best industry practices and scientific understanding of contaminant transport and radiological consequence.

### **8.2.3 Long-term Financing and Guarantees**

Atomic Energy Canada Limited (AECL), a Federal crown corporation, provides the oversight and management of the operating contract on behalf of the Federal Government. Atomic Energy of Canada Limited continues to be the owner of the CRL property, assets and liabilities, regardless of who currently holds the operating contract and responsibilities.

Atomic Energy of Canada Limited, and by extension, the NSDF, benefits from a financial guarantee from Natural Resources Canada [8-11], and therefore, the Federal Government. This greatly increases certainty and confidence that the NSDF Project, once approved, will be completed and not experience funding issues.

### **8.2.4 Long term Management of Technical Competencies**

Chalk River Laboratories do not have a closure date or closure mission. In fact, CRL is currently undergoing a site revitalization, a process which is generating LLW and driving the need for disposal.

Chalk River Laboratories' enduring mission means that qualified technical personnel will continue to work and develop skills related to radiation protection, nuclear safety, decommissioning, and radiation waste management. By extension, the expertise required to continue the safe management and development of the NSDF over several decades should remain at CNL.



The world is currently in a phase of decommissioning some of the first nuclear reactors and nuclear research establishments. It is expected that the knowledge and expertise required to manage the development and maintenance of a disposal facility will be more common in the future. In fact, the Environmental Remediation Management organization in CNL is growing, and is in a position to become a leader in decommissioning and waste management operations. In addition, the NSDF provides a unique opportunity for a possible research and development program to be implemented that could provide testing and monitoring of the engineered barrier systems. This type of R&D would increase the knowledge base of the facility and enhance confidence that technical competencies are cultivated at CNL.

In the unlikely event that CRL ceases its operations as a research establishment before the completion of the NSDF, it is very likely that other nuclear-capable countries would have the necessary expertise to continue the safe operations of the Facility. Atomic Energy of Canada Limited would likely contract operations and maintenance of the NSDF to a qualified bidder, similar to the current government-owned, contractor-operated model of today.

The technical expertise required to safely manage the NSDF will likely be cultivated at CNL. If not, the international nuclear industry is growing and would be able to provide the necessary qualified persons to continue the mission.

#### **8.2.5 Long-term Management of the Chalk River Laboratories Site**

As the enduring Federal entity, AECL has committed to enforcing land-use restrictions on the ECM footprint far into the future, for as long as possible. While enforced, there will be no land development of the ECM footprint. In practice, this means that AECL is committed to managing the repairs and maintenance of the NSDF into the institutional control period.

#### **8.2.6 Stakeholder Engagement**

Canadian Nuclear Laboratories and the NSDF Project have actively engaged the various stakeholders of the NSDF Project, including Federal regulators and agencies, the public, local Indigenous communities, and the local municipalities. Stakeholder engagement has helped shape various aspects of the Facility, such as the preferred site, effluent discharge methodology and location, and reduction of radionuclide inventory. A more comprehensive summary of public engagement activities can be found in the Appendix C and also in the EIS [8-12].

### **8.3 Summary**

This Safety Case document describes the NSDF design, site characteristics and safety requirements, and how the NSDF is an appropriate and responsible solution for LLW that meets the WAC.

Section 1.3 lists safety objectives documented from IAEA documents [8-13] and [8-14], and the CNSC Framework document [8-15]. As a summary, this section discusses how the NSDF meets these objectives.

International Atomic Energy Agency safety objectives include:

*To control the radiation exposure of people and the release of radioactive material to the environment.*

The NSDF design contains multiple physical barriers made of both natural and synthetic materials, designed to contain and isolate the waste material for at least 550 years. All dose acceptance criteria are

met for all facility states and long-term scenarios.

*To reduce the likelihood of events that might lead to a nuclear chain reaction, or a loss of control over the radioactive material or any other source of radiation.*

The NSDF does not contain recoverable quantities of special fissionable material. In addition, the WAC limits the concentrations of specific radionuclides, as well as neutron moderators and reflectors. A Criticality Safety Document was prepared for the Facility, which evaluates the risk of unplanned criticality as being not credible. The NSDF maintains control of radioactive material by a series of physical barriers. In addition to physical barriers, there are also administrative barriers, such as site security and institutional controls that help ensure control over the material.

*To mitigate the consequences of such events if they were to occur.*

In reference to the above point, a loss over the radioactive material is an unlikely event at the NSDF. Most NSDF operations involve the movement of mostly bulk wastes and some packaged wastes. The most consequential event is a fire in the operating waste cell, which is quickly mitigated by CRL's full-time, on-site fire department.

*"...site, design, construct, operate and close a disposal facility so that protection after its closure is optimized, social and economic factors being taken into account. A reasonable assurance also has to be provided that doses and risks to members of the public in the long-term will not exceed the dose limit for members of the public and other risk constraints".*

The PostSA assesses the long-term dose and risk to the members of the public. The results indicate that doses and risk are well below the public dose limits, often less than 1%.

Canadian Nuclear Safety Commission [8-15] safety objectives include:

*The generation of radioactive waste is minimized to the extent practicable by the implementation of design measures, operating procedures and decommissioning practices.*

Canadian Nuclear Laboratories has developed an Integrated Waste Strategy which enables the integration of waste management across CNL, to ensure activities are carried out in a way that protects people and the environment, and complies with Government and Regulatory policies.

The Integrated Waste Strategy considers all types of wastes, and recognizes that there is a hierarchy to waste management practices. From the most favoured option to least favoured, the waste management practices are: Prevent, Reduce, Re-Use, Recycle, and finally dispose.

*The management of radioactive waste is commensurate with the waste's radiological, chemical and biological hazard to the health and safety of persons, to the environment and to national security.*

The ECM is designed to contain and isolate the wastes from the environment for at least 550 years, after which, the radioactivity has decreased to levels close to the natural background concentrations. Since the NSDF Project only accepts LLW and over 99% of the radioactivity; thus, the hazard, decays in the first 100 years after closure, the design of the NSDF Project is commensurate with the hazard.

*The assessment of future impacts of radioactive waste on the health and safety of persons and the environment encompasses the period of time during which the maximum impact is predicted to occur.*

The assessment of future impacts from the Facility is performed in the PostSA document. Canadian Nuclear Laboratories followed the guidance of CNSC's *REGDOC 2.11.1 Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management*, to determine that a 10 000 year assessment timeframe is appropriate for the Facility. This timeframe encompasses the duration of institutional control, the hazardous lifetime of the wastes and the design life of the facility barriers. Peak dose during the most reasonably anticipated, or Normal Evolution of the Facility is 0.015 mSv/y at approximately 4 100 years after closure. The assessment timeframe is consistent with guidance of IAEA SSG-23, which states that safety assessment studies for near-surface disposal facilities typically consider timeframes of a few thousand years. The timeframe is also consistent with the Facility being designed to withstand a 1-in-10 000 year seismic event.

*The predicted impacts on the health and safety of persons and the environment from the management of radioactive waste are no greater than the impacts that are permissible in Canada at the time of the regulatory decision.*

A near surface design is appropriate since the public dose predicted for all plausible scenarios is less than the 1 mSv per year regulatory dose limit for members of the public, as prescribed in the *Radiation Protection Regulations*. In addition, the Normal Evolution Scenario of the PostSA meets the 0.3 mSv per year dose constraint as recommended by IAEA SSR-5. In the pre-closure phase, the regulatory limit and dose constraint above are also met for public exposure.

*The measures needed to prevent unreasonable risk to present and future generations from the hazards of radioactive waste are developed, funded and implemented as soon as reasonably practicable.*

The NSDF is a solution for both legacy wastes generated starting in the 1940s, but also wastes being generated today and in the near future. Wastes generated in the 1940s has been in interim storage since its generation. The responsibility for the management of this material has been effectively passed on to a new generation, ones who were not responsible for its generation. Passing the responsibility for safe management of waste to a future generation is not an acceptable or sustainable long-term practice. The NSDF seeks to end this practice by being a permanent and safe solution for the LLW currently in storage, and up to 1 000 000 m<sup>3</sup> generated by CNL for the next 50 years.

*The trans-border effects on the health and safety of persons and the environment that could result from the management of radioactive waste in Canada, are not greater than the effects experienced in Canada.*

The NSDF and CRL are not located on an international border. The closest portions of the USA are over 200 km south of the site. Dose rates for residents of Ottawa (150 km away, using the Ottawa River as a water source), were calculated to be over a million times lower than the public dose limit, which is indistinguishable from the natural background. Doses further away would be even less, which means there are no trans-border effects from the NSDF Project.

As a radioactive waste disposal facility, the primary concern is the containment of wastes to limit radioactive dose exposure to the public and the environment. Figure 8-16 below shows the calculated dose rates from all scenarios in the PostSA, and compares them to their respective dose acceptance criteria. For perspective, the natural background dose rate in Canada (about 2 mSv/y) is also included.

An examination of Figure 8-16, shows that all scenarios are below respective dose acceptance criteria, and almost all are below the 1 mSv/y public dose limit. The last three scenarios are the “What-If?” scenarios, which are designed to be deliberately pessimistic and conservative to test the extreme bounds of the system.

The Human Intrusion: Mass Excavation and Farming scenario analyses what would happen if the entire waste facility and barrier materials were excavated, mixed, placed back down on the ground, where the resident farmer would then live and raise crops and livestock. Despite the extreme assumptions in this scenario, the dose is still small and less than the public dose limit.

The PostSA evaluated a single scenario that resulted in a calculated radiological consequence greater than the 1 mSv/y regulatory dose limit. This scenario was the Human Intrusion: Shallow Contaminated Well scenario. In this scenario, the resident builds a very shallow well, one that would intersect water that has some direct contact with the wastes. The resident uses the shallow well for drinking, bathing, as well as to water crops and livestock. In the model, the well is placed outside of the ECM, in the groundwater path, towards the marshland. The Ontario Ministry of the Environment maintains a database for each well-constructed in Ontario. An examination of the wells in the region between Rolphton and Pembroke suggests that shallow wells are not common. Water-supply wells typically extend into bedrock with a mean depth of 38 m [8-3]. Therefore, the probability that a human intruder would both live on the ECM, and build a shallow well directly into the waste/into the contaminant plume, is very low. Furthermore, the contaminant plume is located in-between the ECM and the swamp area to the south-west. The construction of a shallow well that close to a source of shallow surface water would result in an undesirable drinking water source, which lowers the probability of this well being used as a primary source of drinking water. This particular scenario calculates the effect of consuming undiluted leachate directly from a waste disposal facility, and concludes that the dose is lower than the natural background experienced by all Canadians. As a result of this scenario studied in the PostSA, CNL has decided to reduce the radionuclide inventory further, in order for this single scenario to also meet the 1 mSv/y regulatory dose limit. This scenario resulted in a reduction of the Pu-239 and I-129 inventories by 58% each, leading to the Licensed Inventory for NSDF.

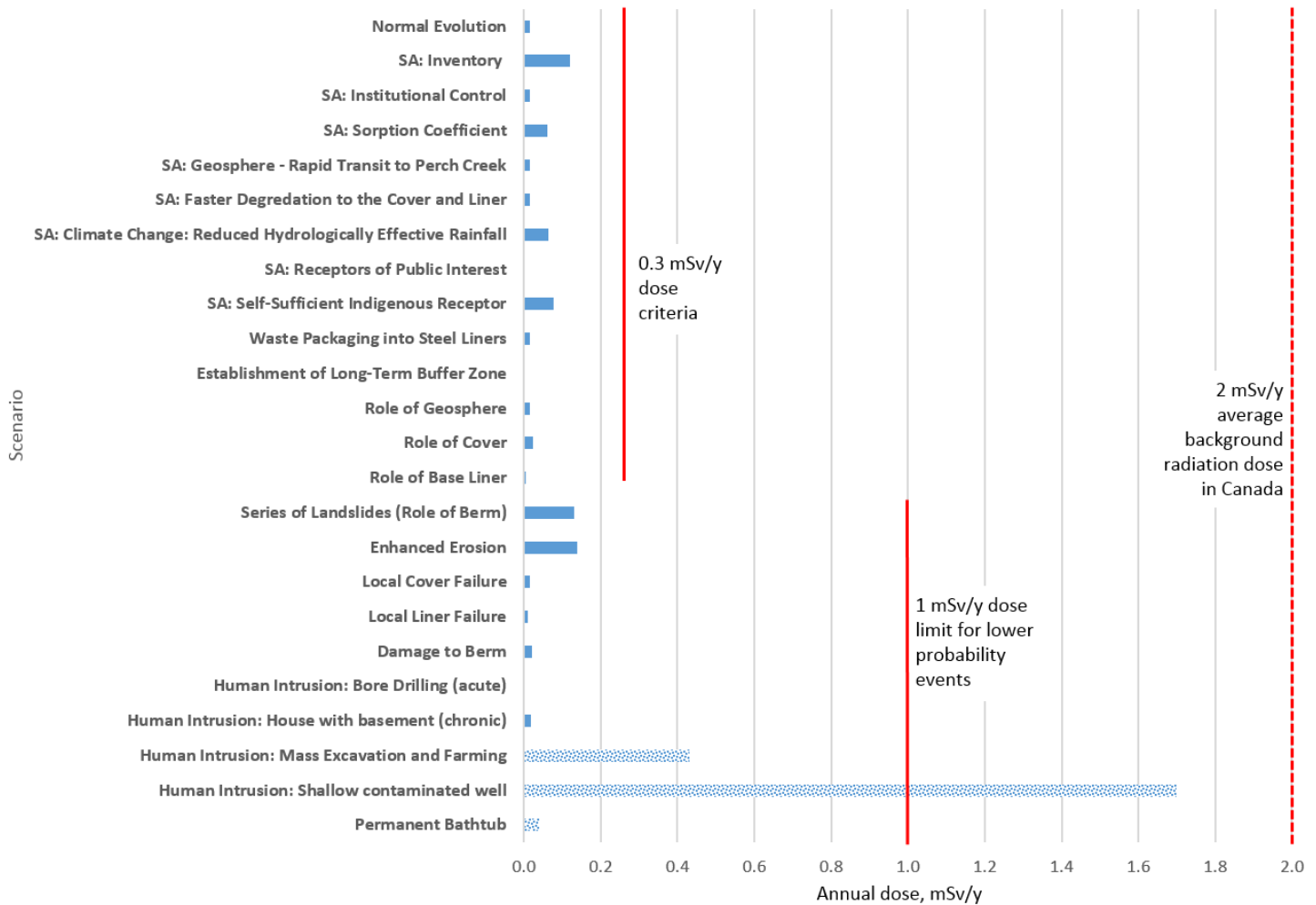


**Figure 8-16 PostSA Dose Summary**

## 8.4 Conclusions

The Safety Case demonstrates that the NSDF Project meets the requirements of IAEA SSR-5 as well as all of the applicable Canadian regulations. Concordance tables which map these requirements to specific reports and analyses can be found in Appendix B.

The waste disposed in the NSDF is contained by a multi-barrier liner and cover system designed to perform multiple safety functions for at least 550 years. The NSDF safety functions are containment, isolation, retardation, monitoring and control. Passive safety engineered features that provide containment include the final cover system, base liner system, and the perimeter berm. The NSDF design relies on passive systems to ensure long-term safety. The safety functions fulfilled by the passive systems are containment, isolation and retardation. The NSDF design, based on multiple safety functions, ensures that safety is not dependent on a single safety function.

The ECM is designed to contain and isolate the disposed radioactivity. Over time the total amount of radioactivity in the wastes will decrease through decay, although the activities of some radionuclides may

increase through ingrowth. The engineered barriers that contain and isolate the wastes will gradually degrade over time, and a small amount of radioactivity will be released from the ECM.

The total planned activity for disposal is  $1.5\text{E}+16$  Bq. The major component of this activity is cobalt-60. The inventory of cobalt-60 for disposal is  $1.47\text{E}+16$  Bq, i.e., 98.1% of the total. Cobalt-60 has a half-life of about 5.3 years, so cobalt-60 will decay to negligible levels (less than 0.1% of the initial values) before the engineered barriers are expected to degrade. This is confirmed by the results of the assessment of the Normal Evolution Scenario in the PostSA, which calculates that at the time the engineered barriers have degraded such that they no longer provide significant physical containment, 99.991% of the disposed inventory has decayed within the ECM. Only 0.005% of the disposed activity has been released from the ECM.

At the end of the assessment timeframe of 10,000 years, the total activity remaining in the ECM was calculated to be  $1.73\text{E}+12$  Bq, with an average activity of 1.1 Bq/gram. This is equal to the local background radioactivity activity at the NSDF site, although the mixture of radionuclides present would be different to the background radioactivity, and hence the radiotoxicity would be different.

After 100 years, 99.984% of the disposed activity has decayed in the ECM, and at 300 years 99.991% of the disposed activity has decayed in the ECM. Therefore, a period of institutional control lasting between 100 years and 300 years will ensure the wastes are isolated from people and the environment while the hazard is greatest.

Dose assessments in the PostSA demonstrate that a person can build a home and live on top of the engineered containment mound after the institutional control period, and receive only 0.015 mSv/y, which is only 1.5% of the public dose limit, and less than 1% of the natural background radiation dose in Canada.

The Safety Case has demonstrated that:

- The associated risk and hazards have been assessed, appropriate limits and conditions have been defined and adequate safety measures have been identified and put in place.
- The conclusions of the safety assessments meet the safety objective, safety strategy and acceptance criteria.
- The safety arguments and evidence demonstrate the safety of the NSDF.
- The management of uncertainties are appropriate to ensure safety.
- The NSDF limits, controls and conditions are appropriate to ensure safety.
- The NSDF design incorporates safety features and multiple safety functions, to ensure the protection of persons, society and the environment.
- The NSDF design has been optimized based on design iterations.
- The NSDF meets the current standards for design and construction and has been engineered for a design life of 550 years.
- The construction, operation, closure and post-closure activities of the NSDF can be undertaken safely.
- CNL management system meets the requirements of CNSC REGDOC 2.1.1 [8-16].

## 8.5 References

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## APPENDIX A MANAGEMENT SYSTEM

The management system, Requirement 25 of Disposal of Radioactive Waste [A-1]:

- Management systems to provide for the assurance of quality shall be applied to all safety related activities, systems and components throughout all the steps of the development and operation of a disposal facility. The level of assurance for each element shall be commensurate with its importance to safety.

The following sections provide a summary of the CNL Management System [A-2]; functional lead areas and functional support areas and the fourteen Safety and Control Areas established by the CNL's Licence Condition Handbook [A-3].

The Safety and Control Areas are [A-3]:

- Management System
- Human Performance Management
- Operating Performance
- Safety Analysis
- Physical Design
- Fitness for Service
- Radiation Protection
- Conventional Health and Safety
- Environmental Protection
- Emergency Management and Fire Protection
- Waste Management
- Security
- Safeguards and Non-Proliferation
- Packaging and Transport

### A.1 MANAGEMENT SYSTEM

Canadian Nuclear Laboratories has a management system comprised of an integrated set of documented policies, expectations, standards, procedures and responsibilities through, which CNL is governed and managed, from the setting of direction through to day-to-day operations, all within a coherent control and accountability framework [A-2]. A core prerequisite for CNL's success in consistently bringing high value to its customers and stakeholders is the effective and efficient governance and management of the company [A-2]. Canadian Nuclear Laboratories is committed to excellence in management, thereby, providing the foundation on which the company and our employees can thrive [A-2]. The Management System [A-2] sets the framework of policies, processes, and procedures used to ensure that the organization can fulfill its mission and achieve its objectives. The management system applies to all CNL management and execution activities [A-2].

Program Description Documents (PDD), PRD and Program GDI, were developed for each of the fourteen SCA in CRL's LCH [A-3]. Prior to 2014, these programs were internally referred to as "Compliance Programs" and have been recently renamed to Functional Support Areas or Program. Both of these terms are likely to be



used in NSDF documents, depending on the timeframe in which they were prepared. Each Functional Support Area and associated top tier documents, PDD and PRD, are listed in CRL's LCH under their respective SCA, and form part of the Compliance Verification Criteria. These specific PDDs and PRDs are controlled copies, identified in the LCH as "licensee documents that require notification of change".

Program Description Documents, define roles and responsibilities and processes to be followed. The PRD maps external requirements to CNL procedural documents and forms. The Program GDI provides the list of approved implementation documents specific to a program. Implementation documents are procedures, instructions and forms that provide the methods for implementing the program processes.

Table A-1 shows the Functional management structure consists of Functional Lead Areas which can be further broken down into individual FSA [A-2].

**Table A-1**  
**Functional Management Structure**

| <b>Functional Lead Area</b>                  | <b>Functional Support Area(s)</b>                                                                                                                                    |
|----------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Management System                            | Management System                                                                                                                                                    |
| Business Administration                      | Supply Chain, Prime Contact, Information Management, Business Management, Information Technology, Cyber Security, and Finance.                                       |
| Business Development and Commercial Ventures | Business Development and Commercial Ventures                                                                                                                         |
| Human Resources                              | Human Resources, and Training and Development                                                                                                                        |
| Engineering                                  | Design Authority and Design Engineering, Configuration Management, Pressure Boundary, Safety Analysis, Construction, and Commissioning.                              |
| Legal, Insurance, Ethics, & Audit            | Legal Services                                                                                                                                                       |
| Corporate Affairs                            | Corporate Affairs                                                                                                                                                    |
| HSSE&Q                                       | Compliance, EmP, Environmental Protection, Fire Protection, Health Centre, NCS, NM&SM, Occupational Safety and Health, Performance Assurance, RP, Quality, Security. |
| Operations                                   | Conduct of Operations, Maintenance, and Property Management.                                                                                                         |
| Environmental Remediation Management         | Transportation of Dangerous Goods, Waste Management, and Decommissioning & Demolition                                                                                |

### **A.1.1            QUALITY**

The Quality Program Description Document [A-4], describes CNL's Quality Program and the Quality Functional Support Area and identifies CNL's top level required methods for operating within the Quality requirements.

The Quality [A-5], combined with the CNL Management System Manual [A-2], provides the framework to implement CNL's Quality Policy [A-5].

Quality requirements are addressed for all CNL facilities/locations and activities in the overall management system, using a graded and integrated approach when possible along with HSSE, statutory and regulatory requirements [A-4]. All work is executed in accordance with controlled procedures to achieve a desired performance that includes both full compliance with the applicable customer requirements along with the efficient and effective delivery of results [A-4]. Details on quality related compliance obligations is documented in the Quality Program Requirements Document [A-6], and includes compliance to CSA N286-12 Management System Requirements for Nuclear Facilities [A-7], CSA N286-05, Management System Requirements for Nuclear Power Plants [A-8] and ISO:9001:2015 Quality Management Systems - Requirements [A-9].

### **A.1.2 COMPLIANCE**

The Compliance Program [A-10], provides the regulatory and licensing framework and independent technical reviews to provide a coordinated and consistent approach in how CNL manages relationships with its regulators. The purpose of this document is to identify the processes and interfaces in place to achieve the Compliance function.

The Compliance Program supports the licencing of CNL nuclear facilities and activities to enable the fulfilment of CNL's mandate. This is accomplished through independent, but related processes to ensure:

- A coordinated and consistent approach in how CNL deals with the CNSC in regards to company-wide regulatory and licensing matters.
- A coordinated and consistent approach in how CNL deals with other regulators (e.g., TSSA, Environment and Climate Change Canada, ESDC) in regards to company-wide regulatory and licensing matters.
- Independent technical review of a proposed nuclear facility or licensed activity before submission to the regulator.

The processes of the Compliance Function are illustrated in Figure A-1. Compliance processes either fall under Regulatory/Licensing activities or the Safety Review Committee.

The Safety Review Committee supports independent technical reviews of major safety documentation, related to CNL's licenced facilities and activities before submission to the regulator. These reviews are based on the type of hazards present and done for the following facilities and activities:

- New facilities
- Major modifications to operating facilities
- Decommissioning activities
- Nuclear criticality safety

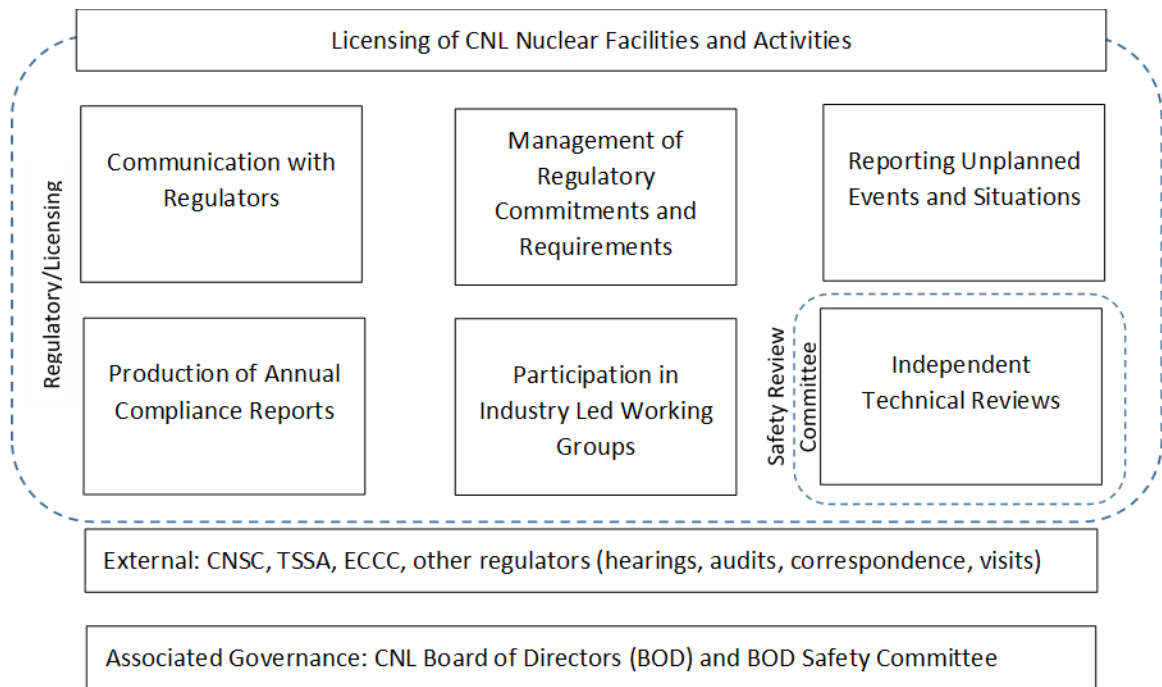


**Figure A-1 Processes of the Compliance Function**

### **A.1.3 SUPPLY CHAIN/PROCUREMENT**

The Program Description [A-11], describes the Supply Chain organizational framework and operational arrangements through which procurement, contracting and Supply Chain Management activity is undertaken and governed pursuant to CNL's Supply Chain policy and policy standards. Supply Chain management represents a key enabling capability and critical success factor for CNL. This Company-wide Process applies to all activities unique to this program, performed by CNL across all sites. Good industry practices are drawn from both internal and external sources, including influences from CNL Parent Body organizations to optimize processes to improve speed to market, flexibility and commercial innovation.

