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DECOMMISSIONING SAFETY ASSESSMENT REPORT

NPD CLOSURE PROJECT

64-508760-ASD-002

Revision 2

Accepted by:

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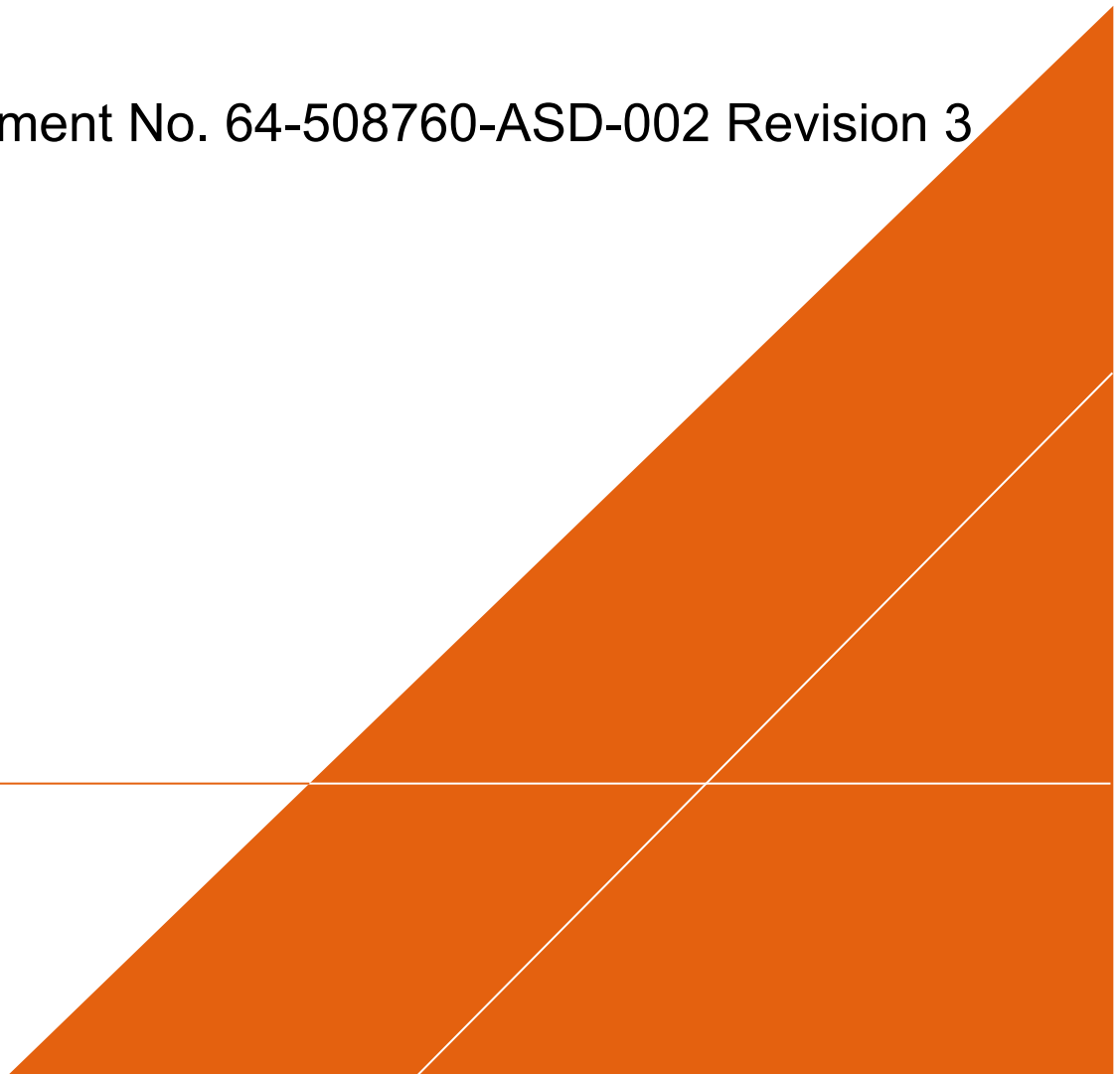