Procurement activity is organized into the five top-level process stages to cover the entire purchasing life cycle. These process stages apply to both the material acquisitions and contract management activities. The stages are:

- Contract Strategy and Planning
- Solicitation and Evaluation
- Contract Award
- Manage Contract
- Closeout

The Contracts and Contractor Management Control Procedure [A-12], provided the key process steps for developing and executing the NSDF design contracts following the five procurement stages. Key processes in the procedure describe “how to”:

- Develop a Technical Scope of Work
- Evaluating proposals
- Award the contract
- Manage and undertake due diligence surveillance activities
- Manage information and records
- Manage risks
- Develop a Design Review Matrix that will identify those qualified to conduct design reviews

#### **A.1.4 INFORMATION MANAGEMENT**

The Information Management Functional Support Area (FSA) [A-13], implements, and monitors controls that apply to all Information Assets, including structured, unstructured, or transitory, and extends to all activities throughout CNL. Information Management follows the requirements of all major standards CNL is certified against, as well as the other standards that have been adopted as best practices [A-13]. All CNL employees are responsible for abiding by the controls that Information Management processes define, especially relating to the information in their direct care [A-13].

The mandate of the Information Management functional support area is to [A-13]:

- Govern the creation, classification, capture, use, dissemination, retention, preservation, and disposition processes of information throughout the enterprise.
- Preserve company records that are centrally archived.
- Uphold the integrity of the Management System Documents framework.
- Uphold the quality of capture of documents into the Electronic Document and Records Management System.
- Provide personnel with information resources on-site, and access to worldwide resources through online subscriptions and inter-library loans.

Information Management facilitates compliance with all applicable requirements to retain and manage information, to deliver targeted services and solutions to the business groups, and to ensure that records remain available and usable until they are no longer required to meet operational or regulatory obligations [A-13]. Information Management is responsible for setting the strategies to manage information, the governance the framework and procedures to guide employees from the creation to the disposition of Information Assets [A-13].

Information Management [A-13] establishes standards and procedures to facilitate:

- The ownership and stewardship of information assets.
- The creation, capture and use of information.

- The storage and protection of records to guarantee their accessibility and usability for the length of time required.
- The disposition of records with due diligence when their retention expires.

Storing and handling information is a controlled activity at CNL. Information Management [A-13] develops and maintains processes to ensure the authenticity and integrity of records so that CNL can meet its long-term information requirements.

Information Management [A-13] applies during all stages of the NSDF life cycle and the collection of information will be retained as a permanent record to be used by future generations.

## A.2 HUMAN PERFORMANCE MANAGEMENT

The Performance Assurance Program [A-14], demonstrates that CNL's company values of safety, respect for people and performance excellence are embedded into the management system's programs and processes. The Performance Assurance Program delivers many benefits to the organization including improved safety, reduced corporate risk, and increased organizational efficiency and effectiveness [A-14]. Figure A-2 provides an overview of the Performance Assurance Program elements.

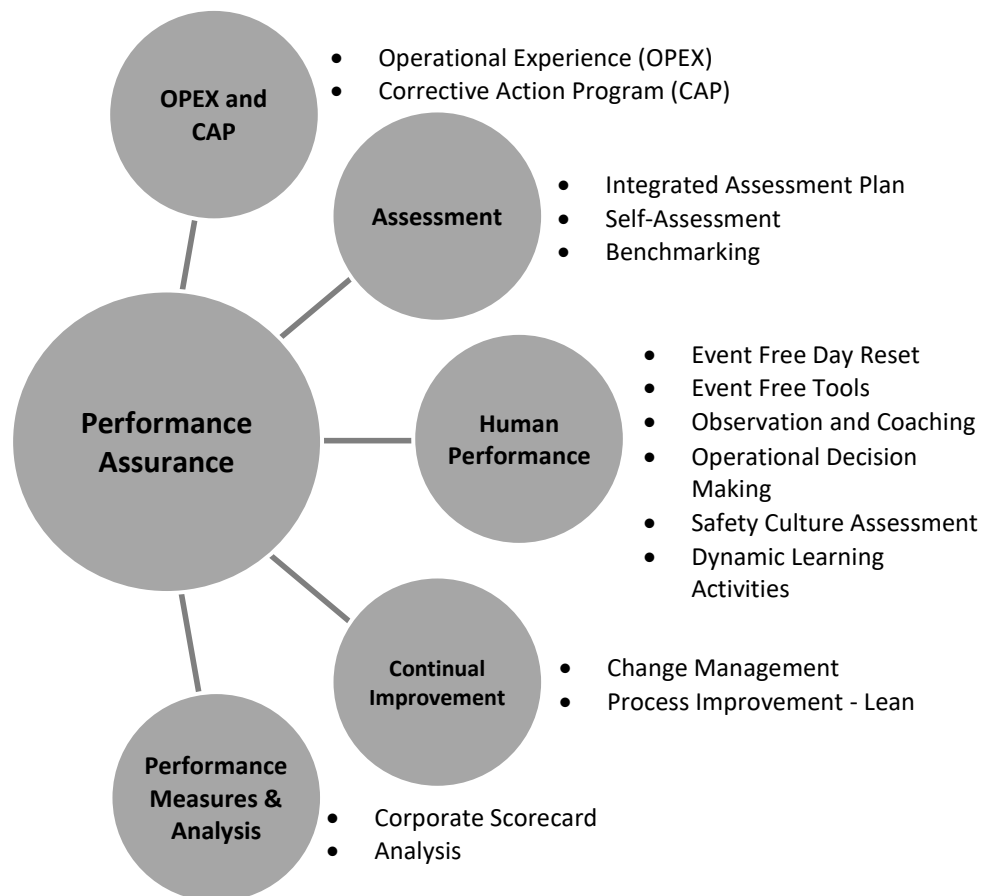


Figure A-2 Performance Assurance Program

Requirements listed in the Performance Assurance Program requirements document [A-15], drive the structure and content of the Performance Assurance Program. The Performance Assurance Program [A-14], uses information from within CNL and from the nuclear industry to improve the safety of operations, improve operational performance and reduce the significance and the occurrence of unplanned events at CNL sites in Canada. The unplanned events reported to OPEX are entered into a database of OPEX that are monitored for trends and used to share any lessons learned. Operating experience and corrective action programs, review and analyze already existing events and issues, OPEX, and lessons to be learned, both from internal and external sources. This determines actions to be implemented to correct non-compliant situations, prevent recurrence of significant problems, and prevent the occurrence of more significant problems. Ongoing and periodic assessment activities are used to validate that the Management System is functioning according to expectation, and that any deficiencies are identified and appropriate action taken to resolve the deficiency. The Human Performance Program assists all employees to anticipate, manage, and monitor the effects of variability in human performance on organizational outcomes. Continual improvement framework is effective in assisting with decision making and promoting organizational learning, innovation and transformation. Canadian Nuclear Laboratories uses a series of key performance indicators to measure the performance of facilities, programs, and organizations. These indicators identify performance improvement or deterioration relative to established goals.

#### **A.2.1 TRAINING AND DEVELOPMENT**

The primary function of the Training & Development Program [A-16], is to ensure that employees are adequately and efficiently trained to safely and competently perform their roles and responsibilities. Canadian Nuclear Laboratories has developed a Systematic Approach to Training (SAT) process that provides a standardized approach to staff training and qualification and ensures that CNL is in compliance with conditions in the applicable license. The purpose of the SAT process is to provide a structured, documented and auditable set of processes that, when implemented, will provide management with the assurance that personnel are trained, competent and qualified for the assigned work.

A graded approach, commensurate with risk, is used in the application of SAT. A graded approach supports decisions related to the specific processes used and the rigor and level of detail required in the supporting training program documents. The most comprehensive levels of SAT processes are applied to the development of training programs for positions performing licensed activities. Systematic Approach to Training is based on fundamental processes and sound practices that systematically assess the need for training, the type of training, as well as the training content, and that provide standards for the development, implementation and evaluation of training.

The NSDF Facility Authority will ensure operating staff are trained and competent to perform their assigned duties by developing NSDF specific training plan in accordance with the requirements of this program. The Facility Authority will authorize the training plan, ensure staff complete the initial training, authorize qualified staff to perform specific licensed activities and specify the continuing training requirements.

#### **A.3 OPERATING PERFORMANCE**

The Conduct of Operations Program [A-17], applies to all Class I and Class II Nuclear Facilities as listed in Site Licences, Certificates, Permits, Facilities, & Licence Representatives [A-18], in service under a CNSC issued CRL Nuclear Research and Test Establishment Operating Licence [A-19], to the personnel associated with the operation of these Facilities, and to activities conducted within these Facilities.

The Conduct of Operations Program provides a compliance framework to ensure facility operations are managed, organized and conducted in a manner that results in high levels of safety, performance, and reliability while maintaining compliance with the applicable acts, standards, codes, regulations, and regulatory requirements. The Class I and Class II Nuclear Facilities are operated within their Limiting Conditions for Safe Operation.

Figure A-3 present an overview of the Conduct of Operations Organization. A FA is assigned to each Class I or II Nuclear Facility and corresponds with appropriate CNSC staff member. The NSDF FA has delegated authority from the Site Licence Holder, for ensuring safety and compliance with all applicable licensing and regulatory requirements, and has the overall responsibility for the safe and compliant operation and use of their respective facility [A-17].

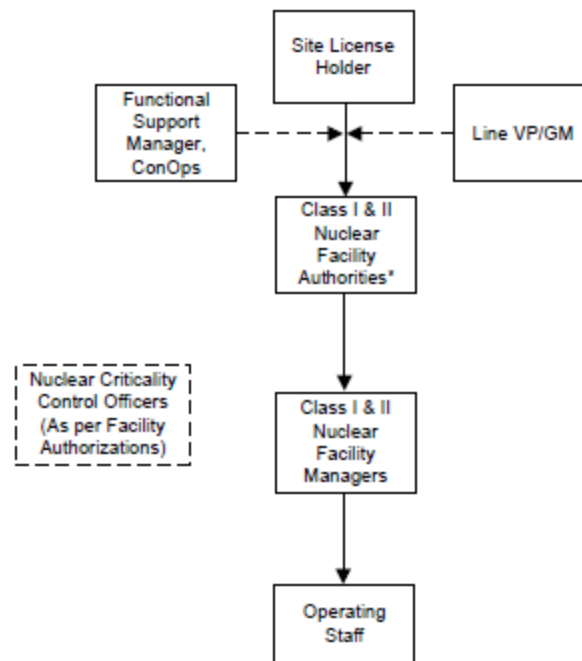


**Figure A-3 Conduct of Operations Organization**

The Conduct of Operations Program includes a series of Management Control Procedures, and the processes detailed in these procedures assists Facilities with the creation of a tailored suite of Facility-specific Conduct of Operations processes.

The NSDF will be added to the list of Class 1 Nuclear Facilities at CRL once Commission Approval to Operate is received. The NSDF FA will be responsible for preparing the suite of NSDF Conduct of Operations Facility Specific Procedures prior to applying for this decision by the Commission. A series of working level procedures will be developed prior to starting operations. A typical list of procedure subjects for Nuclear Facilities include:

- Operating Procedures
- Maintenance Procedures
- Response to Alarms Procedures

- Emergency Procedures
- Surveillance and Monitoring Procedures
- Waste Management Procedures (for waste generated by NSDF activities)
- Operating Limits and Conditions

### **A.3.1 CONSTRUCTION**

The Construction Program Description Document [A-20], describes how the CNL construction process manages construction and installation activities, for work assigned to external contractors. The Construction Process provides the framework for external contractors performing construction and installation activities at CNL sites to ensure they are being adequately controlled and documented within approved safety margins and regulatory/statutory requirements. The Construction Process applies to all construction and installation activities for nuclear and non-nuclear projects throughout CNL executed by external contractors.

The purpose of the Construction Process is to provide effective support to the design phase as well as control and monitoring measures to ensure the successful execution of construction and installation activities in compliance with:

- CSA N286-05, Management System Requirements for Nuclear Power Plants [A-8].
- ISO 9001:2008, Quality management systems [A-9].
- Pressure Boundary Program [A-21] and the associated Pressure Boundary Quality Assurance Manuals.
- National Building Code [A-22].
- National Fire Code of Canada [A-23].
- Ontario Occupational Health and Safety Act and Regulations [A-24].
- Canada Labour Code [A-25].
- Applicable Site Licenses.

Through the implementation of this Construction Process, CNL demonstrates and provides confidence to customers, stakeholders and regulatory authorities that [A-20]:

- Construction Activities are efficiently, effectively and safely delivered.
- Construction Activities are being adequately controlled and documented.
- The system modifications and equipment installation results are deemed safe and appropriate for the intended use.
- The construction activities address any applicable regulatory/statutory requirements.

During construction activities, portions of the work can be assigned to contractors and other participating organizations that are external to CNL. For all construction activities, CNL establishes the QA requirements for the work and evaluate the QA programs developed by such external contractors/participating organizations [A-20]. Canadian Nuclear Laboratories is responsible for the effectiveness of the QA program applied at the construction site [A-20].



As such, CNL performs the following controlling activities on external contractors/participating organizations [A-20]:

- Review and accept the QA program of the external contractors/participating organizations, ensuring that it matches their scope of work and complies with the requirements of the QA standards and overall QA program applied at the construction site.
- Audit the external contractor/participating organizations with a frequency commensurate with their scope of work activities and the maturity of their QA program.
- Oversee the work performed by contractors/participating organizations using established monitoring/acceptance processes.

Figure A-4 presents an overview of the Construction Process [A-20].

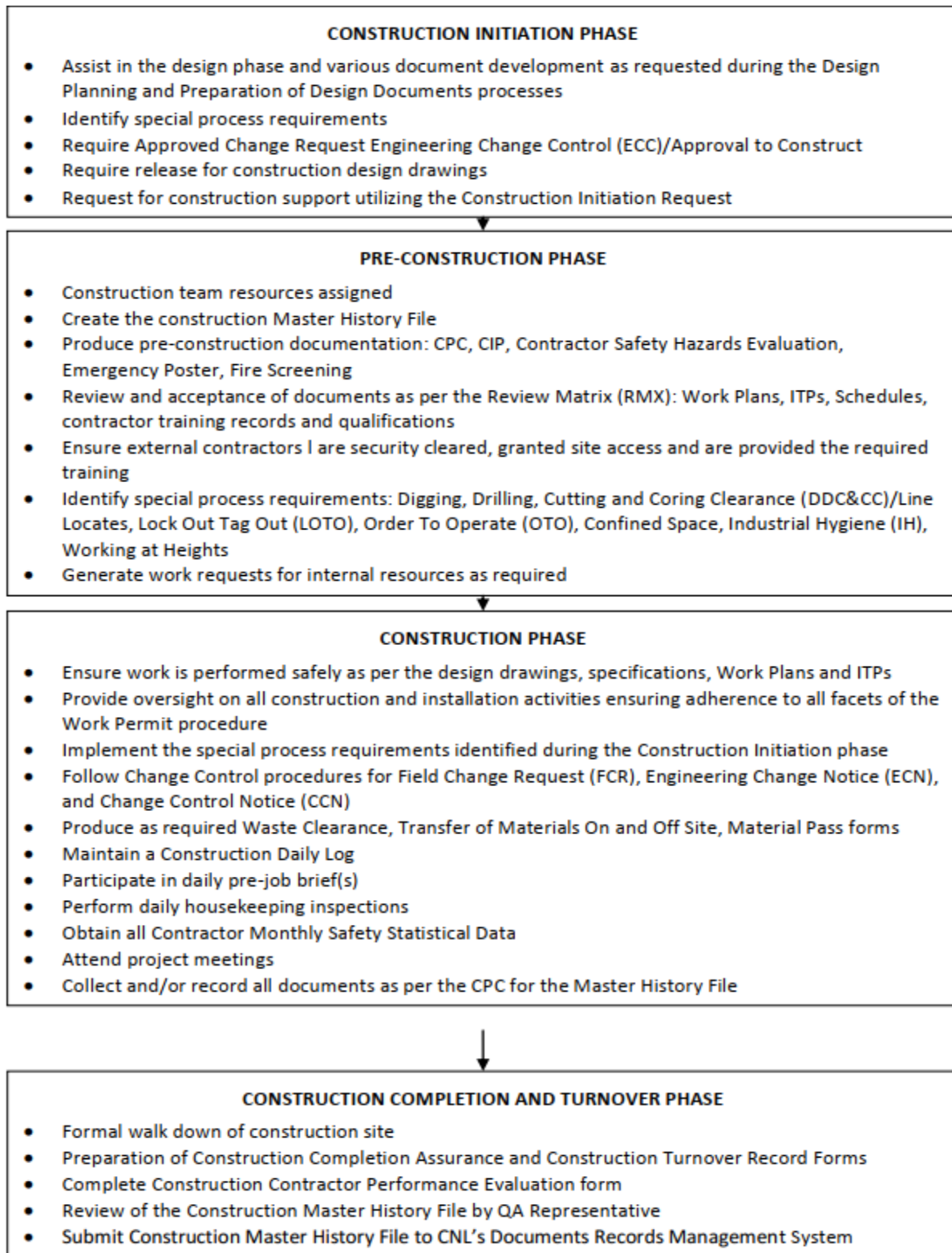


**Figure A-4 Construction Process Overview**

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**A.3.2 COMMISSIONING**

Canadian Nuclear Laboratories Commissioning Program [A-26], applies to all new or refurbished facilities at CNL. This includes current operating facilities where new systems are installed or an existing system is modified, altering the design intent of the original system configuration.

Commissioning starts with planning the commissioning scope, phases, and control points [A-26]. Commissioning ends with the Commissioning Completion Assurance process [A-26].

The Commissioning, functional support area, is to ensure that commissioning is planned, documented, executed and verified according to applicable codes, standards, and regulatory and customer requirements [A-26].

The ultimate commissioning objective is to obtain a building or facility, whose systems function in all respects according to design intent and to meet the needs of the occupants [A-26]. To achieve this, the Commissioning program provides a systematic objective method that will enable commissioning to proceed in a controlled manner, safely and to a high quality [A-26]. The Commissioning Program [A-26], will also enable the necessary assurances/evidence to be provided that the Facility has been constructed in accordance with the design intent and can be operated safely.

The commissioning of a SSCs normally consists of the following periods; planning, preparation, execution, and completion reporting. Figure A-5 presents an overview of the commissioning periods.

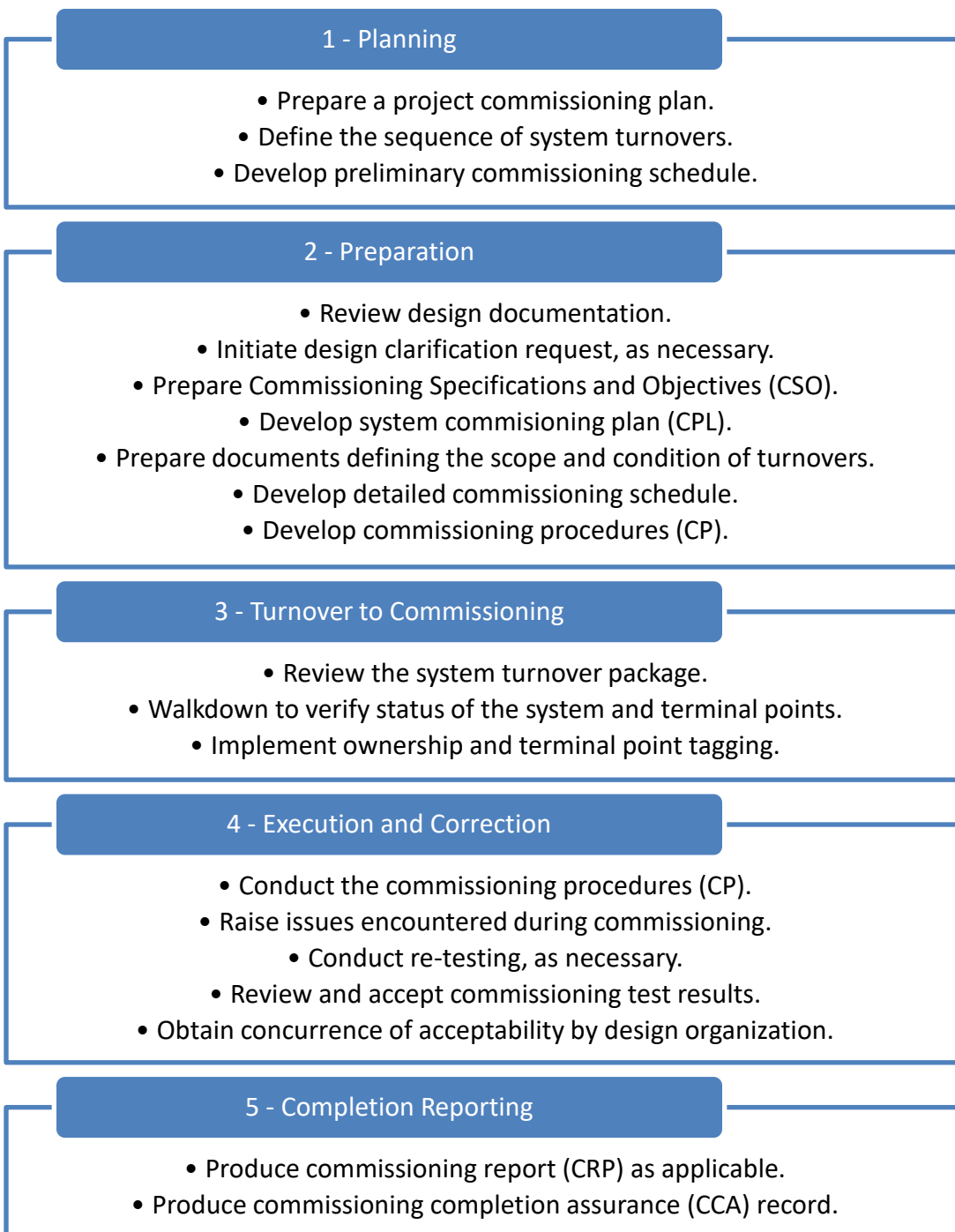


**Figure A-5 Commissioning Periods Overview**

Near Surface Disposal Facilities commissioning activities will follow this process. The Commissioning Plan will provide a systematic process to ensure the NSDF SSCs perform interactively within design parameter limits while meeting the operational, functional and design performance requirements.

Commissioning Procedures establish the conditions under which the equipment performance tests will be conducted. Typically, the procedures specify the test and measurement methods to demonstrate individual components, individual systems and interactive process-system performance meet or exceed the functional

and design performance requirements. The procedures include verification requirements, identify tests that require independent verification and the approved verifier qualifications (TSSA). The procedures will serve as a formal record, documenting actual performance results against the acceptance criteria. Deficiencies will be assessed and prioritized from a safety and functionality perspective and resolved as necessary prior to the advancement to the next commissioning phase.

Inactive Commissioning ends with the Inactive Commissioning Completion Assurance certificate and Inactive Commissioning Report.

Active Commissioning is a term used at CNL to define the period where Operations begin in a progressive manner, controlling the rate at which nuclear substances are introduced. This period is used to further validate the design and to confirm administrative controls are adequate, including:

- Staff training and staffing levels are adequate.
- Operating procedures and response to alarm procedures are effective and correct.
- Demonstrating safety systems function as expected (where practical to do so).
- Demonstrating the individual systems and overall process control performance can operate safely and yield results within the acceptable design range limits.

Active commissioning will not start until Commission Approval to Operate is received. Active commissioning will be conducted by NSDF Operating staff following active commissioning Procedures. Active Commissioning typically ends when the NSDF Facility Authority accepts the completed Active Commissioning Procedures.

### **A.3.3 REPORTING REQUIREMENTS**

The reporting procedure, CNL Reporting to Regulatory Agencies A-27], describes the requirements, the process and the responsibilities for reporting by CNL to the CNSC as required by the Nuclear Safety Control Act [A-28], and the associated regulations, and to other regulatory agencies, as per the applicable legislation.

The requirements of CNL Reporting to Regulatory Agencies, [A-27], constitute a guideline for consistent reporting to regulatory agencies and are applicable to all sites operated by CNL.

The document applies to the CNL employees who are Designated Representatives of the Licensee and are responsible for reporting to the CNSC, and in general, to the CNL staff responsible for reporting to regulatory agencies [A-27].

The information provided in the reports, is used by the regulatory agencies in responding to emergencies, monitoring ongoing events, confirming licensing basis, studying potential safety problems, assessing trends and patterns, monitoring performance, and identifying precursors of more significant events.

### **A.4 SAFETY ANALYSIS**

The Safety Analysis Functional Support Area (FSA), develops and controls the suite of nuclear safety analysis documents required to support the execution of safety analysis at CNL [A-29]. The Safety Analysis FSA processes apply to all safety analysis activities involving CNL SSCs, and all management, supervision and staff across all CNL sites [A-29]. Safety Analysis Program requirements are defined in the Safety Analysis Program Requirements Document [A-30].

As defined by the CNSC [A-31] safety analysis is a systematic evaluation of the potential hazards that is associated with the conduct of a proposed activity or Facility and that considers the effectiveness of

preventive measures and strategies in reducing the effects of such hazards. The relevant hazards, include radiological, nuclear criticality, fire, and chemical. However, with respect to compliance with the NSCA and regulations, the CNSC requirement is limited to consideration of the effects of all relevant hazards on radiological safety, and prevention of nuclear criticality accidents, or chemical hazards directly associated with CNSC licensed radioactive material.

Assessment of non-radiological hazards is included in the scope of other FSAs, such as Occupational Safety & Health [A-32] and Fire Protection [A-33] with aspects relevant to nuclear safety taken into account in Safety Analysis. The assessment of NCS is governed by the Nuclear Criticality Safety FSA [A-34] and the results are an input to the safety case. Radiological hazards related to protection of workers and the public from ionizing radiation, is covered under the Radiation Protection FSA.

The main objective of the program is to provide processes and procedures which define how nuclear safety analysis will be executed, to permit the successful completion of safe engineering design in support of new build, facility modification, facility operation, research and product development, decommissioning and disposal [A-29].

The objectives of safety analysis include [A-29]:

- Confirming that the design of the nuclear facility meets its design and safety requirements.
- Characterizing the events that are applicable to the site and facility design; deriving or confirming OLCs.
- Analyzing and evaluating event sequences that result from failure of SSC.
- Confirming the range of conditions and events taken into account in the design basis.
- Demonstrating that the management of the AOO and DBA is possible by automatic response of either the control systems or safety systems in combination with prescribed operator actions.
- Confirming that the results of a safety analyses are within design limits and dose acceptance criteria.

The safety analysis process includes [A-29]:

- Define the safety analysis plan.
- Identify and classify the hazards and events.
- Execute the safety analysis and assess the results.
- Execute the design and operational support activities.
- Verify, approve and release the results.

Safety analysis documentation is controlled and periodically reviewed and revised throughout the life of a facility or site. Safety analysis is documented in a manner that is permanently retrievable, facilitates independent review by qualified experts, provides traceability, and is reproducible [A-29]. All safety analysis activities are performed using [A-29]:

- Qualified personnel applying a systematic analysis method with justified assumptions.
- Verified and validated computer codes.
- Accounted for uncertainties in the safety analysis models and inputs.
- Traceable and reproducible degrees of conservatism commensurate with the severity of the analyzed event and associated uncertainties.
- Accepted review process.

#### **A.4.1 NUCLEAR CRITICALITY SAFETY**

The NCS Program [A-34] and [A-35], provides a framework for safe operations at CRL and for the prevention of nuclear criticality accidents by conforming to all applicable regulations, company policies and procedures. The NCS Program is responsible for all activities involving the use, process, movement and storage of Fissionable Materials, and applies to activities that may affect NCS (e.g., design, operations, commissioning and decommissioning activities). The focus of NCS at CRL is on those areas that contain equal to or greater than 0.1 kg of fissile nuclides in SFM [A-34].

Nuclear criticality safety is aimed at preventing criticality accidents. The CNL NCS Program [A-34] and [A-35], complies with the CNSC Regulatory Document RD-327 [A-36] and CNSC Guidance Document GD-327 [A-37], which provide the requirements for the prevention of criticality accidents in the handling, storage, processing and transportation of Fissionable Materials, and the long-term management of nuclear waste. Note that in 2019 February, NCS, REGDOC-2.4.3 [A-38], replaced CNSC Regulatory Document RD-327 [A-36] and CNSC Guidance Document GD-327 [A-37].

The following are the foundation of the NCS Program [A-34]:

- Nuclear criticality safety is part of CNL's Nuclear Safety Policy [A-39].
- An adequate margin of sub-criticality is maintained under all normal and credible abnormal conditions (events or event sequences having frequency of occurrence equal to or more than  $10^{-6}$ /year), as demonstrated by using quantitative or semi-quantitative methods.
- Upper subcritical limits are not exceeded under both normal and credible abnormal conditions.
- The consequences of a criticality accident are mitigated to limit the on-site and off-site doses to people.
- Canadian Nuclear Laboratories is compliant with site licence requirements for criticality safety, through Nuclear Criticality Safety Program processes and procedures.

#### **A.5 PHYSICAL DESIGN**

The Design Authority and Design Engineering Program [A-40], maintains and controls the design basis of CNL within approved safety margins and regulatory requirements. The Design Authority and Design Engineering Program [A-40] establishes the requirements for CNL design work, and applies to all design engineering activities performed at CNL sites.

The purpose of the Design Engineering [A-40], is to ensure that design is planned, executed, verified and documented according to applicable codes, standards, and regulatory and design customer requirements.

The Design Authority and Design Engineering Program requirements document [A-41], identifies the requirements associated with the Design Process and provides an index to governing and approved procedural documents and is applicable to the Design Process at CNL.

##### **A.5.1 PRESSURE BOUNDARY PROGRAM**

The Pressure Boundary Program [A-21], applies to design, procurement, fabrication, installation, examination, testing, repair, replacement, modification, construction, and maintenance of pressure retaining systems, and components performed by CNL at the CRL.

The purpose of the Pressure Boundary Program [A-21] is to assure that pressure-retaining systems and components are designed, constructed and operated in full compliance with statutory and legislative

requirements, while promoting and supporting performance excellence with a strong safety culture. The ultimate objective of the Pressure Boundary Program [A-21] and its governing codes and standards is “no pressure boundary failures”.

The Site, Facilities, and Buildings that fall under the auspices of the Pressure Boundary Program are Federally regulated [A-21]. As such, Provincial legislation does not apply to activities conducted on pressure retaining systems and components at CRL [A-21]. The CRL Pressure Boundary Quality Assurance plan [A-42], presents the details of the pressure boundary quality assurance program implemented at CRL.

The Pressure Boundary Program requirements document [A-43], identifies the requirements associated with the Pressure Boundary Program and provides an index to governing and approved procedural documents to ensure Pressure Boundary Program work is planned, implemented and maintained.

The NSDF Project will comply with all aspects of this program until registered systems are placed in a permanent, safe-shutdown-state awaiting decommissioning.

#### **A.5.2 CONFIGURATION MANAGEMENT**

The Configuration Management FSA [A-44], provides the framework to maintain and control the physical configuration of SSCs at CNL. Configuration Management applies to all design, operations, decommissioning and maintenance activities at CNL sites [A-44]. Configuration Management applies to all non-nuclear and nuclear documents, policies, programs and procedures which contain information or instructions that could impact [A-44]:

- Design (both regulatory and owner prescribed), and licensing basis.
- Any plant physical configuration.
- Any configuration item or information.

Although CSA N286.10 Configuration management for high energy reactor facilities [A-45] explicitly excludes decommissioning from its scope, Configuration Management is applied in a graded manner to decommissioning activities at CNL [A-44].

The Configuration Management FSA [A-44], allows for maintaining and controlling the configuration of Nuclear Laboratories facilities within approved safety margins and regulatory requirements when changes or non-identical replacement parts are required. Configuration Management [A-44] ensures that changes are assessed, approved, designed, implemented, commissioned and placed into service within the safety envelope at all CNL sites in accordance with the design requirements.

The Configuration Management FSA [A-44] is compliant with the requirements of CSA N286.10-16, Configuration management for high energy reactor facilities [A-45]. Figure A-6 presents an overview of the Configuration Management model (adapted from [A-45]) [A-44].

The Configuration Management requirements document [A-46], identifies the requirements associated with the configuration management and provides an index to governing and approved procedural documents to ensure Configuration Management is planned, implemented and maintained.



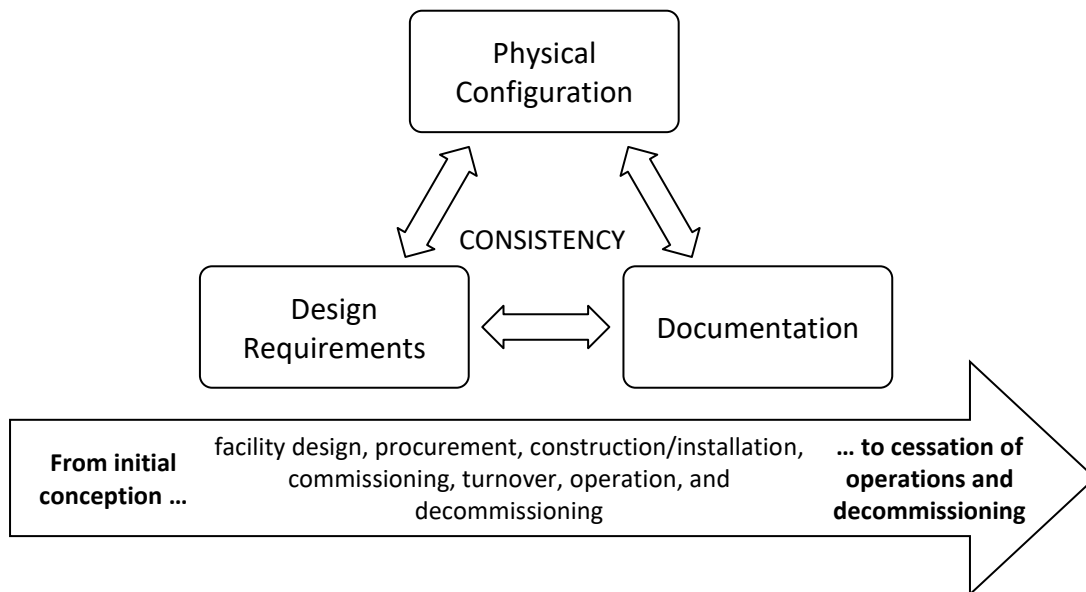


**Figure A-6 Configuration Management Model Overview**

## **A.6 FITNESS FOR SERVICE**

The Fitness for Service, Safety and Control Area is comprised of the Maintenance and Equipment Reliability FSAs.

### **A.6.1 MAINTENANCE**

The primary objective of the Maintenance FSA [A-47], is to provide Asset Custodians with a strategy, identifying which maintenance activities are to be performed, on which SSC's, and at what intervals. The type and frequency of maintenance activity applied to each SSC are commensurate with the importance to safety, design function and required performance [A-47]. The purpose is to establish consistent practices designed to improve the performance and safety of the SSC's [A-47]. Elements of this process help to improve the life and reliability of the SSC as well as avoid any unplanned maintenance activities [A-47].

The Maintenance program requirements document [A-48], identifies the requirements associated with the Maintenance FSA and provides an index to governing and approved procedural documents to ensure Maintenance is planned, implemented and maintained.

The NSDF Project will ensure a categorized list all SSC's that will require maintenance is included in the Enterprise Asset Management System (also referred to as the Computerized Maintenance Management System database). The primary source of this information will be the NSDF Master Equipment List.

### **A.6.2 EQUIPMENT RELIABILITY**

The ERP [A-49], ensures that all safety-related systems (SRS) function reliably in accordance with the relevant design and performance criteria, including any safety goals of the Facility and CNSC.

The ERP [A-49], applies to SRS within licensed nuclear facilities and to their support facilities that may implement any of the key Equipment Reliability elements (Ageing Management, Obsolescence Management and System Health).

The purpose of the ERP [A-49], is to enable Facility personnel to evaluate important equipment, develop and implement long-term equipment improvement plans, monitor equipment performance and condition, and adjust preventive maintenance tasks and frequencies based on equipment performance. The ERP [A-49], assists licensed nuclear facilities and as appropriate, custodians of other complex systems, in improving and maintaining levels of safety and reliability in Facility operation in an efficient and effective manner.

The ERP requirements document [A-50], identifies the requirements of the ERP for CNL, and provides an index to governing and approved procedural documents.

## **A.7 RADIATION PROTECTION**

The RP Program applies to the operation and activities that affect the safety of staff and equipment, in terms of exposure to ionizing radiation at all CNL sites and applies to all employees and other personnel (visitors, contract staff, etc.) conducting work at CNL sites [A-51]. The RP Program applies to all activities conducted where CNL holds a CNSC issued licence in Canada [A-51].

The objective of the RP Program is to ensure and demonstrate compliance with applicable Regulations and Acts and maintain doses to workers ALARA, social and economic factors taken into account [A-52]. Canadian Nuclear Laboratories applies the ALARA principle in all activities involving the use of ionizing radiation. All radiation doses to personnel or members of the public must be justified, in accordance with the ALARA principle and be maintained below regulatory limits.

The RP Program Authority [A-51], has oversight responsibility to ensure Dosimetry Services directly meets or assists the RP Program in meeting the relevant requirements of the RP Program and the Radiation Protection Regulations [A-53].

The RP Program requirements are listed in the CNL RP Requirements [A-52] and include:

- Limiting radiation doses to less than the regulatory limits.
- Limiting detrimental stochastic health effects in employees and members of the public to levels ALARA, social and economic factors being taken into account (ALARA principle).
- Preventing detrimental non-stochastic (deterministic) health effects caused in employees and members of the public by radiation.

Dosimetry is a necessary component of the program, providing a quantitative measure of the effectiveness of the radiation safety program, as it applies to both the individual worker and the collective workforce.

Dosimetry is a fundamental requirement for the demonstration of compliance with regulatory obligations mandated by the site licence. Dosimetry services for personnel and visitors are provided by CNL, and are managed according to the CRL Dosimetry Program [A-54] and [A-55]. These services include monitoring, assessing, recording and reporting doses of ionizing radiation received by all individuals while on-site.

The RP Program [A-51] objectives will continue to be achieved through NSDF Facility design reviews, planning and control of work, personnel qualification and training, provision of internal and external dosimetry, radiation and contamination exposure control procedures, work supervision, and planning for abnormal hazards and exposures.

The level at which the RP Program [A-51] is applied will increase as the NSDF evolves from the design phase to construction. In future phases (construction, operations, maintenance, decommissioning and closure), RP staff will be included in the day-to-day work planning and monitoring activities. The RP Requirements [A-52] will continue to be applied in a graded manner until the end of the NSDF's ICP.

## **A.8 CONVENTIONAL HEALTH AND SAFETY**

The OSH Program applies to all work performed by CNL employees, and to work performed by others on site or work places controlled by CNL [A-32]. The purpose of the OSH Program is to prevent accidents and injury to health arising out of, linked with, or occurring to employees in the course of employment, and to all persons on sites or workplaces controlled by CNL [A-32].

The CNL Safety and Health corporate policy [A-56], establishes the CNL standards and expectations with respect to safety and health.

The OSH Program requirements document [A-57], establishes the requirements for the CNL OSH Program. Canadian Nuclear Laboratories is committed to providing a safe workplace and to compliance with applicable safety and health requirements. The OSH Program complies with applicable Federal and Provincial OSH legislation, regulations and standards.

Canadian Nuclear Laboratories OSH Program [A-32] and requirements, apply all NSDF lifecycles.

## **A.9 ENVIRONMENTAL PROTECTION**

The EnvP Program [A-58], together with the EnvP Program requirements document [A-59], implements CNL's Environment Policy [A-60], and ensures compliance with legal and other environmental obligations applicable at CNL operated sites in Canada. Under the EnvP Program, program requirements apply to operations and activities that may affect the environment in and around CNL sites. A graded approach to requirements is applied based upon environmental risks/events that could occur at any given location. The EnvP Program, also applies to all employees, as well as other personnel (contractors, consultants, attached staff, etc.), conducting work at CNL sites.

The EnvP Program description document [A-58], provides an overview of the Environmental Management System (EMS), referred to as the EnvP Program, which is part of the overall CNL Management System [A-2] as a FSA under HSSE. In addition, the EnvP Program description document [A-58], provides an overview of the key processes, organizational structure and the responsibilities associated with the EnvP Program. The EnvP Program considers life cycle perspective for activities, products and services on and around CNL sites where CNL has control or influence and on products or services off-site which the organization has influence [A-58].

The EnvP Program requirements document [A-59], describes, at a high level the EnvP Program requirements for CNL. The EnvP Program requirements document [A-59] provides the current list of authorized procedures that describe the requirements, organization, responsibilities, processes, and controls that are applicable to the program, projects and other activities of CNL.

Canadian Nuclear Laboratories is governed by Federal regulation and legislation and, where applicable, Provincial and municipal regulation and legislation in the jurisdictions where CNL sites are located. In addition, CNL adheres to worldwide proprietary, industrial and commercial standards such as the International Organization for Standardization (ISO) [A-59]. In particular, under the ISO 14001:2015 standard for Environmental Management Systems [A-61], the EnvP Program is responsible for developing and

implementing CNL's Environmental Management System [A-59]. The EnvP Program is responsible for ensuring CNL's compliance with environmental legal requirements [A-59]. Under the CNL Management System, the EnvP Program for applicable CNL operated sites in Canada, conforms to the ISO 14001:2015 standard for Environmental Management Systems [A-61], however, currently only CRL and WL are ISO 14001 registered [A-58]. The following scope of registration at CRL and WL applies [A-58]: *"The Registration covers the Environmental Management System for the operation of nuclear facilities, conducting research and development to support science and technology, waste management and decommissioning activities"*.

Operations and activities conducted at CNL sites in Canada are bound by environmental requirements specified in the following Federal legislation, but not limited to [A-61]:

- Nuclear Safety and Control Act [A-28].
- Canadian Environmental Protection Act [A-62].
- Fisheries Act [A-63].
- Transportation of Dangerous Goods Act [A-64].
- Species at Risk Act [A-65].

From CNL's Environment Policy [A-60], the Strategic Environmental Objectives are identified [A-58]. The Strategic Environmental Objectives address the potential for significant environmental aspects from CNL operations, business requirements and regulatory requirements, and include [A-58]:

- Prevent Environmental Degradation (includes Pollution Prevention<sup>9</sup>).
- Provide Responsible Environmental Management.
- Demonstrate Environmental (Regulatory) Compliance.
- Provide Improvement of Environmental Protection Systems and Technology.

Environmental monitoring programs are in place to routinely sample and trend effluent from operations and in the environment surrounding CNL sites, including Groundwater Monitoring, ambient air, surface water, sediment, vegetation, wildlife, produce, meat from local farms, etc. The type and amount of monitoring varies from one site to another, based on nature of activities, operations and processes. All environmental monitoring results are published in annual reports and frequent updates on environmental performance are provided to management and to external interested parties and the public.

An index to documentation [A-66], lists the policy, requirements documents and all supporting and implementation procedural documents for environmental protection.

## **A.10 EMERGENCY MANAGEMENT AND FIRE PROTECTION**

The emergency and fire protection, safety and control area includes the EmP Program [A-67] and the Fire Protection Program (FPP) [A-33].

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<sup>9</sup> **Pollution Prevention** - defined by Canadian Environmental Protection Act (CEPA) "as the use of processes, practices, materials, products, substances or energy that avoid or minimize the creation of pollutants and waste and reduce the overall risk to the environment or human health."

**A.10.1 EMERGENCY PREPAREDNESS**

The EmP Program [A-67], provides an operational framework to implement CNL's Health and Safety [A-56] and Environment Policies [A-60], with respect to necessary emergency response measures and compliance with company priorities identified in the Strategic Emergency Management Plan [A-68]. The EmP Program focus is the prevention and mitigation of, preparedness for, response to, and recovery from abnormal or emergent events [A-67]. The EmP Program requirements document [A-69], documents the specific program requirements in the relevant legislations and regulations that are delineated as applicable company-wide and site specific requirements.

The EmP Program [A-67], within the CNL HSSE&Q Programs oversight organization, supports emergency response as required through mutual assistant agreements and as directed through the Federal government of Canada. The EmP Program [A-67] applies to design, operations and other activities that may affect EmP at CNL Canadian sites. The EmP Program [A-67], is used for off-site response support and may be applied at CNL foreign sites upon request.

Emergency preparedness is required at all CNL business locations. A graded approach to requirements is applied based upon an assessment of the most credible events that could occur at any given location [A-67]. Canadian Nuclear Laboratories uses Incident Management System methodology, ensuring a standardized approach with emergency partners for organizational structure, functions, processes and terminology [A-69].

The EmP Program [A-69]:

- Ensures a state of readiness to prevent or mitigate the effects of an emergency/abnormal situation to protect the health and safety of workers, the public, the environment, and CNL's reputation.
- Prepares employees for emergency responses through training, documentation, exercises and drills.
- Establishes liaison and coordination with Federal, Provincial and municipal officials.
- Establishes emergency plans and procedures for the response to and mitigation of harmful effects of emergencies.

Emergency management and response will be influenced by company priorities for emergency decision making [A-68]. The key emergency management priorities include [A-67]:

- Nuclear safety (protect the core; control criticality).
- Public safety.
- Employee safety.
- Environmental safety.
- Business reputation and operations.

The EmP Program [A-67], employs the emergency management process depicted in Figure A-7.



**Figure A-7 Emergency Management Process**

The EmP Program [A-67] aim, is to protect life and minimize loss through the following objectives:

- Ensure a state of readiness to mitigate the effects of an emergency/abnormal situation to protect the health and safety of workers, the public, and the environment.
- Demonstrate compliance to applicable Emergency Management codes and standards [A-2].
- Set CNL standards for a consistent approach to EmP and emergency response.
- Confirm CNL's commitment to safely operate facilities and projects, to a standard consistent with the type and degree of hazard associated with various operations.
- Empower the Program Staff to employ the company's resources to effectively manage the Program.
- Prepare employees for emergency response through training, documentation, and exercises.
- As required by location, establish liaison and coordination with Federal, Provincial and municipal officials and support response actions by off-site authorities and emergency organizations.
- Liaise with the international community to remain current with contemporary ideas and consistent with contemporary practices.
- Establish emergency plans and procedures for the mitigation of harmful effects of emergencies.
- Provide responsible guidance and change control for effective Program management.

#### **A.10.2 FIRE PROTECTION**

The FPP [A-33], provides an overall framework, including requirements, processes and responsibilities to fulfill CNL policies [A-56], [A-70] and [A-60], and regulatory responsibilities pertaining to fire protection at CRL. The FPP provides an operational framework to implement CNL's OSH Program [A-32], with respect to fire protection and to ensure compliance with applicable legal and other requirements.

The FPP [A-33] applies to all CNL employees and to other personnel (contractors, consultants, etc.), conducting work at CNL sites, and applies to design, operations and other activities that may affect fire protection in and around CNL sites. The FPP [A-33] applies a risk graded approach in conjunction with the defence-in-depth principles to its operations and activities in so far as they may affect fire protection.

The FPP requirements document [A-71], specifies the requirements for the FPP activities performed by CNL to meet the applicable licence conditions throughout the life cycle of a site or Facility.

The FPP enables CNL to meet its legal obligations through the following goals [A-71]:

- Minimize the risk of radiological releases to the public that are a result of fire.
- Protect occupants from death or injury due to fire.
- Minimize economic loss resulting from fire damage to structures, equipment, and inventories.
- Minimize the impact of radioactive and hazardous materials on the environment as a result of fire.

The FPP objectives are [A-71]:

- Protect life, property, environment, and provide fire safety.
- Prevent fire losses and degradation of fire protection coverage.
- Provide responsible fire protection and change control that enhances fire protection.
- Demonstrate compliance to applicable fire protection codes and standards.
- Improve fitness for purpose, with respect to fire protection.
- Provide reliable facilities from a fire protection perspective.
- Improve business performance and provide risk management using various tools such as self-assessment, code compliance reviews, fire protection screening processes (engineering change control) and FHA.

The main activities across all CNL site that are associated with the FPP include [A-33] and [A-71]:

- Identification and evaluation of fire hazards.
- Mutual aid.
- Inspection, testing and maintenance of fire protection equipment, apparatus and systems.
- Building inspections and patrols.
- Life safety assessments.
- External OPEX.
- Fire exercises and drills.
- Review of new construction and proposed modifications.
- Review of fire protection systems.
- Hot work permits.
- Fire and emergency response.
- Fire-fighting systems and components.
- Structural fire suppression.
- Wild land fire prevention and suppression.

The Fire Department at CRL are capable of providing fire suppression and emergency response to mitigate loss-of-life and property damage 24 hours per day, 7 days per week (24/7) to meet the requirements of NFPA 600-05 [A-72]. Chalk River Laboratories Fire Department also respond to the following emergencies:

- Vehicle collision extrication (automobile and heavy/commercial vehicle).
- Machinery extrication.
- Confined space rescue.
- Rope rescue.
- Water/ice rescue.
- Hazardous materials response.
- Wildfire suppression.
- Emergency medical response – Health Care Providers level.
- Elevator Rescue.

#### **A.11 WASTE MANAGEMENT**

The Waste Management Program is responsible for documenting the activities involving the waste management lifecycle [A-73]. The Waste Management Program [A-73], addresses the Waste Management Safety and Control Area requirements of CRL and WL, as well as regulatory obligations applicable at CNL operated sites in Canada.

The Waste Management Program [A-73] facilitates and oversees all aspects of the waste management process for all waste types. The Waste Management Program [A-73] mandate, applies to the full lifecycle of waste, including all operations and activities that results in the planning, generation, transportation, processing, storage and/or disposal of waste generated by CNL operated sites or received by CNL operated sites from external organizations. This also includes the waste data management aspects of waste management which is embedded into the process.

The program provides advice to all waste generators, to ensure that activities involving the waste management lifecycle are performed in a manner that protects the workers, the public, and the environment, and are in compliance with the licensing and associated Provincial and Federal documents and standards from the company-wide Management System framework [A-73]. Included within the waste management lifecycle are characterization and records, which facilitate the waste management lifecycle by clearly informing the requirements of each phase [A-73].