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DECOMMISSIONING SAFETY ASSESSMENT REPORT – NPD CLOSURE PROJECT

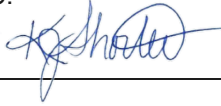
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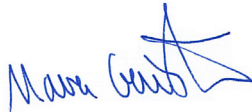
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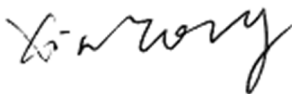
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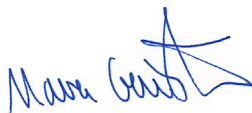
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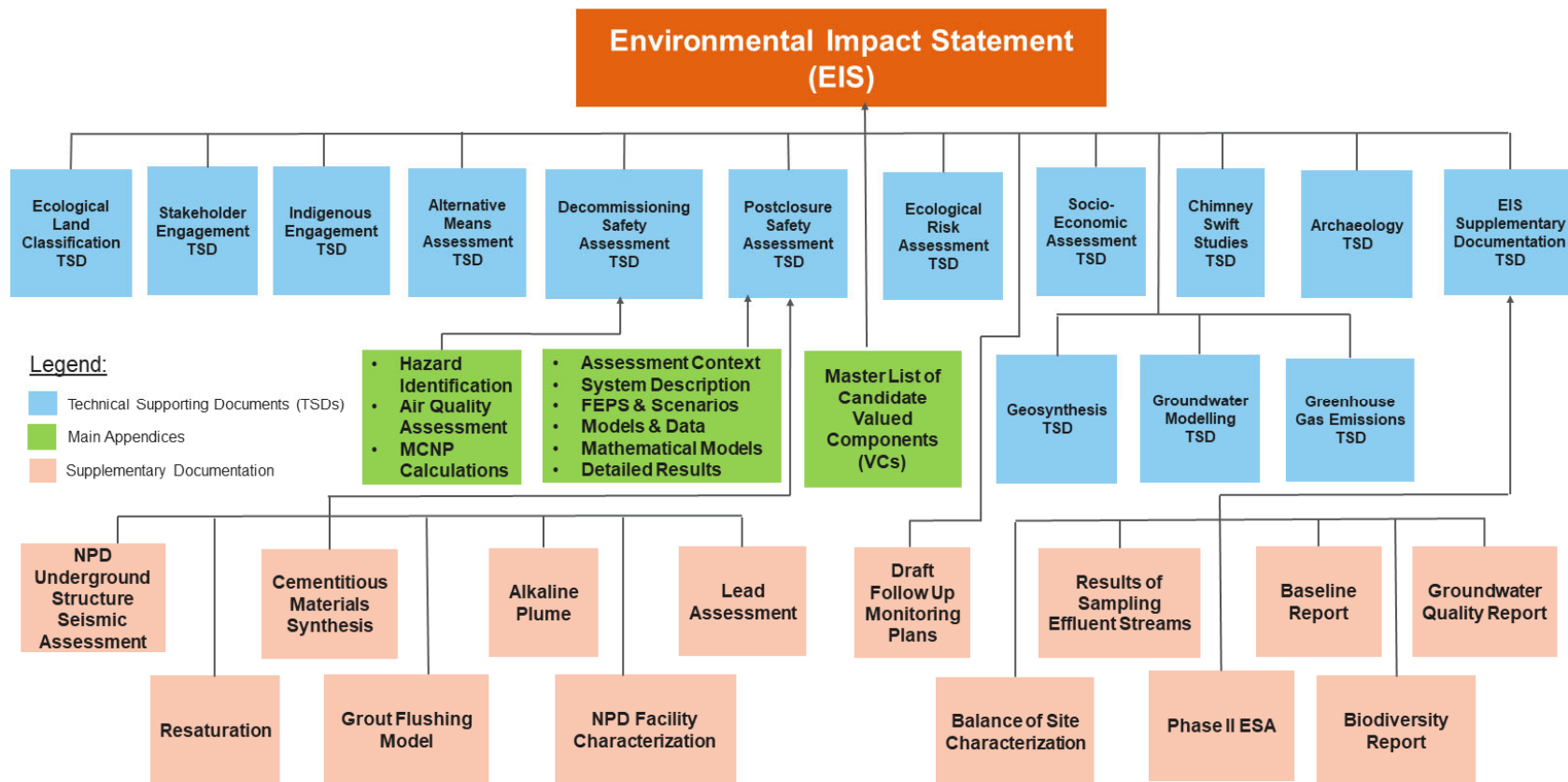
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CNL - Decommissioning Safety Assessment