The Waste Management Program [A-73] translates the specific waste requirements from the relevant Provincial and Federal documents and standards, into program requirements, as described in Waste Management Program Requirements [A-74].

The Waste Management Program description document [A-73]:

- Describes CNL's Waste Management Program, and provides details on the framework through which the Waste Management Program is governed.
- Defines the overall high-level process for managing waste, following the Waste Management lifecycle, and identifies the Waste Management lifecycle process steps to correctly plan, assess, characterize, segregate,



package, transport, process (including pre-treatment, treatment and conditioning), store, and/or dispose of waste.

The Waste Management Program [A-73], ensures that all waste generated or received at CNL operated sites not only meet waste management requirements, but are managed in a safe and environmentally responsible manner in accordance with CNL's Safety and Health Policy [A-56] and CNL's Environment Policy [A-60].

The Waste Management Program [A-73] is driven by a series of requirements [A-74] and supported through a series of Management Control Procedures and Functional Instruction Documents for the application of work processes, practices and activities for managing waste. The Waste Management Program translates applicable regulatory requirements [A-74] into program requirements appropriate for CNL operated sites, and assists CNL management in the implementation of those requirements. The Waste Management Program implements CNL's Environment Policy [A-60] with regards to the management of both solid and liquid waste.

The Waste Management Program [A-73] defines the process for managing waste from the point of generation to final disposition, and maintains the programmatic responsibility/oversight for several support activities necessary to facilitate the effective management of waste.

The Waste Management Program [A-73] is responsible for:

- Developing and maintaining CNL's Integrated Waste Strategy [A-75] that describes how CNL optimizes its strategic approach to waste management. This entails continual update or alteration if changes are made to optimize CNL strategic plans.
- Developing and maintaining a waste transportation strategy for all CNL operated sites.
- Providing waste oversight and SME support to Waste Generators to ensure that the Waste Management lifecycle process and Waste Hierarchy are implemented in accordance with the applicable policies, procedures and standards governing these activities.
- Implementing standardized waste characterization across CNL operated sites to ensure that waste meets the WAC for current and planned storage and disposal facilities.
- Managing the requirements for waste inventory data and forecasting reporting.
- Developing and setting CNL's WM governance, including procedures and other supporting materials (e.g., documentation and training materials), in compliance with applicable requirements (e.g., Acts, regulations, codes, standards and guidance documents), internal interfaces, and other stakeholders, and based on industry best practices.
- Identifying best available options and developing plans for all phases of the WM lifecycle process at CNL operated sites.
- Identifying and addressing gaps in existing WM lifecycle processes through observation, assessments and reviews at CNL operated sites, and benchmarking against other facilities (nuclear and non-nuclear).
- Maintaining cross-functional knowledge spanning the various specialty areas associated with CNL's WM Program (including radiological, mixed, hazardous, and clean waste; waste storage and/or disposal options and facilities; waste minimization and reduction practices; international practices with regards to the long-term management of waste).

In addition, the Waste Management Program [A-73] provides cross-cutting WM-related services to facilitate the effective management of waste throughout its WM lifecycle, so that waste generated by CNL operated sites meets the waste requirements of the storage and/or disposal facility. This is achieved by:

- Providing oversight and guidance to Waste Generators during the pre-generation planning phase of the WM lifecycle to prevent the generation of waste without appropriate controls and approvals; and to reduce, reuse, and recycle potential waste streams to minimize the generation of waste.
- Providing guidance and assistance to Waste Generators with preparation of waste profiles to ensure their waste meets the WAC of the receiving facilities.
- Providing instructions to Waste Generators for the packaging or repacking of waste to produce disposal ready packages, and for the management, handling, labelling, and storage of the waste as required.
- Supporting the development and/or review of Waste Management Plans to ensure they meet applicable storage and/or disposal facility WAC.
- Oversight of waste operations activities to ensure waste verification is conducted in support of the storage and/or disposal facility requirements.
- Maintaining a waste data tracking system to support all CNL operated sites.
- Providing guidance and support to Waste Generators in making waste determinations and completing waste disposition forms to support process knowledge evaluations and waste routing.
- Reviewing/certifying Waste Generator's waste characterization data, and waste certification data, to ensure they meet applicable WAC and data quality objectives.
- Providing oversight of waste shipments, to and from the receiving facility, as required by waste certification processes.

#### **A.11.1 DECOMMISSIONING & DEMOLITION**

The Decommissioning & Demolition Program [A-76], defines the roles and responsibilities that apply to decommissioning activities, and outlines the key process steps associated with decommissioning. The Decommissioning Process provides guidance on decommissioning and remedial activities associated with the lifecycle of a Facility including: design, construction, commissioning, operation, decommissioning and demolition, and remediation.

The Decommissioning Process is based on fundamental management system principles and industry best practices with the goal of achieving excellence in decommissioning and is applied using a graded approach [A-76]. The grading reflects the decommissioning of SSCs and land sites based on the licence requirements, complexity, level of risk and residual hazards present [A-76]. The Decommissioning Process applies to all CNL facilities and associated land sites throughout their lifecycle [A-76].

The decommissioning process is divided into several process activities [A-76]:

- Perform preliminary decommissioning planning.
- Safe shutdown and turnover for decommissioning.
- Execute safe storage and maintenance plans.
- Perform detailed decommissioning planning.
- Execute decommissioning project.

- Execute remediation project.
- Complete decommissioning.

The Decommissioning & Demolition Program requirements document [A-77], identifies the requirements associated with the Decommissioning Process and provides an index to governing and approved procedural documents and is applicable to the Decommissioning Process at CNL.

As per CSA N294, Decommissioning of Facilities Containing Nuclear Substances [A-78], decommissioning process starts at the design stage of a facility or site and applies throughout the lifecycle of the Facility until the Facility or site is permanently retired from service and prepared for reuse or rendered to a predetermined end-state condition [A-77]. The decommissioning strategy for the NSDF Project is documented in the Preliminary Decommissioning Plan [A-79], which addresses the decommissioning activities during the 30 year closure period.

## **A.12 SECURITY**

The Security Program implements CNL's Security Policy within CNL operating sites in Canada and to ensure compliance with all applicable legal and corporate requirements [A-80]. The Security Program applies to the operation and activities that affect the security in and around CNL sites, and applies to all employees and other personnel (visitors, contract staff, etc.) conducting work at CNL sites [A-80]. The Security Program is responsible for ensuring the protection of CNL employees, facilities and nuclear materials in accordance with the CNL Security Policy [A-70].

The Security Program Requirements Document [A-81], provides a summary of legal and other requirements applicable to CNL sites in Canada.

The CRL Security Program is organized into four distinct areas [A-80]:

- Security Program.
- Physical Security Operations and Training.
- Personnel Security, Intelligence and Investigations.
- Security Systems.

## **A.13 SAFEGUARDS AND NON-PROLIFERATION**

The NM&SM Program [A-82] and [A-83], provides NM&SM compliance and services to CNL. The NM&SM Program's primary focus is on facilities that contain Fissionable Materials, therefore, are subject to regulatory safeguards measures and reporting requirements [A-83].

The NM&SM Program applies to all nuclear material and safeguards management activities performed at CNL facilities. The NM&SM Program requirements [A-83], apply to all CNL Sites, CNL employees, and non-CNL Personnel that work at these sites. The NM&SM Program requirements [A-83], applies to all activities involving the procurement and receipt of radioisotopes and radiation sources, as well as the procurement, receipt, disposition, transfer, accounting, safeguards management, storage, and inventory management of nuclear material.

The following are the foundation of the NM&SM Program [A-82]:

- Compliance with the Canadian NSCA [A-28], CNL site licences and CNSC/IAEA regulations.
- All nuclear material on-site shall be accounted for.
- All IAEA safeguards inspection requests are complied with and supported.
- All required IAEA safeguard reports are submitted.
- All safeguards approaches for Projects are designed in co-operation with the Facility.

Nuclear material accountancy is the program of nuclear material accounting and reporting implemented at CNL to satisfy international safeguards agreements. The CRL site has been subdivided into a number of smaller accountancy areas named Material Balance Areas. All buildings/structures containing nuclear material are designated within one of the Material Balance Areas. Nuclear material accountancy covers activities carried out to establish the quantities of nuclear material present within Material Balance Areas, and the changes in those quantities within a defined time period.

#### **A.14 PACKAGING AND TRANSPORT**

The Transportation of Dangerous Goods Program [A-84], applies to all activities involving the transportation of dangerous goods. Transport encompasses all operations associated with the movement of dangerous goods, including: classification, documentation, packaging, safety marks, security, emergency response, training, and regulatory permits and licences [A-84].

The main objectives of the Transportation of Dangerous Goods Program are [A-84]:

- To protect persons, property and the environment from the effects of radiation and hazardous material during transport by establishing and maintaining requirements and processes, necessary to facilitate the safe transport of dangerous goods to and from CNL sites in accordance with regulatory requirements.
- Ensure compliance with applicable regulatory and licence requirements.
- The Transportation of Dangerous Goods Program requirements are listed in the Transportation of Dangerous Goods Program Requirements [A-85].

The aspects of the Transportation of Dangerous Goods Program [A-84], envisaged to apply to the NSDF Project are those requirements associated with receiving and storing dangerous goods. Dangerous goods will be used during construction, operations and closure of the Facility.

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- [A-61] ISO 14001:2015, *Environmental Management Systems – Requirements with Guidance for use*, CAN/CSA ISO 14001:16.
- [A-62] *Canadian Environmental Protection Act*, 1999 (S.C. 1999, c. 33).
- [A-63] *Fisheries Act*, (R.S.C., 1985, c. F-14).
- [A-64] *Transportation of Dangerous Goods Act*, 1992 (1992, c. 34).
- [A-65] *Species at Risk Act*, (S.C. 2002, c. 29).
- [A-66] *Environmental Protection*, 900-509200-GDI-001, Revision 2, 2019 March.
- [A-67] *Emergency Preparedness Program Description Document*, 900-508730-PDD-001, Revision 1, 2018 September.

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- [A-68] *Strategic Emergency Management Plan*, CW-508730-ERP-001, Revision 1, 2012 December.
- [A-69] *Emergency Preparedness Program Requirements Document*, 900-508730-PRD-001, Revision 1, 2019 May.
- [A-70] *Security*, 900-508710-POL-001, Revision 0, 2017 November.
- [A-71] *Emergency Preparedness Program Requirements Document*, 900-508730-PRD-001, Revision 0, 2017 January.
- [A-72] NFPA 600, *Standard for Industrial Fire Brigades* – 2005
- [A-73] *Waste Management Program Description Document*, 900-508600-PDD-001, Revision 1, 2019 January.
- [A-74] *Waste Management Program Requirements Document*, 900-508600-PRD-001, Revision 1, 2019 February.
- [A-75] *CNL Integrated Waste Strategy*, CW-508600-PLA-002, Revision 1, 2019 February.
- [A-76] *Decommissioning and Demolition Program Description*, 900-508300-PDD-001, Revision 1, 2018 November.
- [A-77] *Decommissioning and Demolition*, 900-508300-PRD-001, Revision 1, 2018 November.
- [A-78] Canadian Standards Association, *Decommissioning of Facilities Containing Nuclear Substances*, CSA N294, 2014.
- [A-79] AECOM, *Preliminary Decommissioning Plan*, 232-508300-PLA-001, Revision 1, 2018 September.
- [A-80] *Security Program Description Document*, 900-508710-PDD-001, Revision 2, 2018 October.
- [A-81] *Security Program Requirements Document*, 900-508710-PRD-001, Revision 1, 2018 December.
- [A-82] *Nuclear Materials and Safeguards Management Program Description*, 900-508510-PDD-001, Revision 1, 2017 February.
- [A-83] *Nuclear Materials and Safeguards Management Program Requirements Document*, 900-50510-PRD-001, Revision 1, 2017 February.
- [A-84] *Transportation of Dangerous Goods Program Description Document*, 900-508520-PDD-001, Revision 0, 2017 February.
- [A-85] *Transportation of Dangerous Goods Program Requirements Document*, 900-508520-PRD-001, Revision 0, 2017 February.

## APPENDIX B CONCORDANCE TABLES

Table B-1 is the concordance table for the Class I Nuclear Facilities Regulations. Table B-2 is the concordance table for REGDOC-2.11.1, Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, 2018. Table B-3 is the concordance table for IAEA, Disposal of Radioactive Waste, SSR-5, 2011.

**Table B-1**  
**Concordance Table for Class I Nuclear Facilities Regulations**

| <b>Class I Nuclear Facilities Regulations, SOR/2000-204</b> |                                                                                                                                                                                                                                                             |                                                                                                                                                                                           |
|-------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Paragraph</b>                                            | <b>Requirement</b>                                                                                                                                                                                                                                          | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                  |
| <b>General Requirements</b>                                 |                                                                                                                                                                                                                                                             |                                                                                                                                                                                           |
| 3                                                           | An application for a licence in respect of a Class I nuclear facility, other than a licence to abandon, shall contain the following information in addition to the information required by section 3 of the General Nuclear Safety and Control Regulations: | See below paragraph 3 (a) to 3 (k).                                                                                                                                                       |
| 3 a)                                                        | a description of the site of the activity to be licensed, including the location of any exclusion zone and any structures within that zone;                                                                                                                 | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                                   |
| 3 b)                                                        | plans showing the location, perimeter, areas, structures and systems of the nuclear facility;                                                                                                                                                               | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case, 232-03610-SAR-001.                                                  |
| 3 c)                                                        | evidence that the applicant is the owner of the site or has authority from the owner of the site to carry on the activity to be licensed;                                                                                                                   | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                                   |
| 3 d)                                                        | the proposed management system for the activity to be licensed, including measures to promote and support safety culture;                                                                                                                                   | NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                       |
| 3 d.1)                                                      | the proposed human performance program for the activity to be licensed, including measures to ensure workers' fitness for duty.                                                                                                                             | NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                       |
| 3 e)                                                        | the name, form, characteristics and quantity of any hazardous substances that may be on the site while the activity to be licensed is carried on;                                                                                                           | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004.                                                                                       |
| 3 f)                                                        | the proposed worker health and safety policies and procedures;                                                                                                                                                                                              | NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                       |
| 3 g)                                                        | the proposed environmental protection policies and procedures;                                                                                                                                                                                              | Environmental Protection Plan 232-509200-PLA-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001. |



| <b>Class I Nuclear Facilities Regulations, SOR/2000-204</b> |                                                                                                                                                                                                                                                              |                                                                                                                                                                                                 |
|-------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Paragraph</b>                                            | <b>Requirement</b>                                                                                                                                                                                                                                           | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                        |
| 3 h)                                                        | the proposed effluent and environmental monitoring programs;                                                                                                                                                                                                 | Environmental Protection Plan 232-509200-PLA-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.       |
| 3 i)                                                        | if the application is in respect of a nuclear facility referred to in paragraph 2(b) of the Nuclear Security Regulations, the information required by section 3 of those Regulations;                                                                        | Not applicable. NSDF is not a nuclear power plant.                                                                                                                                              |
| 3 j)                                                        | the proposed program to inform persons living in the vicinity of the site of the general nature and characteristics of the anticipated effects on the environment and the health and safety of persons that may result from the activity to be licensed; and | Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                                                                                         |
| 3 k)                                                        | the proposed plan for the decommissioning of the nuclear facility or of the site.                                                                                                                                                                            | NSDF Safety Analysis Report 232-508770-SAR-002; Preliminary Decommissioning Plan 232-508300-PLA-001.                                                                                            |
| <b>Licence to Prepare Site</b>                              |                                                                                                                                                                                                                                                              |                                                                                                                                                                                                 |
| 4                                                           | An application for a licence to prepare a site for a Class I nuclear facility shall contain the following information in addition to the information required by section 3:                                                                                  | See below paragraph 4 (a) to 4 (e).                                                                                                                                                             |
| 4 a)                                                        | a description of the site evaluation process and of the investigations and preparatory work that have been and will be done on the site and in the surrounding area;                                                                                         | Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                                                                                         |
| 4 b)                                                        | a description of the site's susceptibility to human activity and natural phenomena, including seismic events, tornadoes and floods;                                                                                                                          | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                                         |
| 4 c)                                                        | the proposed program to determine the environmental baseline characteristics of the site and the surrounding area;                                                                                                                                           | Environmental Impact Statement 232-509220-REPT-004.                                                                                                                                             |
| 4 d)                                                        | the proposed quality assurance program for the design of the nuclear facility; and                                                                                                                                                                           | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001.                                |
| 4 e)                                                        | the effects on the environment and the health and safety of persons that may result from the activity to be licensed, and the measures that will be taken to prevent or mitigate those effects.                                                              | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |
| <b>Licence to Construct</b>                                 |                                                                                                                                                                                                                                                              |                                                                                                                                                                                                 |

| <b>Class I Nuclear Facilities Regulations, SOR/2000-204</b> |                                                                                                                                                                                                                                                                                                |                                                                                                                                                                              |
|-------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Paragraph</b>                                            | <b>Requirement</b>                                                                                                                                                                                                                                                                             | <b>Demonstrated in CNL Documentation</b>                                                                                                                                     |
| 5                                                           | An application for a licence to construct a Class I nuclear facility shall contain the following information in addition to the information required by section 3:                                                                                                                             | See below, paragraph 5 a) to 5 m).                                                                                                                                           |
| 5 a)                                                        | a description of the proposed design of the nuclear facility, including the manner in which the physical and environmental characteristics of the site are taken into account in the design;                                                                                                   | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Design Description 232-503212-DD-001; Environmental Impact Statement 232-509220-REPT-004 |
| 5 b)                                                        | a description of the environmental baseline characteristics of the site and the surrounding area;                                                                                                                                                                                              | Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                      |
| 5 c)                                                        | the proposed construction program, including its schedule;                                                                                                                                                                                                                                     |                                                                                                                                                                              |
| 5 d)                                                        | a description of the structures proposed to be built as part of the nuclear facility, including their design and their design characteristics;                                                                                                                                                 | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001.             |
| 5 e)                                                        | a description of the systems and equipment proposed to be installed at the nuclear facility, including their design and their design operating conditions;                                                                                                                                     | NSDF Safety Analysis Report 232-508770-SAR-002; Design Description 232-503212-DD-001; NSDF Safety Case 232-03610-SAR-001.                                                    |
| 5 f)                                                        | a preliminary safety analysis report demonstrating the adequacy of the design of the nuclear facility;                                                                                                                                                                                         | NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                          |
| 5 g)                                                        | the proposed quality assurance program for the design of the nuclear facility;                                                                                                                                                                                                                 | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001.             |
| 5 h)                                                        | the proposed measures to facilitate Canada's compliance with any applicable safeguards agreement;                                                                                                                                                                                              | Nuclear Materials and Safeguard Management Program, NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                      |
| 5 i)                                                        | the effects on the environment and the health and safety of persons that may result from the construction, operation and decommissioning of the nuclear facility, and the measures that will be taken to prevent or mitigate those effects;                                                    | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                      |
| 5 j)                                                        | the proposed location of points of release, the proposed maximum quantities and concentrations, and the anticipated volume and flow rate of releases of nuclear substances and hazardous substances into the environment, including their physical, chemical and radiological characteristics; | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                      |

| <b>Class I Nuclear Facilities Regulations, SOR/2000-204</b> |                                                                                                                                                                                                                               |                                                                                                                                               |
|-------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Paragraph</b>                                            | <b>Requirement</b>                                                                                                                                                                                                            | <b>Demonstrated in CNL Documentation</b>                                                                                                      |
| 5 k)                                                        | the proposed measures to control releases of nuclear substances and hazardous substances into the environment;                                                                                                                | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.       |
| 5 l)                                                        | the proposed program and schedule for recruiting, training and qualifying workers in respect of the operation and maintenance of the nuclear facility; and                                                                    | NSDF Safety Analysis Report 232-508770-SAR-002.                                                                                               |
| 5 m)                                                        | a description of any proposed full-scope training simulator for the nuclear facility.                                                                                                                                         | Not applicable to the NSDF Project.                                                                                                           |
| <b>Licence to Operate</b>                                   |                                                                                                                                                                                                                               |                                                                                                                                               |
| 6                                                           | An application for a licence to operate a Class I nuclear facility shall contain the following information in addition to the information required by section 3:                                                              | See below, paragraph 6 a) to 6 n).                                                                                                            |
| 6 a)                                                        | a description of the structures at the nuclear facility, including their design and their design operating conditions;                                                                                                        | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Design Description 232-503212-DD-001.                     |
| 6 b)                                                        | a description of the systems and equipment at the nuclear facility, including their design and their design operating conditions;                                                                                             | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Design Description 232-503212-DD-001.                     |
| 6 c)                                                        | a final safety analysis report demonstrating the adequacy of the design of the nuclear facility;                                                                                                                              | NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                           |
| 6 d)                                                        | the proposed measures, policies, methods and procedures for operating and maintaining the nuclear facility;                                                                                                                   | NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001; Operations and Maintenance (O&M) Plan 232-508220-PLA-001. |
| 6 e)                                                        | the proposed procedures for handling, storing, loading and transporting nuclear substances and hazardous substances;                                                                                                          | Operations and Maintenance (O&M) Plan 232-508220-PLA-001; NSDF Safety Analysis Report 232-508770-SAR-002.                                     |
| 6 f)                                                        | the proposed measures to facilitate Canada's compliance with any applicable safeguards agreement;                                                                                                                             | Nuclear Materials and Safeguard Management Program, NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.       |
| 6 g)                                                        | the proposed commissioning program for the systems and equipment that will be used at the nuclear facility;                                                                                                                   | NSDF Safety Analysis Report 232-508770-SAR-002; Commissioning Plan 232-505250-PLA-001; NSDF Safety Case 232-03610-SAR-001.                    |
| 6 h)                                                        | the effects on the environment and the health and safety of persons that may result from the operation and decommissioning of the nuclear facility, and the measures that will be taken to prevent or mitigate those effects; | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.       |

| <b>Class I Nuclear Facilities Regulations, SOR/2000-204</b> |                                                                                                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                         |
|-------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Paragraph</b>                                            | <b>Requirement</b>                                                                                                                                                                                                                                                                             | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                                |
| 6 i)                                                        | the proposed location of points of release, the proposed maximum quantities and concentrations, and the anticipated volume and flow rate of releases of nuclear substances and hazardous substances into the environment, including their physical, chemical and radiological characteristics; | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                 |
| 6 j)                                                        | the proposed measures to control releases of nuclear substances and hazardous substances into the environment;                                                                                                                                                                                 | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                 |
| 6 k)                                                        | the proposed measures to prevent or mitigate the effects of accidental releases of nuclear substances and hazardous substances on the environment, the health and safety of persons and the maintenance of national security, including measures to                                            | NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                 |
| 6 k) (i)                                                    | assist off-site authorities in planning and preparing to limit the effects of an accidental release,                                                                                                                                                                                           | Emergency Preparedness see NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                                          |
| 6 k) (ii)                                                   | notify off-site authorities of an accidental release or the imminence of an accidental release,                                                                                                                                                                                                | Emergency Preparedness see NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                                          |
| 6 k) (iii)                                                  | report information to off-site authorities during and after an accidental release,                                                                                                                                                                                                             | Emergency Preparedness see NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                                          |
| 6 k) (iv)                                                   | assist off-site authorities in dealing with the effects of an accidental release, and                                                                                                                                                                                                          | Emergency Preparedness see NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                                          |
| 6 k) (v)                                                    | test the implementation of the measures to prevent or mitigate the effects of an accidental release;                                                                                                                                                                                           | Emergency Preparedness see NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                                          |
| 6 l)                                                        | the proposed measures to prevent acts of sabotage or attempted sabotage at the nuclear facility, including measures to alert the licensee to such acts;                                                                                                                                        | CNL Security Program see NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Safety Case 232-03610-SAR-001.                                                                                                                                                            |
| 6 m)                                                        | the proposed responsibilities of and qualification requirements and training program for workers, including the procedures for the requalification of workers; and                                                                                                                             | Proposed responsibilities of and qualification requirements: NSDF Safety Analysis Report 232-508770-SAR-002 Section 10 and NSDF Facility Authorization 232-00583-FA-001. Training Program to be developed: NSDF Safety Analysis Report 232-508770-SAR-002 Section 10.5. |
| 6 n)                                                        | the results that have been achieved in implementing the program for recruiting, training and qualifying workers in respect of the operation and maintenance of the nuclear facility.                                                                                                           | Training Program to be developed: NSDF Safety Analysis Report 232-508770-SAR-002 Section 10.5.                                                                                                                                                                          |
| 7                                                           | Licence to Decommission                                                                                                                                                                                                                                                                        | Not applicable to the NSDF Project.                                                                                                                                                                                                                                     |
| 8                                                           | Licence to Abandon                                                                                                                                                                                                                                                                             | Not applicable to the NSDF Project.                                                                                                                                                                                                                                     |

| <b>Class I Nuclear Facilities Regulations, SOR/2000-204</b> |                                 |                                          |
|-------------------------------------------------------------|---------------------------------|------------------------------------------|
| <b>Paragraph</b>                                            | <b>Requirement</b>              | <b>Demonstrated in CNL Documentation</b> |
| 9 - 13                                                      | Certification of Persons        | Not applicable to the NSDF Project.      |
| 14                                                          | Records to be kept and retained | Not applicable to the NSDF Project.      |

Table B-2

**Concordance Table for REGDOC-2.11.1, Assessing the Long-Term Safety of Radioactive Waste Management**

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                                      |               |                |                                                                                                                                                                                                 |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                        |
| <b>Legislated Requirements</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                 |               |                |                                                                                                                                                                                                 |
| Paragraph 12(1)(c) of the General Nuclear Safety and Control Regulations requires that every licensee “take all reasonable precautions to protect the environment and the health and safety of persons and to maintain the security of nuclear facilities and nuclear substances.”                                                                                                                                                                                             | 2             | 3.2 #1         | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |
| Paragraph 4(d) of the General Nuclear Safety and Control Regulations requires that an application for a licence to abandon a nuclear substance, nuclear facility, prescribed equipment or prescribed information contain, in addition to other information, shall contain information on “the effects on the environment and the health and safety of persons that may result from the abandonment, and the measures that will be taken to prevent or mitigate those effects;” | 2             | 3.2 #2         | Requirement is currently not applicable to the NSDF Project.                                                                                                                                    |
| Paragraph 3(k) of the Class I Nuclear Facilities Regulations requires that an application for a licence for a Class I nuclear facility, other than a licence to abandon, include “the proposed plan for the decommissioning of the nuclear facility or of the site.”                                                                                                                                                                                                           | 2             | 3.2 #3         | Preliminary Decommissioning Plan 232-508300-PLA-001; NSDF Safety Analysis Report 232-508770-SAR-002.                                                                                            |
| Paragraph 4(e) of the Class I Nuclear Facilities Regulations requires that an application for a licence to prepare a site for a Class I facility contain, in addition to other information, information on “the effects on the environment and the health and safety of persons that may result from the activity to be licensed, and the measures that will be taken to prevent or mitigate those effects.”                                                                   | 3             | 3.2 #4         | Environmental Impact Statement 232-509220-REPT-004.                                                                                                                                             |
| Paragraph 5(f) of the Class I Nuclear Facilities Regulations requires that an application for a licence to construct a Class I nuclear facility include “a preliminary safety analysis report demonstrating the adequacy of the design of the nuclear facility;”                                                                                                                                                                                                               | 3             | 3.2 #5         | NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                         |

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                               |               |                |                                                                                                                                                             |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                                                                                    |
| Paragraph 5(i) of the Class I Nuclear Facilities Regulations requires that an application for a licence to construct a Class I nuclear facility include information on “the effects on the environment and the health and safety of persons that may result from the construction, operation and decommissioning of the nuclear facility, and the measures that will be taken to prevent or mitigate those effects;”                                                    | 3             | 3.2 #6         | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-58770-SAR-002; Environmental Impact Statement 232-509220-REPT-004                       |
| Paragraph 5(j) of the Class I Nuclear Facilities Regulations requires that an application for a licence to construct a Class I nuclear facility include information on “the proposed location of points of release, the proposed maximum quantities and concentrations, and the anticipated volume and flow rate of releases of nuclear substances and hazardous substances into the environment, including their physical, chemical and radiological characteristics;” | 3             | 3.2 #7         | Environmental Impact Statement 232-509220-REPT-004; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Analysis Report 232-508770-SAR-002. |
| Paragraph 5(k) of the Class I Nuclear Facilities Regulations requires that an application for a licence to construct a Class I nuclear facility include information on “the proposed measures to control releases of nuclear substances and hazardous substances into the environment;”                                                                                                                                                                                 | 3             | 3.2 #8         | Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Analysis Report 232-58770-SAR-002.                                                          |
| Paragraph 6(c) of the Class I Nuclear Facilities Regulations requires that an application for a licence to operate a Class I nuclear facility include “a final safety analysis report demonstrating the adequacy of the design of the nuclear facility;”                                                                                                                                                                                                                | 3             | 3.2 #9         | NSDF Safety Analysis Report 232-58770-SAR-002.                                                                                                              |
| Paragraph 6(h) of the Class I Nuclear Facilities Regulations requires that an application for a licence to operate a Class I nuclear facility include information on “the effects on the environment and the health and safety of persons that may result from the operation and decommissioning of the nuclear facility, and the measures that will be taken to prevent or mitigate those effects;”                                                                    | 3             | 3.2 #10        | Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Analysis Report 232-508770-SAR-002.                                                         |
| Paragraph 6(i) of the Class I Nuclear Facilities Regulations requires that an application for a licence to operate a Class I nuclear facility include information on “the proposed location of points of release, the proposed maximum quantities and concentrations, and the anticipated volume and flow rate of                                                                                                                                                       | 3             | 3.2 #11        | Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Analysis Report 232-508770-SAR-002, NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                                          |               |                |                                                                                                                                        |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------------|----------------------------------------------------------------------------------------------------------------------------------------|
| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                                                               |
| releases of nuclear substances and hazardous substances into the environment, including their physical, chemical, and radiological characteristics;"                                                                                                                                                                                                                                                                                                                               |               |                |                                                                                                                                        |
| Paragraph 6(j) of the Class I Nuclear Facilities Regulations requires that an application for a licence to operate a Class I nuclear facility include information on "the proposed measures to control releases of nuclear substances and hazardous substances into the environment;"                                                                                                                                                                                              | 3             | 3.2 #12        | NSDF Safety Case 232-03610-SAR-001; Environmental Impact Statement 232-509220-REPT-004; NSDF Safety Analysis Report 232-58770-SAR-002. |
| Paragraphs 7(f) and (k) of the Class I Nuclear Facilities Regulations require that an application for a licence to decommission a Class I facility contain, in addition to other information, "the effects on the environment and the health and safety of persons that may result from the decommissioning, and the measures that will be taken to prevent or mitigate those effects;" and "a description of the planned state of the site on completion of the decommissioning." | 3,4           | 3.2 #13        | Requirement is currently not applicable to the NSDF Project.                                                                           |
| Paragraph 8(a) of the Class I Nuclear Facilities Regulations stipulates that an application for a licence to abandon a Class I nuclear facility shall contain, in addition to the information required by sections 3 and 4 of the General Nuclear Safety and Control Regulations, "the results of the decommissioning;"                                                                                                                                                            | 4             | 3.2 #14        | Requirement is currently not applicable to the NSDF Project.                                                                           |
| Subparagraph 3(a)(viii) of the Uranium Mines and Mills Regulations requires that an application for a licence in respect of a uranium mine or mill, other than a licence to abandon, contain, in addition to the information required by section 3 of the General Nuclear Safety and Control Regulations, "the proposed plan for the decommissioning of the mine or mill;"                                                                                                         | 4             | 3.2 #15        | Requirement is not applicable to the NSDF Project.                                                                                     |
| Subparagraph 3(c)(iii) of the Uranium Mines and Mills Regulations requires that an application for a licence in respect of a uranium mine or mill, other than a licence to abandon, contain information on "the effects on the environment that may result from the activity to be licensed, and the measures that will be taken to prevent or mitigate those effects;"                                                                                                            | 4             | 3.2 #16        | Requirement is not applicable to the NSDF Project.                                                                                     |



| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                              |               |                |                                                    |
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| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                     | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>           |
| Subparagraph 3(d)(i) of the Uranium Mines and Mills Regulations requires that an application for a licence in respect of a uranium mine or mill, other than a licence to abandon, contain information on “the effects on the health and safety of persons that may result from the activity to be licensed, and the measures that will be taken to prevent or mitigate those effects;” | 4             | 3.2 #17        | Requirement is not applicable to the NSDF Project. |
| Paragraph 7(d) of the Uranium Mines and Mills Regulations requires that an application for a licence to decommission a uranium mine or mill contain “a description of the planned state of the site upon completion of the decommissioning work;”                                                                                                                                      | 4             | 3.2 #18        | Requirement is not applicable to the NSDF Project. |
| Paragraph 8(b) of the Uranium Mines and Mills Regulations requires that an application for a licence to abandon a uranium mine or mill contain, in addition to other information, “the results of the decommissioning work;”                                                                                                                                                           | 4             | 3.2 #19        | Requirement is not applicable to the NSDF Project. |
| Paragraph 4(t) of the Class II Nuclear Facilities Regulations requires that an application for a licence to operate a Class II nuclear facility include “the proposed plan for the decommissioning of the nuclear facility;”                                                                                                                                                           | 4             | 3.2 #20        | Requirement is not applicable to the NSDF Project. |
| Paragraph 5(i) of the Class II Nuclear Facilities Regulations stipulates that an application for a licence to decommission a Class II nuclear facility shall include information on “the effects on the environment and the health and safety of persons that may result from the decommissioning, and the measures that will be taken to prevent or mitigate those effects;”          | 4             | 3.2 #21        | Requirement is not applicable to the NSDF Project. |
| Paragraph 5(k) of the Class II Nuclear Facilities Regulations stipulates that an application for a licence to decommission a Class II nuclear facility shall include “a description of the planned state of the site upon completion of the decommissioning.”                                                                                                                          | 4             | 3.2 #22        | Requirement is not applicable to the NSDF Project. |

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                                                                           |               |                |                                                                                                                                                                                                 |
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| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                        |
| Paragraph 19(1) of CEAA 2012 states that the environmental assessment of a designated project must take into account the following factors: “(a) the environmental effects of the designated project, including the environmental effects of malfunctions or accidents that may occur in connection with the designated project and any cumulative environmental effects that are likely to result from the designated project in combination with other physical activities that have been or will be carried out. | 4             | 3.2            | NSDF Safety Case 232-03610-SAR-001; Environmental Impact Statement 232-509220-REPT-004.                                                                                                         |
| <b>Licensing considerations for long-term management</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                            |               |                |                                                                                                                                                                                                 |
| An applicant for a CNSC licence should provide reasonable assurance that the proposed plans for the long-term management of radioactive waste that will arise from the licensed activities are consistent with all applicable requirements.                                                                                                                                                                                                                                                                         | 7             | 4.3.1          | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                                     |
| The design of a nuclear facility should be optimized to exceed all applicable requirements. In particular, a radioactive waste management facility should more than meet the regulatory limits, remaining below those limits by a margin that provides assurance of safety for the long term.                                                                                                                                                                                                                       | 7             | 4.3.2          | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                                     |
| Sufficient detail should be included to allow independent calculations to confirm assessment results, whether by means of simplified calculations or by complete reproduction of the results.                                                                                                                                                                                                                                                                                                                       | 7             | 4.3.3          | NSDF Safety Analysis Report 232-58770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                          |
| <b>Developing a Long-Term Safety Case</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |               |                |                                                                                                                                                                                                 |
| Demonstrating long-term safety consists of providing reasonable assurance that waste management will be conducted in a manner that protects human health and the environment.                                                                                                                                                                                                                                                                                                                                       | 8             | 5              | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |
| The CNSC expects the safety assessment to demonstrate the applicant’s understanding of the waste management system through a well-structured, transparent, and traceable methodology. The assessment documentation should provide a clear and complete record of the decisions made and the assumptions adopted in developing the model of the waste management system. The parameters and variables used to run the model and to arrive at a given set of results should be reported and justified.                | 8             | 5.1            | NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                         |

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                      |               |                |                                                                                                                                                                                                 |
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| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                        |
| In order to provide the best possible representation of reality, a realistic best-estimate assessment of the waste management system is expected to use real site and as-built facility data, site-specific scenarios, and accurate models of the processes being simulated.                                                                                                                                                                                   | 9             | 5.2.2          | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |
| The applicant should demonstrate that the waste management system will maintain its integrity and reliability under extreme conditions, disruptive events, or unexpected containment failure, including inadvertent human intrusion.                                                                                                                                                                                                                           | 10            | 5.3            | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                     |
| <b>Defining Acceptance Criteria</b>                                                                                                                                                                                                                                                                                                                                                                                                                            |               |                |                                                                                                                                                                                                 |
| <b>Criteria for protection of persons and the environment</b>                                                                                                                                                                                                                                                                                                                                                                                                  |               |                |                                                                                                                                                                                                 |
| The regulatory requirements for protection of persons and the environment from both radiological and non-radiological hazards of radioactive wastes lead to four distinguishable sets of acceptance criteria for a long-term assessment:<br>1. Radiological protection of persons;<br>2. Protection of persons from hazardous substances;<br>3. Radiological protection of the environment; and<br>4. Protection of the environment from hazardous substances. | 12            | 6.2            | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Analysis Report 232-508770-SAR-002.                                                     |
| <b>Radiological protection of persons</b>                                                                                                                                                                                                                                                                                                                                                                                                                      |               |                |                                                                                                                                                                                                 |
| Long-term safety assessments of a facility or contaminated site should provide reasonable assurance that the regulatory radiological dose limit for public exposure (currently 1 mSv/a) will not be exceeded.                                                                                                                                                                                                                                                  | 12            | 6.2.1          | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                                     |
| <b>Protection of persons from hazardous substances</b>                                                                                                                                                                                                                                                                                                                                                                                                         |               |                |                                                                                                                                                                                                 |
| Where available, the Canadian Council of Ministers of the Environment's (CCME's) Canadian Environmental Quality Guidelines (CCME 2002) for protection of human health should be used for benchmark or toxicological reference values. Where the CCME's human health guidelines are not available, human health-based provincial guidelines should be used.                                                                                                     | 14            | 6.2.2          | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                                     |
| <b>Protection of the environment from hazardous substances</b>                                                                                                                                                                                                                                                                                                                                                                                                 |               |                |                                                                                                                                                                                                 |

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                                                                             |               |                |                                                                                                                                             |
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| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                                                                    |
| Non-radiological acceptance criteria for protection of the environment can include concentration or flux of hazardous substances. The Canadian Environmental Quality Guidelines (CCME 2002) for water, sediment, and soil are appropriate benchmarks for conservative assessments. Provincial guidelines can be used where appropriate for substances for which federal guidelines have not been established.                                                                                                         | 15            | 6.2.4          | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                 |
| <b>Performing Long-Term Assessments</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |               |                |                                                                                                                                             |
| The CNSC expects the applicant to use a structured approach to assess the long-term performance of a waste management system. Although long-term assessments are done with different levels of detail and rigour for different purposes, the overall methodology for performing them should include the following elements:<br>1. Selection of appropriate methodology;<br>2. Assessment context;<br>3. System description;<br>4. Timeframes;<br>5. Assessment scenarios; and<br>6. Development of assessment models. | 15            | 7              | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                 |
| Applicants are encouraged to consult with CNSC staff on issues concerning the appropriate methodologies for long-term assessments of their particular circumstances, and are expected to document and justify the methodology they have used.                                                                                                                                                                                                                                                                         | 15            | 7.1            | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001.                                                 |
| The terms of reference should present the purpose and rationale for the assessment.                                                                                                                                                                                                                                                                                                                                                                                                                                   | 17            | 7.2.1          | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                 |
| The assessment context should describe the regulatory framework under which the assessment will be conducted. This description should demonstrate understanding of the federal and provincial regulatory requirements, as well as any international obligations that apply to the project.                                                                                                                                                                                                                            | 17            | 7.2.2          | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                 |
| The criteria by which the assessment results will be judged should be identified in the assessment context.                                                                                                                                                                                                                                                                                                                                                                                                           | 17            | 7.2.3          | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |               |                |                                                                                                                                                                               |
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| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                                                                                                      |
| The assessment context should also include a description of the approach used to demonstrate safety over the long-term and gain confidence in the results, and how that approach addresses the principles of radioactive waste management.                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 18            | 7.2.4          | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                   |
| The system description should present both the characteristics of the site and the design of the waste management system. The waste management system and the way its components function should be described in sufficient detail to provide a clear understanding of how safety and environmental protection will be achieved. The system description should also include a description of the type of waste to be managed and the management system to be employed (i.e., disposal or storage on surface or at depth using combinations of engineered containment barriers and natural isolation barriers).                                                                              | 18            | 7.3            | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001. |
| Site characterization should include a description of the environment of the site, such as the ecological, geological, hydrological, and climatic conditions. This description should include sufficient information on the baseline conditions to allow thorough assessment of the impact of the licensed activities. Site characteristics must be sufficiently defined to produce an accurately descriptive model. For long-term waste management facilities, site characterization activities will take place over many years, and should be carried out under a formal site characterization plan that includes quality assurance/quality control (QA/QC) protocols to verify the data. | 18            | 7.3.1          | NSDF Safety Case 232-03610-SAR-001; Environmental Impact Statement 232-509220-REPT-004;                                                                                       |
| The waste management system and the way that its components function should be described in sufficient detail to provide a clear understanding of how safety and environmental protection will be achieved, and how the different components of the system will interact with each other and with the environment in the long term.                                                                                                                                                                                                                                                                                                                                                         | 19            | 7.3.2          | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004;                                       |

| Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |        |         |                                                                                             |
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| Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Page # | Section | Demonstrated in CNL Documentation                                                           |
| Assessments of the future impact that may arise from the radioactive waste are expected to include the period of time during which the maximum impact is predicted to occur. The assessment should provide a rationale for the assessment time frame. The approach taken to determine respective periods of time used in the assessment should take into account the following elements:1. Hazardous lifetime of the contaminants associated with the waste;2. Duration of the operational period (before the facility reaches its end state);3. Design life of engineered barriers;4. Duration of both active and passive institutional controls; and5. Frequency of natural events and human-induced environmental changes (e.g., seismic occurrence, flood, drought, glaciation, climate change, etc.).The assumed performance time frames of engineered barriers and the evolution of their safety function with time should be documented and justified, with reference to current national or international standards where appropriate. | 19, 20 | 7.4     | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |

| Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |        |         |                                                                                              |
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| Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Page # | Section | Demonstrated in CNL Documentation                                                            |
| A long-term assessment scenario should be sufficiently comprehensive to account for all of the potential future states of the site and the biosphere. It is common for a safety assessment to include a central scenario of the normal, or expected, evolution of the site and the facility over time, and additional scenarios that examine the potential impact of disruptive events or modes of containment failure. Each scenario presented in a safety assessment should include specific information about: 1. The timeframe on which the assessment is based; 2. The duration (start to finish) during which institutional controls are relied upon as a safety feature; and 3. The identity and characteristics of the assumed receptors and critical groups. A safety assessment should present and justify the techniques and criteria used to develop the scenarios that are analyzed. Scenarios should be developed in a systematic, transparent, and traceable manner through a structured analysis of relevant features, events, and processes (FEPs) that are based on current and future conditions of site characteristics, waste properties, and receptor characteristics and their lifestyles. | 20     | 7.5     | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-508770-SAR-001. |
| The safety assessment should demonstrate that the set of scenarios developed is credible and comprehensive. Some FEPs or scenarios may be excluded from the assessment if there is an extremely low likelihood that they would occur, or if they would have trivial impact. Considering the range of scenarios that can be developed for different waste management systems at different stages in their life cycles, applicants are expected to propose the criteria for excluding FEPs and scenarios and consult with CNSC staff as to their acceptability. The approach and screening criteria used to exclude or include scenarios should be justified and well documented.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 21     | 7.5     | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001.  |

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |               |                |                                                                                              |
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| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                     |
| A normal evolution scenario should be based on reasonable extrapolation of present day site features and receptor lifestyles. It should include expected evolution of the site and degradation of the waste disposal system (gradual or total loss of barrier function) as it ages. The decision about which natural disruptive events should be included is based on the probability of their occurrence within the timeframe of the assessment. Normal evolution scenarios should also take into account the failure modes of the containment and isolation systems. These failures can result not only from natural degradation of barriers, but from unpredictable disruptive events that might be expected to occur once or more during the assessment period, including penetration of the barriers by intrusion. | 21            | 7.5.1          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                      |
| Disruptive event scenarios postulate the occurrence of unlikely events leading to possible penetration of barriers and abnormal loss of containment. Intrusion not only breaches containment barriers, but may result in waste being redistributed outside the barriers, potentially exposing the public and the environment. Assessments of human intrusion therefore need to estimate the exposure of persons and the environment that would result from waste redistribution. Scenarios of inadvertent intrusion, where the intruder is not aware of the hazards of the waste, should estimate the exposure of the intruder; however, assessment of intentional human intrusion, in which the intruder is assumed to be aware of the hazard of the waste, need not consider the exposure of the intruder.            | 21, 22        | 7.5.2          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-508770-SAR-001. |
| A submission from a licence applicant should identify the role that institutional controls play in waste management system safety, and how that role is taken into account in the safety assessment. Any intention of relying on institutional controls to ensure long-term safety should be documented and justified in the long-term assessment.                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 22            | 7.5.3          | NSDF Safety Case 232-03610-SAR-001.                                                          |



| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |               |                |                                                                                             |
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| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                    |
| The development of assessment scenarios should include identification of humans and environmental receptors that may be exposed to radioactive and hazardous substances. The critical group is a group of people representative of those individuals in the population that are expected to receive the highest annual radiological dose.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 23            | 7.5.4          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| The habits and characteristics that are assumed for the human critical group should be based on reasonably conservative and plausible assumptions that consider current lifestyles and available site-specific or region-specific information. The assessment should model the biosphere, which will be the receiving environment for the contaminants, based as much as possible on the site specific information in the system description.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 23            | 7.5.4          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                     |
| Long-term assessments usually employ a variety of computational tools to predict future conditions for comparison to acceptance criteria that indicate safety.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 24            | 7.6            | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| An assessment model should be consistent with the site description, waste properties, and receptor characteristics, and with the quality and quantity of data available to characterize the site, waste, exposure pathways, and receptors. A systematic process should be used to ensure that the set of data used for developing the assessment model is accurate and representative. The conceptual model should account for uncertainties, incomplete information in the system description, and simplifications and assumptions adopted during interpretation of the site characterization data. These simplifications and assumptions, and any resulting restrictions or limitations in the model, should be identified and discussed in the assessment. The sets of input data that define the scenarios being analyzed by the assessment model should be consistent with the conceptual model of the site, the limitations of the analysis tools, and the restrictions imposed by the assumptions and simplifications on which each scenario is based. | 24, 25        | 7.6.1          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |

| <b>Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management, REGDOC-2.11.1, Volume III, 2018 May.</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |               |                |                                                                                             |
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| <b>Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | <b>Page #</b> | <b>Section</b> | <b>Demonstrated in CNL Documentation</b>                                                    |
| All software used in an assessment should conform to accepted quality assurance (QA) standards. The equations used to construct the model using such generic tools should also be subject to QA protocols. Alternatively, the equations should be justified for use in the given assessment. All computer software used for long-term assessments should be verified.                                                                                                                                                                                                                                                                                                              | 25            | 7.6.2          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| Confidence in the computing tools alone is not generally sufficient for regulatory purposes. The assessment model should be shown to use those tools correctly and within their limitations, and input data for the model should be verified according to an acceptable QA standard, to an extent consistent with the rigor of the assessment. The input data, the scenarios analyzed, and the resulting predictions, should all be shown to be consistent with the assumptions and limitations of the assessment model. In addition, the assessment model as a whole (scenario, conceptual model, input data, and mathematical model) should be validated to the extent possible. | 25            | 7.6.3          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| As a result, the model evaluation process should concentrate on identifying and understanding the key physical, chemical, and biological processes that are important to safety at the various space and time scales of concern in the assessment.                                                                                                                                                                                                                                                                                                                                                                                                                                 | 26            | 7.6.3          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| Model evaluation should include sensitivity analyses to show whether the model output responds as expected to variations in the model input parameter values. Model evaluation should also include uncertainty and importance analyses to show which parameters control the variability in model output. These analyses should demonstrate how well the model replicates what is known and understood about the processes and mechanisms being simulated. The results obtained from these analyses should be shown to conform to the limitations and restrictions of the assumptions in the assessment model.                                                                      | 26            | 7.6.3          | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |

| <b>Interpretation of Results</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |        |     |                                                                                             |
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| When interpreting the assessment results, the applicant should demonstrate a thorough understanding of the underlying science and engineering principles that are controlling the assessment results. Interpretation should include evaluation of compliance with the acceptance criteria and analysis of the uncertainties associated with the assessment.                                                                                                                                                                                                                                                                                                                                                                                                                                          | 26, 27 | 8   | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| The results of the assessment should also be analyzed to show consistency with system performance expectations and with the complete set of assumptions and simplifications used in developing the models and scenarios. Any unexpected results or discrepancies should be investigated and explained.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | 27     | 8   | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| Comparison of the assessment results with acceptance criteria to provide a reasonable assurance of future safety should include discussion of the conservatism of the model results, and the conservatism built into the acceptance criteria for the safety indicators.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | 27     | 8.1 | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| While in most cases acceptance criteria are expressed as single values, both deterministic and probabilistic assessment results have an associated uncertainty. It is expected that the comparison between the assessment results and the acceptance criteria will explicitly take the uncertainty in the assessment results into account, as follows:<br>1. For deterministic assessments, the range of uncertainty in the calculated result as determined by a sensitivity analysis (or importance analysis) is expected to be explicitly included in the comparison; and<br>2. For probabilistic assessments, the likelihood of exceeding the acceptance criterion should be determined from the calculated results distribution, if the criterion is expressed as a single value of consequence. | 27     | 8.1 | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |
| A formal uncertainty analysis of the predictions should be performed to identify the sources of uncertainty. This analysis should distinguish between uncertainties arising from:<br>1. Input data;<br>2. Scenario assumptions;<br>3. The mathematics of the assessment model; and<br>4. The conceptual models.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | 27     | 8.1 | NSDF Post-Closure Safety Assessment 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001. |

**Table B-3**  
**Concordance Table for Disposal of Radioactive Waste, SSR-5**

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |            |                    |                                                                                        |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Paragraph  | Safety Requirement | Demonstrated in CNL Documentation                                                      |
| <b>Governmental, Legal and Regulatory Framework</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |            |                    |                                                                                        |
| <b>Requirement 1: Government responsibilities.</b> The government is required to establish and maintain an appropriate governmental, legal and regulatory framework for safety within which responsibilities shall be clearly allocated for disposal facilities for radioactive waste to be sited, designed, constructed, operated and closed. This shall include: confirmation at a national level of the need for disposal facilities of different types; specification of the steps in development and licensing of facilities of different types; and clear allocation of responsibilities, securing of financial and other resources, and provision of independent regulatory functions relating to a planned disposal facility. |            |                    |                                                                                        |
| 17                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | 3.6, 3.7   | See SSR-5.         | This requirement is met by Government agencies and their legal responsibilities.       |
| <b>Requirement 2: Responsibilities of the regulatory body.</b> The regulatory body shall establish regulatory requirements for the development of different types of disposal facility for radioactive waste and shall set out the procedures for meeting the requirements for the various stages of the licensing process. It shall also set conditions for the development, operation and closure of each individual disposal facility and shall carry out such activities as are necessary to ensure that the conditions are met.                                                                                                                                                                                                  |            |                    |                                                                                        |
| 18, 19                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 3.8 - 3.11 | See SSR-5.         | This requirement is met by the CNSC and the licensing process for a disposal facility. |
| <b>Requirement 3: Responsibilities of the operator.</b> The operator of a disposal facility for radioactive waste shall be responsible for its safety. The operator shall carry out safety assessment and develop and maintain a safety case, and shall carry out all the necessary activities for site selection and evaluation, design, construction, operation, closure and, if necessary, surveillance after closure, in accordance with national strategy, in compliance with the regulatory requirements and within the legal and regulatory infrastructure.                                                                                                                                                                    |            |                    |                                                                                        |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                       |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                              |
| 19                                                                                            | 3.12             | The operator has to be responsible for developing a disposal facility that is practicable and safe and for demonstrating its safety, consistent with the requirements of the regulatory body. This task has to be undertaken in consideration of: the characteristics and quantities of the radioactive waste to be disposed of; the site or sites available; the mining, excavation, construction and engineering techniques available; and the legal and regulatory infrastructure and regulatory requirements. The operator also has to be responsible for developing a safety case, on the basis of which decisions on the development, operation and closure of the disposal facility have to be made (see Requirements 17–19). | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001. |
| 20                                                                                            | 3.13             | The operator has to conduct or commission the research and development work necessary to ensure that the planned technical operations can be practically and safely accomplished, and to demonstrate this. The operator likewise has to conduct or commission the research work necessary to investigate, to understand and to support the understanding of the processes on which the safety of the disposal facility depends. The operator also has to carry out all the necessary investigations of sites and of materials and has to assess their suitability and obtain all the data necessary for the purposes of safety assessment.                                                                                           | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004.                                                                                               |
| 20                                                                                            | 3.14             | The operator has to establish technical specifications that are justified by safety assessment, to ensure that the disposal facility is developed in accordance with the safety case. This has to include waste acceptance criteria (see Requirement 20) and other controls and limits to be applied during construction, operation and closure.                                                                                                                                                                                                                                                                                                                                                                                     | Design Description 232-503212-DD-001; Waste Acceptance Criteria 232-508600-REPT-003; Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment, 232-509240-ASD-004; NSDF Safety Case 232-03610-SAR-001.          |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b>                                                                                                                                                                                                                                                                                                                                                                                  |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                       |
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| <b>Page</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                              |
| 20                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 3.15             | The operator has to retain all the information relevant to the safety case and the supporting safety assessment for the disposal facility and has to retain the inspection records that demonstrate compliance with regulatory requirements and with the operator's own specification. Such information and records have to be retained, at least up until the time when the information is shown to be superseded, or until responsibility for the disposal facility is passed on to another organization. This occurs, for example, at closure of the facility, when all relevant information and records have to be transferred to the organization assuming responsibility for the facility and its safety. | NSDF Safety Case, 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Design Requirements, 232-503212-DR-001; Design Description 232-503212-REPT-00.                                                                   |
| 20                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 3.16             | The operator has to cooperate with the regulatory body and has to supply all the information that the regulatory body may request. This need to preserve the records for long periods of time has to be taken into account in selecting the format and media to be used for records.                                                                                                                                                                                                                                                                                                                                                                                                                            | CNL-CNRC Administrative Protocol for the Near Surface Disposal Facility Project at Chalk River Laboratories, e-Doc 5021273                                                                                                            |
| <b>Safety Approach</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                       |
| <b>Requirement 4: Importance of safety in the process of development and operation of a disposal facility. Throughout the process of development and operation of a disposal facility for radioactive waste, an understanding of the relevance and the implications for safety of the available options for the facility shall be developed by the operator. This is for the purpose of providing an optimized level of safety in the operational stage and after closure.</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                       |
| 21                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 3.17             | Disposal facilities for radioactive waste may be developed and operated over a period of several years or several decades. Key decisions, such as decisions on site selection and evaluation, and on the design, construction, operation and closure of the disposal facility, are expected to be made as the project develops. In this process, decisions are made on the basis of the information available at the time, which may be either quantitative or qualitative, and the confidence that can be planned in that information.                                                                                                                                                                         | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001. |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                       |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                         |
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| Page                                                                                                                                                                                                                                                                                                                                                         | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Demonstrated in CNL Documentation                                                                                                                                                                                                                                       |
| 21                                                                                                                                                                                                                                                                                                                                                           | 3.18      | Decisions on the development, operation and closure of the facility are constrained by external factors, which include: national policy and preferences, the capacity and capability of existing storage and disposal facilities to accommodate waste, and the availability of suitable sites and geological formations to host planned new disposal facilities. An adequate level of confidence in the safety of each disposal facility has to be developed before decisions are taken.                                                                            | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001.                                   |
| 21                                                                                                                                                                                                                                                                                                                                                           | 3.19      | At each major decision point, the implications for the safety of the available design options and operational options for the disposal facility have to be considered and taken into account. Ensuring safety, both in the operational stage and after closure, is the overriding concern at each decision point. If more than one option is capable of providing the required level of safety, then other factors also have to be considered. These factors could include public acceptability, cost site ownership, existing infrastructure and transport routes. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001.                                   |
| 21                                                                                                                                                                                                                                                                                                                                                           | 3.20      | Consideration has to be given to locating the facility away from significant known mineral resources, geothermal water and other valuable subsurface resources. This is to reduce the risk of human intrusion into the site and to reduce the potential for use of the surrounding area to be in conflict with the facility. The safety of the facility has to be considered at every step in the decision making process to ensure that safety is optimized in the sense discussed in the Appendix.                                                                | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001.                                   |
| <b>Requirement 5: Passive means for the safety of the disposal facility. The operator shall evaluate the site and shall design, construct, operate and close the disposal facility in such a way that safety is ensured by passive means to the fullest extent possible and the need for actions to be taken after closure of the facility is minimized.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                         |
| 22                                                                                                                                                                                                                                                                                                                                                           | 3.21      | In the operational stage of a disposal facility for radioactive waste, certain active control measures have to be applied. However, where passive features such as the shielding and containment provided by the packaging material can provide safety, then safety has to be ensured by such passive means.                                                                                                                                                                                                                                                        | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Waste Acceptance Criteria 232-508600-REPT-003; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001. |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    |                                                                                                                                                                                                                                                                                  |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                                         |
| 22                                                                                            | 3.22             | To some extent, the safety of a disposal facility can depend on some future actions such as maintenance work or surveillance. However, this dependence has to be minimized to the extent possible. This is necessary because of the possibility that safety measures that depend on future actions, such as maintenance work or surveillance, will not be taken or will not be continued. The cumulative probability of the failure of such safety measures will gradually increase. Furthermore, and consistent with the Fundamental Safety Principles, SF-1, disposal of radioactive waste is intended to discharge the responsibility for safety of the waste producers and the operator to the fullest extent possible, thereby minimizing the responsibilities that are retained or are passed on to successor organizations. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001; Operations and Maintenance Plan 232-508220-PLA-001; Post-Closure Care Plan 232-508220-PLA-004. |
| 22                                                                                            | 3.23             | For a geological disposal facility, it is possible to provide for safety after closure by means of passive features. It is likewise possible to provide for the safety of a borehole disposal facility after closure by means of passive features, owing to the host geology. In the case of a near surface disposal facility, actions such as maintenance, monitoring or surveillance may be necessary for a period of time after closure to ensure safety.                                                                                                                                                                                                                                                                                                                                                                       | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001; Operations and Maintenance Plan 232-508220-PLA-001; Post-Closure Care Plan 232-508220-PLA-004. |
| 22                                                                                            | 3.24             | Providing for the safety of a disposal facility after closure by means of passive features will entail proper closure of the facility and ending the need for its active management. The cessation of management means that the disposal facility, with its associated radiological hazard, is no longer under active control. It is the performance of the natural and engineered barriers that provides safety after closure, together, for a near surface disposal facility, with institutional controls.                                                                                                                                                                                                                                                                                                                       | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001.                                                                                                |



| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                    |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                       |
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| Page                                                                                                                                                                                                                                                                                                                                                                                      | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | Demonstrated in CNL Documentation                                                                                                                                                                                                     |
| 22                                                                                                                                                                                                                                                                                                                                                                                        | 3.25      | In practice, even in those cases in which passive features are the primary means for providing a reasonable assurance of safety, institutional controls, including restrictions on land use, and a programme for monitoring may be necessary in the post-closure period. Institutional controls and monitoring are the subject of Requirements 21 and 22.                                                                                                                                                                               | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001.                                                     |
| <b>Requirement 6: Understanding of a disposal facility and confidence in safety. The operator of a disposal facility shall develop an adequate understanding of the features of the facility and its host environment and of the factors that influence its safety after closure over suitably long time periods, so that a sufficient level of confidence in safety can be achieved.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |                                                                                                                                                                                                                                       |
| 23                                                                                                                                                                                                                                                                                                                                                                                        | 3.26      | Confidence has to be assured by the results of safety assessment for a disposal facility. The features of the facility and its host environment that provide for safety have to be identified, in addition to those factors that might be detrimental. It has to be demonstrated that these features and factors are sufficiently well characterized and understood. Any uncertainties have to be taken into consideration in the assessment of safety.                                                                                 | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001. |
| 23                                                                                                                                                                                                                                                                                                                                                                                        | 3.27      | The purpose of this demonstration is to establish, with a high level of confidence, that the disposal facility and its host environment can be relied on to provide the necessary containment and isolation over the timescales envisaged. Certain features of the disposal facility and its environment may contribute to safety, but may be less quantifiable, such as the remoteness of the site. The reasoning with regard to such factors has to be based on more qualitative arguments, and such factors provide a safety margin. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001. |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                |
| 23                                                                                            | 3.28             | An understanding of the features of a disposal facility and how it will perform over time is necessary in order to be able to demonstrate the dependability of certain design features. This demonstration is assisted if such design features are robust (i.e., their performance is of low sensitivity to possible events and processes causing disturbances). Sufficient evidence has to be obtained of their feasibility and effectiveness before construction activities are commenced.                                                                                                                                                      | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001; Seismic Analysis 232-503212-DK-002; Base Liner and Final Cover Evaluation and Optimization 232-508600-TN-002; Base Liner and Final Cover Performance and Life Cycle Evaluation 232-508600-TN-006; Slope Stability Analysis 232-503212-REPT-002; NSDF Geomembrane Relative Performance Report 232-503212-REPT-024. |
| 23                                                                                            | 3.29             | In this regard, the range of possible events and processes causing disturbances that it is reasonable to include in such considerations has to be subject to agreement by the regulatory body and subsequent approval by inclusion in the safety case. These considerations permit the development of an understanding of whether or not such events and processes cause disturbances that could lead to the widespread loss of safety functions.                                                                                                                                                                                                 | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004.                                                                                                                                                                                                                                                                                                                                                         |
| 23                                                                                            | 3.30             | Understanding of the performance of the disposal system and its safety features and processes evolves as more data are accumulated and scientific knowledge is developed. Early in the development of the concept, the data obtained and the level of understanding gained have to assure sufficient confidence to be able to commit resources for further investigations. Before the start of construction, during emplacement of waste and at closure of the facility, the level of understanding has to be sufficient to support the safety case or fulfilling the regulatory requirements applicable for the particular stage of the project. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001.                                                                                                                                                                                                                                                                                                                   |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| 24                                                                                            | 3.31             | In establishing these regulatory requirements, it has to be recognized that there are various types and components of uncertainty inherent in modelling complex environmental systems. It also has to be recognized that there are, inevitably, significant uncertainties associated with projecting the performance of a disposal system over time.                                                                                                                                                                                                                              | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004.                                                                                                                                                                                                                                                                                                                              |
| <b>Design Concepts for Safety</b>                                                             |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |
| 24                                                                                            | 3.32             | A disposal facility is designed to contain the radionuclides associated with the radioactive waste and to isolate them from the accessible biosphere. The disposal facility is also designed to retard the dispersion of radionuclides in the geosphere and biosphere and to provide isolation of the waste from aggressive phenomena that could degrade the integrity of the facility. The various elements of the disposal system, including physical components and control procedures, contribute to performing safety functions in different ways over different timescales. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Base Liner and Final Cover Evaluation and Optimization 232-508600-TN-002; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001; Base liner and final cover performance and life cycle evaluation 232-508600-TN-006; Slope stability analysis 232-503212-REPT-002; Seismic Analysis 232-503212-DK-002. |
| 24                                                                                            | 3.33             | Requirements are established in this section for ensuring that there is adequate defence in depth, so that safety is not unduly dependent on a single element of the disposal facility, such as the waste package; or a single control measure, such as verification of the inventory of waste packages; or the fulfilment of a single safety function, such as by containment of radionuclides or retardation of migration; or a single administrative procedure, such as a procedure for site access control or for maintenance of the facility.                                | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Design Description 232-503212-DD-001.                                                                                                                                                                                                                                                                                                                                                                                                    |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                              |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Demonstrated in CNL Documentation                                                                                                                                                                                                                                            |
| 24                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 3.34      | Adequate defence in depth has to be ensured by demonstrating that there are multiple safety functions, that the fulfilment of individual safety functions is robust and that the performance of the various physical components of the disposal system and the safety functions they fulfil can be relied upon, as assumed in the safety case and supporting safety assessment. It is the responsibility of the operator to demonstrate fulfilment of the following design requirements to the satisfaction of the regulatory body. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001. |
| <b>Requirement 7: Multiple safety functions. The host environment shall be selected, the engineered barriers of the disposal facility shall be designed and the facility shall be operated to ensure that safety is provided by means of multiple safety functions. Containment and isolation of the waste shall be provided by means of a number of physical barriers of the disposal system. The performance of these physical barriers shall be achieved by means of diverse physical and chemical processes together with various operational controls. The capability of the individual barriers and controls together with that of the overall disposal system to perform as assumed in the safety case shall be demonstrated. The overall performance of the disposal system shall not be unduly dependent on a single safety function.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                              |
| 25                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 3.35      | The engineered and physical barriers that make up the disposal system are physical entities, such as the waste form, the packaging, the backfill, and the host environment and geological formation. A safety function may be provided by means of a physical or chemical property or process that contributes to containment and isolation, such as: impermeability to water; limited corrosion, dissolution, leach rate and solubility; retention of radionuclides; and retardation of radionuclide migration.                    | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001. |
| 25                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 3.36      | Active controls can also fulfil safety functions or contribute to confidence in natural and engineered barriers and safety functions. The presence of a number of physical and other elements performing safety functions gives assurance that even if any of them do not perform fully as expected (e.g., owing to an unexpected process or an unlikely event), a sufficient margin of safety will remain.                                                                                                                         | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001. |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                              |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Demonstrated in CNL Documentation                                                                                                                                                                                                                                            |
| 25                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 3.37      | The physical elements and their safety functions can be complementary and can work in combination. The performance of a disposal system is thus dependent on different physical elements and on other elements that perform safety functions, which act over different time periods. For example, the roles of the waste package and the host geological formation for a geological disposal facility may vary in different time periods.                                                                                                                                                                                            | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001. |
| 25                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 3.38      | The safety case has to explain and justify the functions performed by each physical element and other features. It also has to identify the time periods over which physical components and other features are expected to perform their various safety functions, and also the alternative or additional safety functions that are available if a physical element does not fully perform or another safety function is not fulfilled.                                                                                                                                                                                              | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001. |
| <b>Requirement 8: Containment of radioactive waste. The engineered barriers, including the waste form and packaging, shall be designed, and the host environment shall be selected, so as to provide containment of the radionuclides associated with the waste. Containment shall be provided until radioactive decay has significantly reduced the hazard posed by the waste. In addition, in the case of heat generating waste, containment shall be provided while the waste is still producing heat energy in amounts that could adversely affect the performance of the disposal system.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                                                                                                                                                              |
| 26                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | 3.39      | The containment of radioactive waste implies designing the disposal facility to avoid or minimize the release of radionuclides. Releases of small amounts of gaseous radionuclides and of small fractions of other highly mobile species from some types of radioactive waste may be inevitable. Such releases, nevertheless, have to be demonstrated to be acceptable by means of safety assessment. The containment may be provided by the characteristics of the waste form and the packaging and by the characteristics of other engineered components of the disposal system and the host environment and geological formation. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001.                                        |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                                                                                                  |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                                                                                                         |
| 26                                                                                            | 3.40             | The containment of the radionuclides in the waste form and the packaging over a defined period has to ensure that the majority of shorter lived radionuclides decay in situ. For low level waste, such periods would be of the order of several hundred years.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001; Waste Acceptance Criteria, 232-508600-REPT-003.                                                            |
| 26                                                                                            | 3.41             | Radioactive waste from mining and mineral processing may include radionuclides with very long half-lives. Providing assurance of the integrity of the containment features of disposal facilities for such waste over the corresponding timescales requires particular consideration. If the waste has activity levels for which the dose and/or risk criteria for human intrusion into such facilities (see para. 2.15) might be exceeded, alternative disposal options will have to be considered. Possible alternative options include, for example, disposal of the waste below the surface, or separation of the radionuclide content giving rise to the higher dose, as determined by the safety case for the disposal facility.                                                                        | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                                                                                                                                      |
| 27                                                                                            | 3.42             | Containment is most important for more highly concentrated radioactive waste, such as intermediate level waste and vitrified waste from fuel reprocessing, or for spent nuclear fuel. Attention also has to be given to the durability of the waste form. The most highly concentrated waste has to be emplaced in a containment configuration that is designed to retain its integrity for a long enough period of time to enable most of the shorter lived radionuclides to decay and for the associated generation of heat to decrease substantially. Such containment may not be practicable or necessary for low level waste. The containment capability of the waste package has to be demonstrated by means of safety assessment to be appropriate for the waste type and the overall disposal system. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001; Waste Acceptance Criteria, 232-508600-REPT-003; Waste Placement and Compaction Plan, B1550-508600-PLA-001. |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                       |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Demonstrated in CNL Documentation                                                                                                                                                                                                     |
| <b>Requirement 9: Isolation of radioactive waste. The disposal facility shall be sited, designed and operated to provide features that are aimed at isolation of the radioactive waste from people and from the accessible biosphere. The features shall aim to provide isolation for several hundreds of years for short lived waste and at least several thousand years for intermediate and high level waste. In so doing, consideration shall be given to both the natural evolution of the disposal system and events causing disturbance of the facility.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                       |
| 27                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 3.43      | For near surface facilities, isolation has to be provided by the location and the design of the disposal facility and by operational and institutional controls.                                                                                                                                                                                                                                                                                                                                                                                                      | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001. |
| 27                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 3.44      | Isolation means design to keep the waste and its associated hazard apart from the accessible biosphere. It also means design to minimize the influence of factors that could reduce the integrity of the disposal facility. Sites and locations with higher hydraulic conductivities have to be avoided. Access to waste has to be made difficult to gain without, for example, violation of institutional controls for near surface disposal. Isolation also means providing for a very slow mobility of radionuclides to impede migration from disposal facilities. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001. |
| 27                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 3.45      | Location of a disposal facility in a stable geological formation provides protection of the facility from the effects of geomorphological processes, such as erosion and glaciation. The disposal facility has to be located away from known areas of significant underground mineral resources or other valuable resources. This will reduce the likelihood of inadvertent disturbance of the facility and will avoid resources being made unavailable for exploitation.                                                                                             | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001. |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                             |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                 |
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| Page                                                                                                                                                                                                                                                                                                                                               | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Demonstrated in CNL Documentation                                                                                                               |
| 28                                                                                                                                                                                                                                                                                                                                                 | 3.46      | In some cases, it may not be possible to provide sufficient assurance of separation from the accessible biosphere, owing to phenomena such as uplift, erosion and glaciation. In such cases, and if the remaining activity in the waste is still significant at the time such phenomena occur, the possibility of human intrusion has to be evaluated in determining the degree of isolation provided.                                                                                                                                                                                                                                                                                                                                                                                                                                      | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004. |
| 28                                                                                                                                                                                                                                                                                                                                                 | 3.47      | Over time periods of several thousand years or more, the migration of a fraction of the longer lived and more mobile radionuclides from the waste in a geological disposal facility (or in other facilities that may include longer lived radionuclides, such as borehole facilities) may be inevitable. The safety criteria to apply in assessing such possible releases are set out in para. 2.15. Caution needs to be exercised in applying criteria for periods far into the future. Beyond such timescales, the uncertainties associated with dose estimates become so large that the criteria might no longer serve as a reasonable basis for decision making. For such long time periods after closure, indicators of safety other than estimates of dose or individual risk may be appropriate, and their use has to be considered. | NSDF Safety Case 232-03610-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                     |
| <b>Requirement 10: Surveillance and control of passive safety features. An appropriate level of surveillance and control shall be applied to protect and preserve the passive safety features, to the extent that this is necessary, so that they can fulfil the functions that they are assigned in the safety case for safety after closure.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                 |



| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                     |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                              |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                       | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Demonstrated in CNL Documentation                                                                                                                                                                                                                                                                                                                            |
| 28                                                                                                                                                                                                                                                                                                                                                                                                                         | 3.48      | For the disposal of intermediate level radioactive waste, the passive safety features (barriers) have to be sufficiently robust so as not to require repair or upgrading. The long term safety of a disposal facility for radioactive waste is required not to be dependent on active institutional control (see Requirement 22). For near surface disposal facilities, measures for surveillance and control of the disposal facility might be instituted. These measures might include restrictions on access by people and animals, inspection of physical conditions, retention of appropriate maintenance capabilities, and surveillance and monitoring as a method of checking whether performance is as specified (i.e., checking for degradation). The intent of surveillance and monitoring is not to measure radiological parameters but to ensure the continuing fulfilment of safety functions. | NSDF Safety Case 232-03610-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004;                                                                                                                                                              |
| <b>Framework for Disposal of Radioactive Waste</b>                                                                                                                                                                                                                                                                                                                                                                         |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                              |
| <b>Requirements 11: Step by step development and evaluation of disposal facilities. Disposal facilities for radioactive waste shall be developed, operated and closed in a series of steps. Each of these steps shall be supported, as necessary, be integrative evaluations of the site, of the options for design, construction, operation and management, and of the performance and safety of the disposal system.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                                                                                              |
| 29                                                                                                                                                                                                                                                                                                                                                                                                                         | 4.2       | The step by step approach to the development of a disposal facility also allows opportunities for independent technical review, regulatory review, and political and public involvement in the process (see para. 1.18). This approach is taken to provide an opportunity to ensure the quality of the technical programme and the associated decision making. For the operator, it provides a framework in which sufficient confidence in the technical feasibility and safety of the disposal facility can be built at each step in its development.                                                                                                                                                                                                                                                                                                                                                      | NSDF Safety Case, 232-508770-SAR-001, Section 5 - Design Iteration and Optimization; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004.CNL-CNSC Administrative Protocol for the Near Surface Disposal Facility Project at Chalk River Laboratories. |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                               |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                                                                                                                                                      |
| 29                                                                                            | 4.3              | Confidence has to developed and refined by means of iterative design and safety studies as the project progresses. The process has to provide for: the collection, analysis and interpretation of the relevant scientific and technical data; the development of designs and operational plans; and the development of the safety case for safety in the operational stage and after closure. The step by step process provides access for all interested parties to the safety basis for the disposal facility. This facilitates the relevant decision making processes that enable the operator to proceed to the next significant step in the development of the facility, and on to its operation and, finally, its closure. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001.<br>CNL-CNRC Administrative Protocol for the Near Surface Disposal Facility Project at Chalk River Laboratories. |
| 30                                                                                            | 4.4              | The step by step approach to the development of a disposal facility also allows opportunities for independent technical review, regulatory review, and political and public involvement in the process. The nature of the reviews and involvement will depend on national practices and on the facility in question. Technical reviews by, or on behalf of, the operator and the regulatory body may focus on site selection and evaluation and design options, the adequacy of the scientific basis and analyses, and whether safety standards and requirements have been met.                                                                                                                                                  | NSDF Safety Case 232-508770-SAR-001.                                                                                                                                                                                                                                                                                                                                                          |
| 30                                                                                            | 4.5              | Alternative waste management options, the site selection and evaluation process and aspects of public acceptability, for example, may be considered in farther reaching reviews. Technical reviews have to be undertaken prior to selection of a disposal option, prior to selection of a site, prior to construction and prior to operation. Periodic reviews also have to be undertaken during the operation of the facility and following closure, up to termination of the facility licence.                                                                                                                                                                                                                                 | NSDF Safety Case 232-508770-SAR-001; Environmental Impact Statement 232-509220-REPT-004; Site Selection Report 232-10300-TN-001.                                                                                                                                                                                                                                                              |
| <b>The Safety Case and Safety Assessment</b>                                                  |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                                                                                                                                                                               |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |                                                                                                                                                                                                                                                                               |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                                      |
| 30                                                                                            | 4.6              | The development of a safety case and supporting safety assessment for review by the regulatory body and interested parties is central to the development, operation and closure of a disposal facility for radioactive waste. The safety case is an essential input to all important decisions concerning the disposal facility. It has to provide the basis for understanding the disposal system and how it will behave over time. It has to address site aspects and engineering aspects, providing the logic and rationale for the design, and has to be supported by safety assessment. It also has to address the management system put in place to ensure quality for all aspects important to safety. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001. |
| 30                                                                                            | 4.7              | At any step in the development of a disposal facility, the safety case also has to identify and acknowledge the unresolved uncertainties that exist at that stage and their safety significance, and approaches for their management.                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | NSDF Safety Case 232-508770-SAR-001.                                                                                                                                                                                                                                          |
| 30                                                                                            | 4.8              | The safety case has to include the output of the safety assessment (see paras 4.9–4.11), together with additional information, including supporting evidence and reasoning on the robustness and reliability of the facility, its design, the logic of the design, and the quality of safety assessment and underlying assumptions.                                                                                                                                                                                                                                                                                                                                                                           | NSDF Safety Case 232-508770-SAR-001.                                                                                                                                                                                                                                          |
| 31                                                                                            | 4.9              | The safety case may also include more general arguments relating to the disposal of radioactive waste and information to put the results of safety assessment into perspective. Any unresolved issues at any step in the development or in the operation or closure of the facility have to be acknowledged in the safety case and guidance has to be provided for work to resolve these issues.                                                                                                                                                                                                                                                                                                              | NSDF Safety Case 232-508770-SAR-001.                                                                                                                                                                                                                                          |
| 31                                                                                            | 4.10             | Safety assessment is the process of systematically analysing the hazards associated with a disposal facility and assessing the ability of the site and the design of the facility to provide for the fulfilment of safety functions and to meet technical requirements. Safety assessment has to include quantification of the overall level of performance, analysis of the associated uncertainties and comparison with the relevant design requirements and safety standards. The assessments have to be site specific since the host environment of a disposal system, in contrast to engineered systems, cannot be standardized.                                                                         | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001.                                                     |

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| 31                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 4.11      | As site investigations and design studies progress, safety assessment will become increasingly refined and specific to the site. At the end of a site investigation, sufficient data have to be available for a complete assessment. Any significant deficiencies in scientific understanding, data or analysis that might affect the results presented also have to be identified in the safety assessment. Depending on the stage of development of the facility, safety assessment may be used in focusing research, and its results may be used to assess compliance with the safety objective and safety criteria.                                                                                                                                                                                                                                                                                                                                                         | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Design Requirements 232-503212-DR-001; Design Description 232-503212-DD-001. |
| <b>Requirement 12: Preparation, approval and use of the safety case and safety assessment for a disposal facility. A safety case and supporting safety assessment shall be prepared and updated by the operator, as necessary, at each step in the development of a disposal facility, in operation and after closure. The safety case and supporting safety assessment shall be submitted to the regulatory body for approval. The safety case and supporting safety assessment shall be sufficiently detailed and comprehensive to provide the necessary technical input for informing the regulatory body and for informing the decisions necessary at each step.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 |                                                                                                                                                                                                                                                                               |
| 31                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | 4.12      | A facility specific safety case has to be prepared early in the development of a disposal facility to provide a basis for licensing decisions and to guide activities in research and development, site selection and evaluation and design. The safety case has to be developed progressively and elaborated as the project proceeds. It has to be presented to the regulatory body at each step in the development of the disposal facility. The regulatory body might require an update of, or revision to, the safety case before given steps can be taken, or such an update or revision may be necessary to gain political or public support for taking the next step in the development of the disposal facility or for its operation or closure. The formality and level of technical detail of the safety case will depend on the stage of development of the project, the decision in hand, the audience to which it is addressed and specific national requirements. | NSDF Safety Case 232-508770-SAR-001.                                                                                                                                                                                                                                          |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                                                                                                                 |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                  |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Demonstrated in CNL Documentation                                                                                                                                                                |
| 32                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 4.13      | Safety assessment in support of the safety case has to be performed and updated throughout the development and operation of the disposal facility and as more refined site data become available. Safety assessment has to provide input to ongoing decision making by the operator. Such decision making may relate to subjects for research, development of a capability for assessment, allocation of resources and development of waste acceptance criteria.                                                                                                                                                                         | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Waste Acceptance Criteria, 232-508600-WAC-003.      |
| 32                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 4.14      | Safety assessment also has to identify key processes relevant to safety and to contribute to the development of an understanding of the performance of disposal facilities. It has to support judgements with regard to alternative management options as an element of optimizing protection and safety. Such an understanding has to provide the basis for the safety arguments presented in the safety case. The operator has to decide on the timing and the level of detail of the safety assessment, in consultation with and subject to the approval of the regulatory body.                                                      | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004. |
| <b>Requirement 13: Scope of the safety case and safety assessment. The safety case for a disposal facility shall describe all safety relevant aspects of the site, the design of the facility and the managerial control measures and regulatory controls. The safety case and supporting safety assessment shall demonstrate the level of protection of people and the environment provided and shall provide assurance to the regulatory body and other interested parties that safety requirements will be met.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                  |
| 32                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | 4.15      | The safety case for a disposal facility has to address safety both in operation and after closure. It may also address safety in transport, for which requirements are established in Ref. [17]. All aspects of operation relevant to safety are considered, including surface and underground excavation, construction and mining work, waste emplacement, and backfilling, sealing and closing operations. Consideration has to be given to both occupational exposure and public exposure resulting from conditions of normal operation and anticipated operational occurrences over the operating lifetime of the disposal facility. | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                         |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |                                                                                                                                          |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | <b>Demonstrated in CNL Documentation</b>                                                                                                 |
| 33                                                                                            | 4.16             | Accidents of a lesser frequency, but with significant radiological consequences (i.e., possible accidents that could give rise to radiation doses over the short term in excess of annual dose limits (see Section 2)), have to be considered with regard to both their likelihood of occurrence and the magnitude of possible radiation doses. The adequacy of the design and of the operational features also has to be evaluated.                                                                                                                                                                                                                                                                                                                                                                                             | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |
| 33                                                                                            | 4.17             | With regard to safety after closure, the expected range of possible developments affecting the disposal system and events that might affect its performance, including those of low probability, have to be considered in the safety case and supporting assessment by the following means" (a) By presenting evidence that the disposal system, its possible evolutions and events that might affect it are sufficiently well understood; (b) By demonstrating the feasibility of implementing the design; (c) By providing convincing estimates of the performance of the disposal system and a reasonable level of assurance that all the relevant safety requirements will be complied with and that radiation protection has been optimized; (d) By identifying and presenting an analysis of the associated uncertainties. | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |
| 33                                                                                            | 4.18             | The safety case may include the presentation of multiple lines of reasoning based, for example, on studies of natural analogues and palaeohydrogeological studies, suitable characteristics of the site, properties of the host geological formation, engineering considerations, operational procedures and institutional assurances.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | NSDF Safety Case, 232-508770-SAR-001.                                                                                                    |
| 33                                                                                            | 4.19             | The performance of the disposal system under expected and less likely evolutions and events, which can be outside the design performance range of the disposal facility, has to be analysed in the safety assessment. A judgement of what is to be considered the expected evolution and less likely evolution has to be discussed between the regulatory body and the operator. If necessary, sensitivity analyses and uncertainty analyses would be undertaken to gain an understanding of the performance of the disposal system and its components under a range of evolutions and events.                                                                                                                                                                                                                                   | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                      |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                          |
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| Page                                                                                                                                                                                                                                                                                                                                                                        | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Demonstrated in CNL Documentation                                                                                                        |
| 34                                                                                                                                                                                                                                                                                                                                                                          | 4.20      | The consequences of unexpected events and processes may be explored to test the robustness of the disposal system. In particular, the resilience of the disposal system has to be assessed. Quantitative analyses have to be undertaken at least over the time period for which regulatory requirements apply. However, the results from detailed models for safety assessment purposes are likely to be more uncertain for timescales extending into the far future.                                    | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |
| 34                                                                                                                                                                                                                                                                                                                                                                          | 4.21      | For timescales extending into the far future, arguments may be needed to illustrate safety, on the basis, for example, of complementary safety indicators, such as concentrations and fluxes of radionuclides of natural origin in the geosphere and biosphere and bounding analyses. While such assessments cannot yield precise levels of possible doses or risks, the results may provide a tool to indicate the level of safety and verify that no alternative design would have obvious advantages. | NSDF Safety Case, 232-508770-SAR-001; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                            |
| 34                                                                                                                                                                                                                                                                                                                                                                          | 4.22      | The management systems established to provide assurance of quality in these design features and operational features have to be addressed in the safety case.                                                                                                                                                                                                                                                                                                                                            | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; Quality Assurance Plan, 232-514200-QAP-001 (Design).    |
| <b>Requirement 14: Documentation of the safety case and safety assessment. The safety case and supporting safety assessment for a disposal facility shall be documented to a level of detail and quality sufficient to inform and support the decision to be made at each step and to allow for independent review of the safety case and supporting safety assessment.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                          |
| 34                                                                                                                                                                                                                                                                                                                                                                          | 4.23      | The necessary scope and structure of the documentation setting out the safety case and supporting safety assessment will depend on the step reached in the project for the disposal facility and on national requirements. This includes consideration of the needs of different interested parties for information. Important considerations in documenting the safety case and supporting safety assessment are justification, traceability and clarity.                                               | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                               |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          | Demonstrated in CNL Documentation                                                                                                                                                                                                                                                             |
| 34                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 4.24      | Justification concerns explaining the basis for the choices that have been made and the arguments for and against the decisions, especially those decisions concerning the main arguments for safety. Traceability concerns the ability of an independent qualified person to follow what has been done. The traceability has to enable technical and regulatory review. Justification and traceability both require a well-documented record of the decisions made and the assumptions made in the development and operation of a disposal facility, and of the models and data used in deriving a particular set of results for safety assessment purposes.                                                                                                               | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Safety Action Tracking Database 232-503230-SAL-001; Design Input and Assumptions Database 232-505222-DIS-001; Design Description, 232-503212-DD-001. |
| 35                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 4.25      | Clarity concerns good structure and presentation at an appropriate level of detail so as to allow an understanding of the safety arguments. This requires the results of work to be presented in the documents in such a way that interested parties for whom the material is intended can gain a good understanding of the safety arguments and their basis. Different types and styles of document may be necessary to provide material that is useful to different parties.                                                                                                                                                                                                                                                                                              | NSDF Safety Case, 232-508770-SAR-001; Safety Analysis Report 232-503230-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                                                                                      |
| <b>Steps in the Development, Operation and Closure of a Disposal Facility</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                               |
| <b>Requirement 15: Site characterization for a disposal facility. The site for a disposal facility shall be characterized at a level of detail sufficient to support a general understanding of both the characteristics of the site and how the site will evolve over time. This shall include its present condition, it's probably natural evolution and possible natural events, and also human plans and actions in the vicinity that may affect the safety of the facility over the period of interest. It shall also include a specific understanding of the impact on safety of features, events and processes associated with the site and the facility.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             |                                                                                                                                                                                                                                                                                               |
| 35                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 4.26      | An understanding of the site for a disposal facility has to be gained in order to present a convincing scientific description of the disposal system on which the more conceptual descriptions that are used in the safety assessment can be based. The focus has to be on features, events and processes relating to the site that could have an impact on safety and that are addressed in the safety case and supporting safety assessment. In particular, this has to demonstrate that there is adequate geological, geomorphological or topographical stability (as appropriate to the type of facility), and features and processes that contribute to safety. It also has to demonstrate that other features, events and processes do not undermine the safety case. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004.                                                                                              |



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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     | Demonstrated in CNL Documentation                                                                                                                                                                                                                                                                    |
| 35                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 4.27      | Characterization of the geological aspects has to include activities such as the investigation of long term stability, faulting and the extent of fracturing in the host geological formation: seismicity; volcanism; the volume of rock suitable for the construction of disposal zones; geotechnical parameters relevant to the design; groundwater flow regimes; geochemical conditions; and mineralogy. The extent of characterization necessary will depend on the types of disposal facility and the site in question.                                                                                                                                                                                                           | Geotechnical Report 232-10180-REPT-001; Groundwater flow Modelling of the NSDF 232-509249-REPT-001.                                                                                                                                                                                                  |
| 36                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 4.28      | A graded approach has to be adopted, depending on the hazard potential of the waste and the complexity of the site and disposal facility design, in accordance with the guidance cited in footnote 5 (SSG-23). Site characterization undertaken in an iterative manner has to provide input to, and has, in turn, to be guided by, the safety case. Additionally, investigation of, for example, natural background radiation and the radionuclide content in soil, groundwater and other media may contribute to a better understanding of the characteristics of the site of the disposal facility. It may also assist in the evaluation of radiological impacts on the environment by providing a reference for future comparisons. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Geotechnical Report 232-10180-REPT-001; Groundwater flow Modelling of the NSDF 232-509249-REPT-001. |
| 36                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | 4.29      | Characterization of the surface environmental features has to include natural aspects, such as hydrological and meteorological aspects and flora and fauna. It also has to cover human activities in the vicinity of the site relating to normal residential settlement patterns and industrial and agricultural activities. Due regard has to be given to the probable natural evolution of the site, including effects of erosion and climate change.                                                                                                                                                                                                                                                                                | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Geotechnical Report 232-10180-REPT-001; Groundwater flow Modelling of the NSDF 232-509249-REPT-001. |
| <b>Requirement 16: Design of a disposal facility. The disposal facility and its engineered barriers shall be designed to contain the waste with its associated hazard, to be physically and chemically compatible with the host geological formation and/or surface environment, and to provide safety features after closure that complement those features afforded by the host environment. The facility and its engineered barriers shall be designed to provide safety during the operational period.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                                                                                                                                      |

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| 36                                                                                     | 4.30      | The designs of disposal facilities for radioactive waste may differ widely, depending on the types of waste to be disposed of and the host geological formation and/or surface environment. In general, optimal use has to be made of the safety features offered by the host environment. This has to be done by designing a disposal facility that does not cause unacceptable long term disturbance of the site, is itself protected by the site and performs safety functions that complement the natural barriers.                                                                                                                                                                                                                                                                                          | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004; Geotechnical Report 232-10180-REPT-001; Groundwater flow Modelling of the NSDF 232-509249-REPT-001; Design Description 232-503212-DD-001.                    |
| 36                                                                                     | 4.31      | The layout has to be designed so that waste is emplaced in the most suitable locations. In the event that fissile materials are present in the waste, maintaining a subcritical configuration has to be part of the design considerations. Key features, such as shafts and seals in geological disposal facilities, have to be appropriately located. Materials used in the facility have to be resistant to degradation under the conditions prevailing in the facility (e.g., conditions of chemistry and temperature) and selected also to limit any undesirable impacts on the safety functions of any element of the disposal system.                                                                                                                                                                      | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Criticality Safety Document, 232-508550-CSD-001; Design Description 232-503212-DD-001; Landfill Development and Sequencing Plan B1550-505240-PLA-001; Waste Placement and Compaction Plan, B1550-508600-PLA-001. |
| 37                                                                                     | 4.32      | Disposal facilities, in particular disposal facilities for high level and intermediate level waste, are expected to perform over much longer timescales than the periods usually considered in engineering applications. Investigation of the ways in which analogous natural materials have behaved in geological formations in nature, or how ancient artefacts and structures have behaved over time, may contribute to confidence in the assessment of long term performance. Demonstration of the feasibility of fabrication of waste containers and of the construction of engineered barriers with the necessary features, for example, in underground laboratories, is important for the purpose of assessment and for contributing to confidence that an adequate level of performance can be achieved. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004.                                                                                                                                                                                                                  |

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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                         | Demonstrated in CNL Documentation                                                                                                                                                                                                                                                                        |
| <b>Requirement 17: Construction of a disposal facility. The disposal facility shall be constructed in accordance with the design as described in the approved safety case and supporting safety assessment. It shall be constructed in such a way as to preserve the safety functions of the host environment that have been shown by the safety case to be important for safety after closure. Construction activities shall be carried out in such a way as to ensure safety during the operational period.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                          |
| 37                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 4.33      | Construction of a disposal facility can be a complex technical undertaking that might be constrained, particularly if it is carried out underground, by the conditions and the properties of the host geological formation and by the techniques that are available for underground excavation and construction. An adequate level of characterization has to be completed before construction is begun. Excavation and construction activities have to be carried out in such a way as to avoid unnecessary disturbance of the host environment. Sufficient flexibility in engineering techniques has to be adopted to allow for variations to be encountered, such as variations in rock conditions or groundwater conditions in underground facilities. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement, 232-509220-REPT-004; Design Description 232-503212-DD-001; Construction Quality Assurance Plan, 232-508244-PLA-001; Landfill Development and Sequencing Plan, B1550-505240-PLA-001. |
| 37                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | 4.34      | Excavation and construction of a disposal facility could continue after the commencement of operation of part of the facility and after the emplacement of waste packages. Such overlapping of construction and operational activities has to be planned and carried out so as to ensure safety, both in operation and after closure.                                                                                                                                                                                                                                                                                                                                                                                                                      | Environmental Impact Statement 232-509220-REPT-004; Design Description 232-503212-DD-001; Construction Quality Assurance Plan 232-508244-PLA-001; Landfill Development and Sequencing Plan B1550-505240-PLA-001.                                                                                         |
| <b>Requirement 18: Operation of a disposal facility. The disposal facility shall be operated in accordance with the conditions of the licence and the relevant regulatory requirements so as to maintain safety during the operational period and in such a manner as to preserve the safety functions assumed in the safety case that are important to safety after closure.</b>                                                                                                                                 |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                                                                                                                                                                                                                                                                                          |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                               |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                             | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                                      |
| 38                                                                                            | 4.35             | All operations and activities important to the safety of a disposal facility have to be subjected to limitations and controls and emergency plans have to be put in place. The various procedures and plans have to be documented and the documentation has to be subject to appropriate control procedures. The safety case has to address and justify both the design and the operational management arrangements that are used to ensure that the safety objective and criteria set out in Section 2 are met. Additional, facility specific criteria may be established by the regulatory body or by the operator. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Environmental Impact Statement 232-509220-REPT-004.                                                                              |
| 38                                                                                            | 4.36             | The safety case also has to demonstrate that hazards and other radiation risks to workers and to members of the public under conditions of normal operation and anticipated operational occurrences have been reduced as low as reasonably achievable. Active control of safety has to be maintained for as long as the disposal facility remains unsealed, and this may include an extended period after the emplacement of waste and before the final closure of the facility.                                                                                                                                      | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Impact Statement 232-509220-REPT-004; ALARA Assessment, NSDF-508740-ALR-001.                                                                                               |
| 38                                                                                            | 4.37             | Fissile material, when present, has to be managed and has to be emplaced in the disposal facility in a configuration that will remain subcritical. This may be achieved by various means, including the appropriate distribution of fissile material during the conditioning of the waste and the proper design of the waste packages. Assessments have to be undertaken of the possible evolution of the criticality hazard after waste emplacement, including after closure.                                                                                                                                        | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Criticality Safety Document, 232-508550-CSD-001.                                                                                                                                         |
| 38                                                                                            | 4.38             | The safety of a disposal facility after closure will depend on a number of activities and design features, which can include the backfilling and sealing or capping of the disposal facility. Closure has to be considered in the initial design of the facility, and plans for closure and seal or cap designs have to be updated as the design of the facility is developed. Before construction activities commence, there has to be sufficient evidence that the performance of the backfilling, sealing and capping will function as intended to meet the design requirements.                                   | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Construction Quality Assurance Plan 232-508244-PLA-001; Design Description, 232-503212-DD-001; Closure Plan, 232-508220-PLA-003. |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                           |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                 |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                             | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | Demonstrated in CNL Documentation                                                                                                                                                                                                                                               |
| <b>Requirement 19: Closure of a disposal facility. A disposal facility shall be closed in a way that provides for those safety functions that have been shown by the safety case to be important after closure. Plans for closure, including the transition from active management of the facility, shall be well defined and practicable, so that closure can be carried out safely at an appropriate time.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                 |
| 38                                                                                                                                                                                                                                                                                                                                                                                                               | 4.38      | The safety of a disposal facility after closure will depend on a number of activities and design features, which can include the backfilling and sealing or capping of the disposal facility. Closure has to be considered in the initial design of the facility, and plans for closure and seal or cap designs have to be updated as the design of the facility is developed. Before construction activities commence, there has to be sufficient evidence that the performance of the backfilling, sealing and capping will function as intended to meet the design requirements. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Construction Quality Assurance Plan 232-508244-PLA-001; Design Description, 232-503212-REPT-003; Closure Plan, 232-508220-PLA-003. |
| 39                                                                                                                                                                                                                                                                                                                                                                                                               | 4.39      | The disposal facility has to be closed in accordance with the conditions set for closure by the regulatory body in the facility's authorization, with particular consideration given to any changes in responsibility that may occur at this stage. Consistent with this, the installation of closure features may be performed in parallel with waste emplacement operations.                                                                                                                                                                                                      | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description, 232-503212-REPT-003; Closure Plan, 232-508220-PLA-003.                                                         |
| 39                                                                                                                                                                                                                                                                                                                                                                                                               | 4.40      | Backfilling and the placement of seals or caps may be delayed for a period after the completion of waste emplacement, for example, to allow for monitoring to assess aspects relating to safety after closure or for reasons relating to public acceptability. If such features are not to be put in place for a period of time after the completion of waste emplacement, then the implications for safety during operation and after closure have to be considered in the safety case.                                                                                            | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description, 232-503212-REPT-003; Closure Plan, 232-508220-PLA-003.                                                         |
| <b>Assurance of Safety</b>                                                                                                                                                                                                                                                                                                                                                                                       |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                 |
| <b>Requirement 20: Waste acceptance in a disposal facility. Waste packages and unpackaged waste accepted for emplacement in a disposal facility shall conform to criteria that are fully consistent with, and are derived from, the safety case for the disposal facility in operation and after closure.</b>                                                                                                    |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |                                                                                                                                                                                                                                                                                 |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                            |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                                                                                   |
| 39                                                                                            | 5.1              | Waste acceptance requirements and criteria for a given disposal facility have to ensure the safe handling of waste packages and unpackaged waste in conditions of normal operation and anticipated operational occurrences. They also have to ensure the fulfilment of the safety functions for the waste form and waste packaging with regard to safety in the long term. Examples of possible parameters for waste acceptance criteria include the characteristics and performance requirements of the waste packages and the unpackaged waste to be disposed of, such as the radionuclide content or activity limits, the heat output and the properties of the waste form and packaging.                                                             | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Waste Acceptance Criteria, 232-508600-REPT-003.                                                               |
| 40                                                                                            | 5.2              | Modelling and/or testing of the behaviour of waste forms has to be undertaken to ensure the physical and chemical stability of the different waste packages and unpackaged waste under the conditions expected in the disposal facility, and to ensure their adequate performance in the event of anticipated operational occurrences or accidents.                                                                                                                                                                                                                                                                                                                                                                                                      | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Waste Acceptance Criteria, 232-508600-REPT-003; Bearing Capacity and Settlement Analysis 232-503212-REPT-010. |
| 40                                                                                            | 5.3              | Waste intended for disposal has to be characterized to provide sufficient information to ensure compliance with waste acceptance requirements and criteria. Arrangements have to be put in place to verify that the waste and waste packages received for disposal comply with these requirements and criteria and, if not, to confirm that corrective measures are taken by the generator of the waste or the operator of the disposal facility. Quality control of waste packages has to be undertaken and is achieved mainly on the basis of records, preconditioning testing (e.g., of containers) and control of the conditioning process. Post-conditioning testing and the need for corrective measures have to be limited as far as practicable. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Waste Acceptance Criteria, 232-508600-REPT-003.                                                                                                                       |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                              |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        | Demonstrated in CNL Documentation                                                                                                                                                                                                            |
| <b>Requirement 21: Monitoring programmes at a disposal facility. A programme of monitoring shall be carried out prior to, and during, the construction and operation of a disposal facility and after its closure, if this is part of the safety case. This programme shall be designed to collect and update information necessary for the purpose of protection and safety. Information shall be obtained to confirm the conditions necessary for the safety of workers and members of the public and protection of the environment during the period of operation of the facility. Monitoring shall also be carried out to confirm the absence of any conditions that could affect the safety of the facility after closure.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                              |
| 40                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 5.4       | Monitoring has to be carried out at each step in the development and in the operation of a disposal facility. The purposes of the monitoring programme include: (a) Obtaining information for subsequent assessments; (b) Assurance of operational safety; (c) Assurance that conditions at the facility for operation are consistent with the safety assessment; (d) Confirmation that conditions are consistent with the safety after closure. Monitoring programmes have to be designed and implemented so as not to reduce the overall level of safety of the facility after closure.                                                 | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; Environmental Protection Plan 232-509200-PLA-001; Monitoring and Reporting Plan 232-508220-PLA-002; Environmental Impact Statement 232-509220-REPT-004. |
| <b>Requirement 22: The period after closure and institutional controls. Plans shall be prepared for the period after closure to address institutional control and the arrangements for maintaining the availability of information on the disposal facility. These plans shall be consistent with passive safety features and shall form part of the safety case on which authorization to close the facility is granted.</b>                                                                                                                                                                                                                                                                                                       |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                           |                                                                                                                                                                                                                                              |
| 41                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 5.6       | The long term safety of a disposal facility for radioactive waste has not to be dependent on active institutional control. Even the violation of passive safety features cannot give rise to the criteria for intervention being exceeded. Additionally, the safety of the disposal facility has not to be dependent solely on institutional controls. Institutional controls cannot be the sole or main component of safety for a near surface disposal facility. The ability of the institutional controls to provide the contributions to safety envisaged in the safety case has to be demonstrated and justified in the safety case. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001; Post closure care plan, 232-508220-PLA-004.               |
| 41                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | 5.7       | The risk of intrusion into a disposal facility for radioactive waste may be reduced over a longer timescale than that foreseen for active controls by the use of passive controls, such as the preservation of information by the use of markers and archives, including international archives.                                                                                                                                                                                                                                                                                                                                          | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001.                                                           |

| <b>IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April</b> |                  |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |                                                                                                                                                                                              |
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| <b>Page</b>                                                                                   | <b>Paragraph</b> | <b>Safety Requirement</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                              | <b>Demonstrated in CNL Documentation</b>                                                                                                                                                     |
| 42                                                                                            | 5.8              | Institutional controls over a disposal facility for radioactive waste have to provide additional assurance of the safety and nuclear security of the facility. Examples include provision for preventing access to the site by intruders and post-operational monitoring capable of providing early warning of the migration of radionuclides from the disposal facility before they reach the site boundary.                                                                                                                                                                                                                                                                                                                          | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001.           |
| 42                                                                                            | 5.9              | Near surface disposal facilities are generally designed on the assumption that institutional control has to remain in force for a period of time. For short lived waste, the period will have to be several tens to hundreds of years following closure. Such controls will be either active or passive in nature. For near surface disposal of waste from mining and mineral processing that includes very long lived radionuclides, and which generally comprises large volumes, activity concentrations have to be limited so that ongoing active institutional control does not have to be relied on as a safety measure. Waste with activity concentrations above the limitations has to be disposed of below the ground surface. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001.           |
| 42                                                                                            | 5.10             | The status of a disposal facility beyond the period of active institutional control differs from the release of a nuclear installation site from regulatory control after decommissioning in as much as release of the site of a disposal facility for unrestricted use is generally not contemplated. The site location and the facility design have to reduce the likelihood of intrusion.                                                                                                                                                                                                                                                                                                                                           | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Design Description 232-503212-DD-001.           |
| 42                                                                                            | 5.11             | For near surface facilities, the waste acceptance criteria will limit any consequences of human intrusion to within the specified criteria (see para. 2.15), even if control over the site is lost. The dose constraint (see para. 2.15) adopted for doses to members of the public applies for the anticipated normal evolution of the site following the period of institutional control.                                                                                                                                                                                                                                                                                                                                            | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004; Waste Acceptance Criteria, 232-508600-REPT-003. |



| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                             |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                  |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                               | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Demonstrated in CNL Documentation                                                                                                                                                                                                                                                                                |
| 42                                                                                                                                                                                                                                                                                                                                                                                                                 | 5.13      | Disposal facilities may not be closed for several tens of years or more after operations have commenced. Plans for possible future controls and the period over which they would be applied may initially be flexible and conceptual in nature, but plans have to be developed and refined as the facility approaches closure. Consideration has to be given to: local land use controls; site restrictions or surveillance and monitoring; local, national and international records; and the use of durable surface and/or subsurface markers. Arrangements have to be made to be able to pass on information about the disposal facility and its contents to future generations to enable any future decisions on the disposal facility and its safety to be made. | NSDF Safety Case 232-508770-SAR-001; Design Description 232-503212-DD-001; Post-Closure Care Plan, 232-508220-PLA-004; Preliminary Decommissioning Plan, 232-508300-PLA-001.                                                                                                                                     |
| 43                                                                                                                                                                                                                                                                                                                                                                                                                 | 5.14      | While the facility remains licensed, the operator has to provide institutional controls. It is envisaged that the responsibility for whatever passive measures for institutional control are necessary following termination of the licence will have to revert to the government at some level.                                                                                                                                                                                                                                                                                                                                                                                                                                                                      | NSDF Safety Case 232-508770-SAR-001; Preliminary Decommissioning Plan, 232-508300-PLA-001.                                                                                                                                                                                                                       |
| <b>Requirement 23: Consideration of the State system of accounting for, and control of, nuclear material. In the design and operation of disposal facilities subject to agreements on accounting for, and control of, nuclear material, consideration shall be given to ensuring that safety is not compromised by the measures required under the system of accounting for, and control of, nuclear material.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |                                                                                                                                                                                                                                                                                                                  |
| 43                                                                                                                                                                                                                                                                                                                                                                                                                 | 5.17      | During the operation of a disposal facility for waste that includes fissile material, surveillance for the purposes of IAEA safeguards is aimed at ensuring the continuity of knowledge concerning the fissile material and the absence of any undeclared activities at the site in relation to such material.                                                                                                                                                                                                                                                                                                                                                                                                                                                        | NSDF Safety Case 232-508770-SAR-001; Criticality Safety Document, 232-508550-CSD-001; Nuclear Materials and Safeguards Management 900-508510-PDD-001.                                                                                                                                                            |
| 44                                                                                                                                                                                                                                                                                                                                                                                                                 | 5.19      | Since IAEA nuclear safeguards are internationally supervised, their continuation might increase confidence in the longevity of administrative controls and this would also help to prevent inadvertent disturbance of the geological disposal facility.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               | NSDF Safety Case 232-508770-SAR-001; Appendix A to the Administrative Protocol for the Near Surface Disposal Facility Project at Chalk River Laboratories identifies Safeguard and non-proliferation required in support of license application; Nuclear Materials and Safeguards Management 900-508510-PDD-001. |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                         |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                       |
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| Page                                                                                                                                                                                                                                                                                                                                                           | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       | Demonstrated in CNL Documentation                                                     |
| <b>Requirement 24: Requirements in respect of nuclear security measure. Measures shall be implemented to ensure an integrated approach to safety measures and nuclear security measures in the disposal of radioactive waste.</b>                                                                                                                              |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                       |
| 44                                                                                                                                                                                                                                                                                                                                                             | 5.20      | Where nuclear security measures are necessary to prevent unauthorized access by individuals and to prevent the unauthorized removal of radioactive material, safety measures and nuclear security measures have to be implemented in an integrated approach.                                                                                                                                                                                                                                                                                                                                                             | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report, 232-508770-SAR-002. |
| 44                                                                                                                                                                                                                                                                                                                                                             | 5.21      | The level of nuclear security has to be commensurate with the level of radiological hazard and the nature of the waste.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  | NSDF Safety Case 232-508770-SAR-001.                                                  |
| <b>Requirement 25: Management Systems. Management systems to provide for the assurance of quality shall be applied to all safety related activities, systems and components throughout all the steps of the development and operation of a disposal facility. The level of assurance for each element shall be commensurate with its importance to safety.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                       |
| 45                                                                                                                                                                                                                                                                                                                                                             | 5.22      | An appropriate management system that integrates quality assurance programmes will contribute to confidence that the relevant requirements and criteria for site selection and evaluation, design, construction, operation, closure and safety after closure are met. The relevant activities, systems and components have to be identified on the basis of the results of systematic safety assessment. The level of attention assigned to each aspect has to be commensurate with its importance to safety. The management system is required to comply with the relevant IAEA safety standards on management systems. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report, 232-508770-SAR-002. |
| 45                                                                                                                                                                                                                                                                                                                                                             | 5.23      | The management system specifies the role of management and the organizational structure to be used for implementing processes for all safety related activities. It also specifies the responsibilities and authorities of the various personnel and organizations involved in managing and implementing the processes and assessing the quality of all work relating to safety.                                                                                                                                                                                                                                         | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report, 232-508770-SAR-002. |
| 45                                                                                                                                                                                                                                                                                                                                                             | 5.24      | While the host environment of a disposal facility is important to safety, it cannot be designed or manufactured, but only characterized, and that to only a limited extent. The elements of the management system that provide assurance of the quality of the relevant safety related processes have to be designed with account taken of the nature of the host environment.                                                                                                                                                                                                                                           | NSDF Safety Case 232-508770-SAR-001.                                                  |

| IAEA Safety Standards - Disposal of Radioactive Waste, SSR-5, STI/PUB/1449, 2011 April                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                              |
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| Page                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Paragraph | Safety Requirement                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | Demonstrated in CNL Documentation                                                                                                            |
| 45                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 5.25      | The design, characterization and assessment of a disposal facility have to include several sequential and sometimes overlapping steps with an increasing degree of detail and accuracy. However, a degree of irreducible uncertainty that is impossible to eliminate by any measures might always remain. The significance of this uncertainty is assessed in the evaluation of the safety case and supporting safety assessment.                                                                                                                                                                                                                                                                                                                                                    | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002; NSDF Post-Closure Safety Assessment 232-509240-ASD-004. |
| 46                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 5.26      | The management system for a disposal facility has to provide for the preparation and retention of documentary evidence to illustrate that the necessary quality of data has been achieved; that components have been supplied and used in accordance with the relevant specifications; that the waste packages and unpackaged waste comply with established requirements and criteria; and that they have been properly emplaced in the disposal facility. The management system also has to ensure the collation of all the information that is important to safety and that is recorded at all steps of the development and operation of the facility, and the preservation of that information. This information is important for any reassessment of the facility in the future. | NSDF Safety Case 232-508770-SAR-001; NSDF Safety Analysis Report 232-508770-SAR-002.                                                         |
| <b>Existing Disposal Facilities</b>                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                  |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                              |
| <b>Requirement 26: Existing disposal facilities. The safety of existing disposal facilities shall be assessed periodically until termination of the licence. During this period, the safety shall also be assessed when a safety significant modification is planned or in the event of changes with regard to the conditions of the authorization. In the event that any requirements set down in this Safety Requirements publication are not met, measures shall be put in place to upgrade the safety of the facility, economic and social factors being taken into account.</b> |           |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |                                                                                                                                              |
| 46                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   | 6.2       | Periodic safety assessment for a disposal facility has to be aimed at providing an overall assessment of the status of protection and safety at the facility. It has to include an analysis of the operational experience acquired and possible improvements that could be made, with account taken of the existing situation and of whatever new technological developments or changes in regulatory control there might be.                                                                                                                                                                                                                                                                                                                                                        | NSDF Safety Case 232-508770-SAR-001.                                                                                                         |

## APPENDIX C PUBLIC AND STAKEHOLDER ENGAGEMENT

Transparency is important to build confidence in the level of safety offered by the NSDF design and in CNL's ability to construct and operate a NSDF. Canadian Nuclear Laboratories has employed a variety of methods to inform, educate and discuss the Project with stakeholders, and have enabled the public to provide valuable feedback into the Project. Engagement activities commenced on 2015 October 29. Table C-1 presents a summary of the NSDF public engagement activities. The complete list of engagements is presented in Section 4 of the EIS [C-2].

**Table C-1**  
**Frequency of Public and Stakeholder Engagements**

| Description of Engagement Method                                    | Year |      |      |      |       |
|---------------------------------------------------------------------|------|------|------|------|-------|
|                                                                     | 2016 | 2017 | 2018 | 2019 | Total |
| Presentations and Site Tours                                        | 12   | 25   | 12   | 11   | 61    |
| Public Information Sessions                                         | 14   | 8    | 1    | 0    | 23    |
| Community Events and Updates                                        | 2    | 4    | 5    | 6    | 17    |
| Employee Engagements                                                | 4    | 1    | 1    | 2    | 8     |
| Webinars                                                            | 0    | 0    | 1    | 2    | 3     |
| Other Engagement Methods and Activities                             |      |      |      |      |       |
| Webpage                                                             |      |      |      |      |       |
| Fact Sheets                                                         |      |      |      |      |       |
| Poster Boards                                                       |      |      |      |      |       |
| Newsletter                                                          |      |      |      |      |       |
| Advertising – Newspaper and Radio Stations                          |      |      |      |      |       |
| Social Media – Facebook, Twitter, You Tube, Instagram and Linked In |      |      |      |      |       |

The engagement activities provided CNL with an opportunity for dialogue with members of the public. The majority of public concerns with the NSDF Project could typically be associated with one or more of the following themes:

- Justification for the Project.
- Waste Inventory.
- Design/engineering details.
- Long-term Accountability.
- Alternative Means Assessment (including site selection).
- Environmental Events (flooding, earthquakes, etc.).
- Protection of the Ottawa River.

This feedback pointed-out areas where CNL could improve elements of the Project. This led the Project to:

- Conduct more comprehensive safety assessments.
- Increase the robustness of the Facility through design changes.
- Reduce the radiological waste inventory.
- Improve communication methods.

The NSDF Project will continue Stakeholder engagement efforts to support growth in awareness and understanding of the Project. Planned future engagement methods and activities include:

- Annual Conferences.
- Annual Public Events (i.e., Petawawa SHOWCASE, Downtown Connect).
- Renfrew County Municipal Councils – Project overview/updates.
- Quarterly Project update webinars.
- Quarterly website review and content update. (Note: new information will be updated as it becomes available.
- CRL Environmental Stewardship Council meeting – Project updates.
- CNL Corporate kiosk/storefront – Project information.
- Project update letter/invitation to intervenors.
- Bi-monthly Project breakfast briefings.
- Informational videos.

#### **C.1 COMMUNICATIONS AND INVOLVEMENT WITH CNSC STAFF**

Once CNSC staff have carefully considered all of the NSDF design and safety documents, they will make a recommendation to the Commission on both the EA and the application to construct the NSDF, enabling the Commission to make the decisions. “To facilitate the preparation and review of documents required for these two decisions, the CNSC and CNL have mutually decided to formally document the various steps in an administrative protocol”.

The purpose of the protocol is to outline the framework and schedule for CNL to submit the technical information in support of both the EA and license to construct application. Adherence to this protocol allows sufficient time for CNSC staff review and satisfactory resolution of issues. In addition to this, CNL and CNSC staff met (and continue to meet), when necessary to clarify intentions and to facilitate mutual understandings. Table C-2 presents a list of many of the most significant technical documents that have been submitted for CNSC staff review and comment from the start of the project up to 2019 November. For particularly important topics such as radiological inventory, WAC, and PostSA, theme meetings often preceded the submissions to present one or more of the following:

- The management process followed, or modelling codes were used for conducting a technical study.
- A summary of technical information contained in the document, and/or
- How CNL incorporated CNSC comments on previous document submissions.

**Table C-2**  
**NSDF Technical Documents Submitted to CNSC Staff for Review**

| <b>2016</b>                                                                     |
|---------------------------------------------------------------------------------|
| Project Description, Near Surface Disposal Facility at Chalk River laboratories |
| Submission of Environmental Impact Statement for Groups 1, 2 and 3 for the NSDF |
| Aboriginal Engagement Report                                                    |
| Technical Scope of Work for NSDF Design and Consulting Services                 |
| <b>2017</b>                                                                     |
| ALARA Assessment                                                                |

|                                                                                                                                                                                                                                                                             |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Assessment of NSDF Project Documentation with Respect to IAEA SSR-5                                                                                                                                                                                                         |
| Bearing Capacity and Settlement Analysis                                                                                                                                                                                                                                    |
| CNL Waste Management On-Site Package Checklist, Radionuclide Calculator for CRL Solid Active Waste, Gamma Spectrometry of Three B25 Bins from Building 375, Gamma Spectrometry of a Marine Container Filled with Active Waste from Building 200A Ion Exchange Column system |
| Commissioning Plan                                                                                                                                                                                                                                                          |
| Consequence of Failure Analysis                                                                                                                                                                                                                                             |
| Construction Quality Assurance Plan                                                                                                                                                                                                                                         |
| Construction Schedule                                                                                                                                                                                                                                                       |
| Criticality Safety Document                                                                                                                                                                                                                                                 |
| Derivation of Specific Activity Limits for NSDF Waste Streams & NSDF Acceptable Waste Packaging                                                                                                                                                                             |
| Design Requirements                                                                                                                                                                                                                                                         |
| Draft Safety Analysis Report                                                                                                                                                                                                                                                |
| Environmental Protection Plan                                                                                                                                                                                                                                               |
| Environmental Impact Statement                                                                                                                                                                                                                                              |
| Features, Events, & Processes                                                                                                                                                                                                                                               |
| Fire Hazard Analysis                                                                                                                                                                                                                                                        |
| Geologic Waste Management Facility Descriptive Geosphere Site Model Report Phase 1                                                                                                                                                                                          |
| Groundwater Flow Modelling of the NSDF 60% Design                                                                                                                                                                                                                           |
| Hazard Identification                                                                                                                                                                                                                                                       |
| Leachate Management Plan                                                                                                                                                                                                                                                    |
| Long-Term Seismic Hazard Assessment & NSDF Seismic and Structural Design Documentation                                                                                                                                                                                      |
| Monitoring and Reporting Plan                                                                                                                                                                                                                                               |
| Multidisciplinary Subsurface Investigation, Phase 2, For the Detailed Design of the Near Surface Disposal Facility Project at CRL                                                                                                                                           |
| NSDF Seismic Analysis                                                                                                                                                                                                                                                       |
| Operations and Maintenance Plan                                                                                                                                                                                                                                             |
| Performance Assessment                                                                                                                                                                                                                                                      |
| Pilot Scale Test Report                                                                                                                                                                                                                                                     |
| Post-Closure Care Plan                                                                                                                                                                                                                                                      |
| Preliminary Decommissioning Plan                                                                                                                                                                                                                                            |
| Radiation Protection Plan                                                                                                                                                                                                                                                   |
| Revised Groundwater Flow Report                                                                                                                                                                                                                                             |
| Revised Waste Acceptance Criteria                                                                                                                                                                                                                                           |
| Safety Related Systems List                                                                                                                                                                                                                                                 |
| Security Letter                                                                                                                                                                                                                                                             |
| Seismic Analysis & Structural Calculations                                                                                                                                                                                                                                  |
| Site Selection Report                                                                                                                                                                                                                                                       |
| Slope Stability Analysis                                                                                                                                                                                                                                                    |
| Solubility Limits for Each Radionuclide / Free-Water Diffusivity for Each Radionuclide                                                                                                                                                                                      |
| Subsurface Radionuclide Migration from the Chemical Pit                                                                                                                                                                                                                     |
| Third Party Code Review & Fire Hazard Analysis                                                                                                                                                                                                                              |
| Waste Acceptance Criteria                                                                                                                                                                                                                                                   |
| Waste Forecast Analysis                                                                                                                                                                                                                                                     |
| Waste Management Area Training Plan                                                                                                                                                                                                                                         |
| Waste Management Plan                                                                                                                                                                                                                                                       |
| WWTP Process Design Report                                                                                                                                                                                                                                                  |

| <b>2018</b>                                                                                                            |
|------------------------------------------------------------------------------------------------------------------------|
| Design Codes on the systems involved in R3 <sup>10</sup> events                                                        |
| Geological Survey of Canada Seismic Source Model for CNL and Probabilistic Seismic Hazard Analysis                     |
| Long-Term Seismic Hazard Assessment                                                                                    |
| Near Surface Disposal Facility Mixed Waste constituents of Potential Concern Inventory                                 |
| NSDF Reference Inventory Report                                                                                        |
| Physical Characterization of Perch Lake                                                                                |
| Preliminary Decommissioning Plan                                                                                       |
| Revised Seismic-related Documents for the Near Surface Disposal Facility Project                                       |
| Safety Classification and Design Rules for NSDF Structures, Systems and Components                                     |
| Seismic Criteria and Assessment                                                                                        |
| WWTP Treated Effluent Discharge Options                                                                                |
| <b>2019</b>                                                                                                            |
| Air Quality Assessment for the Near Surface Disposal Facility                                                          |
| ALARA Assessment                                                                                                       |
| Base Liner and Final Cover Evaluation and Optimization                                                                 |
| Bearing Capacity, Settlement, and Lateral Earth Pressure Analysis                                                      |
| Characterization of Water and Sediments from and around Perch Lake                                                     |
| Climate Change Assessment for the Near Surface Disposal Facility Project                                               |
| Components for Safety Classified Systems                                                                               |
| Construction Quality Assurance Plan                                                                                    |
| Criticality Safety Document                                                                                            |
| Design Description                                                                                                     |
| Design Requirements                                                                                                    |
| Ecological Risk Assessment                                                                                             |
| Effluent Discharge Targets                                                                                             |
| Environmental Assessment Stakeholder Activities Report – NSDF and NPD Closure Projects                                 |
| Environmental Impact Statement                                                                                         |
| Groundwater Flow Modelling of the Near Surface Disposal Facility                                                       |
| Hazard Identification and Analysis                                                                                     |
| Historic Results Non-Radioactive and Radioactive Surface Water Monitoring at Selected Stations in the Perch Lake Basin |
| Indigenous Engagement Report                                                                                           |
| Leachate and Wastewater Characterization                                                                               |
| Multidisciplinary Subsurface Investigation Phase 1 / Subsurface Geotechnical Survey                                    |
| Commissioning Plan                                                                                                     |
| Site Selection Report                                                                                                  |
| Effluent Discharge Targets                                                                                             |
| Facility Authorization                                                                                                 |
| Operations & Maintenance Plan                                                                                          |
| Operations and Maintenance Plan                                                                                        |
| Physical Characterization of Perch Lake                                                                                |

<sup>10</sup> “R3” refers to a Risk Rating of 3, a result of an assessment of frequency and consequence.

|                                                                                |
|--------------------------------------------------------------------------------|
| Post-Closure Safety Assessment 3rd Iterations to the NSDF Project              |
| Radiation Protection Plan                                                      |
| Reference Inventory                                                            |
| Revised Fire Hazards Analysis                                                  |
| Revised Mixed Waste Constituents of Potential Concern Inventory Technical Note |
| Safety Analysis Report                                                         |
| Seismic Analysis                                                               |
| Seismic Criteria and Assessment                                                |
| Slope Stability Analysis                                                       |
| Stage 4 Archeological Assessment                                               |
| Stakeholder Engagement Report                                                  |
| Submission of Revised Near Surface Disposal Facility Design Description        |
| Surface Water Quality Assessment for the Near Surface Disposal Facility        |
| Waste Acceptance Criteria                                                      |
| Waste Characterization                                                         |
| Waste Placement and Compaction Plan                                            |

## C.2 INDIGENOUS ENGAGEMENT

An Aboriginal Engagement Report (AER) Technical Supporting Document (TSD) for the proposed NSDF Project, was prepared in 2016 by CNL in accordance with CNSC regulations. The first two AER revisions capture engagements activities up until 2017 October, thus, supporting the preparation of the draft EIS. A third revision was prepared by CNL [C-1] in support of the revised draft EIS and capture activities up until 2019 March. To align with the CNSC REGDOC-3.2.2, Revision 3 included the new title of Indigenous Engagement Report (IER). A fourth revision has been prepared by CNL [C-2] in support of the final EIS. A fifth revision will be prepared in support of CNL's submission of the Commission Member Document in preparation for a CNSC Commission Hearing.

A proposed list of Indigenous communities, with a potential interest in the NSDF Project, was identified by CNL and included in the IER TSD [C-1]. The proposed list was based on the identified potential or established Indigenous or treaty rights of Indigenous communities in the vicinity of the Project. See Section 6.2.2 of the EIS [C-2] for more information on the selected communities and the rationale for inclusion.

Various engagement methods were designed to communicate information to and solicit input from identified Indigenous communities and organizations, while fulfilling CNL's corporate and regulatory objectives. The methods CNL has utilized to date, or plans to undertake, are highly diverse and vary based on expressed community need and desired methods. This includes general information activities to focused community meetings and workshops to long-term relationship building activities. Table C-3 lists the NSDF Project Indigenous engagement methods.

In Section 6.2.4 of the EIS [C-2], these activities are described for each community but, in general, the methods have included those summarized in the below table. Project-specific examples are included however, long-term relationship building engagements and funding were also a key activity. Canadian Nuclear Laboratories recognizes a mutual desire to establish long term relationship agreements to help facilitate many aspects both related and unrelated to projects such as NSDF. While although CNL may have various projects over time, it is important to both the communities and CNL that these relationships endure, grow and respond to future activities.



Feedback received from communications with Indigenous communities includes information on traditional land use activities by Indigenous groups, and input on the selection of VCs for study in the EIS [C-2].

**Table C-3**  
**NSDF Project Indigenous Engagement Methods**

| Engagement Method                                                                | Example Activities                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
|----------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Project Specific Agreements and Long-Term Relationship Meetings and Negotiations | <p>Project-specific Agreements (i.e. separate Memoranda of Understanding (MOUs) entered into with the AOO and the MNO):</p> <ul style="list-style-type: none"> <li>• Provision of funding to assist in resource capacity development; and</li> <li>• Capacity assistance and building, as appropriate, such as basic costs to support meetings such as hall rental or production of print materials, in-kind access to the technical expertise of CNL staff, reimbursement for some expenses to participate in engagement activities such as site visits, tours.</li> </ul> <p>Broader long-term relationship agreements with CNL.</p> |
| Technical Assistance and Contribution Agreements                                 | <p>Provision of funding to assist in technical review.</p> <p>Peer review studies and engagements with Indigenous organization consultants and staff.</p> <p>Work plan development to formalize engagement processes with communities and/or organization representatives.</p>                                                                                                                                                                                                                                                                                                                                                         |
| Project Specific Meetings and Workshops                                          | <p>Meetings/workshops with Indigenous community and/or organization representatives to discuss the Project and potential effects.</p> <p>Community meetings/open houses.</p> <p>Presentations to Indigenous communities and/or organization representatives upon request.</p> <p>Targeted community initiatives.</p> <p>Workshop attendance and cultural awareness training.</p> <p>Technical meetings, upon request, to provide interested communities and/or organization representatives an opportunity to discuss more detailed technical information concerning the NSDF Project.</p>                                             |
| Specific Communications Activities                                               | <p>Letters to Indigenous communities and/or organization representatives (accompanied by follow-up calls).</p> <p>Email correspondence and/or phone calls with Indigenous communities and/or organization representatives.</p> <p>Distributing the IER to Indigenous communities and/or organization representatives.</p> <p>Distributing copies of maps, technical studies or reports upon request.</p> <p>Webinars and online meetings with Indigenous communities and organizations.</p>                                                                                                                                            |
| General Communications Activities                                                | NSDF Project notifications and newspaper advertisements.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                               |

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|  | ESC meetings (for ESC member communities).<br>Public information sessions, including display materials and handouts.<br>Media notifications/releases.<br>Webpage content.<br>Site visits and participation in National Indigenous Day.<br>Participation and presentation at Indigenous Youth Summit.<br>NSDF Project site visits and benchmarking tours. |
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### C.3 REFERENCES

- [C-1] *NSDF Environmental Impact Statement*, 232-509220-REPT-004, Revision 1, 2019 November.
- [C-2] *Indigenous Engagement Report – Near Surface Disposal Facility*, 232-513130-REPT-001, Revision 4, October 2020.