This Technical Supporting Document (TSD) has been prepared in support of the Nuclear Power Demonstration (NPD) Closure Project. The project qualifies as a Designated Project under the *Canadian Environmental Assessment Act (2012)*, and therefore, an Environmental Impact Statement (EIS) is being prepared as part of the Environmental Assessment process.

The findings of this TSD have been summarized in the NPD Closure Project EIS (CNL Doc #64-509200-ENA-004 Rev.2). The following figure shows the various documents associated with the EIS, and their relationships.



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APPENDICES

APPENDIX A: COMMON TOOLS USED IN ACCIDENTS ASSESSMENT

APPENDIX B: HAZARD IDENTIFICATION

APPENDIX C: ATMOSPHERIC DISPERSION MODELLING

APPENDIX D: MCNP SIMULATION OF DRILLING

APPENDIX E: DETAILED RESULTS – RADIOLOGICAL & NON-RADIOLOGICAL

APPENDIX F: AIR QUALITY ASSESSMENT FOR THE NPD PROJECT

APPENDIX G: SCENARIOS COMPARISON: SAR vs. DECOMSA

APPENDIX H: BOUNDING SCENARIO PROCESS

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1.0 INTRODUCTION

1.1 Background

Canadian Nuclear Laboratories (CNL) is undertaking the decommissioning of the Nuclear Power Demonstration (NPD) reactor, near Rolphton, in Rolph Township, Ontario. NPD was the first Canadian power reactor, operating from 1962 to 1987. NPD is currently in a safe shut-down state, under its own licence (*Waste Facility Decommissioning Licence, Nuclear Power Demonstration*) (CNSC 2019). CNL is advancing the decommissioning of the NPD site, and is pursuing the preferred approach of In-Situ Disposal (ISD) (see the updated Alternative Means Assessment Report (Garisto & McKee, 2019) for selection details).

The present NPD Closure Project is to complete the necessary licensing approach, safety assessments (Decommissioning Safety Assessment (DecomSA) and Postclosure Safety Assessment (PostSA)), Environmental Impact Statement (EIS), and other licensing support studies to allow for ISD to proceed.

1.2 Scope of the Present Report

This report presents the DecomSA for the NPD In-Situ Disposal project.

The DecomSA assesses the safety of human receptors (i.e. workers and members of the public) from normal operations and accidents (including Anticipated Operational Occurrences (AOOs) among the range of potential events) as part of the decommissioning plan for the site. The DecomSA also provides information on releases to the environment related to applicable accident scenarios (including AOOs) and normal activities. Long-term safety (i.e. post-decommissioning) is assessed separately, as part of the PostSA, which is documented in the PostSA Technical Supporting Document (PostSA TSD).

Additionally, the DecomSA provides valuable safety-related information that will be accounted for in the project's Detailed Decommissioning Plan (DDP) (Aikens 2019).

The DecomSA focuses on assessing safety to members of the public and workers from the following:

- Exposure to chemical stressors associated with the NPD facility (Titterington, 2016) (see Sections 8.0 and 9.0):
 - lead;
 - mercury;
 - asbestos; and,
 - PCBs.

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- Exposure to radiological stressors (see Sections 8.0 and 9.0):
 - radionuclide contamination; and,
 - external gamma radiation.
- Conventional accidents (see Section 8.3.3).

Exposure effects on non-human biota are assessed separately in the 2020 *Ecological Risk Assessment (EcoRA) Technical Supporting Document (TSD)* (Garisto *et al.*, 2020a), though its conclusions are reproduced in this DecomSA – at a high level – for completeness. Non-exposure effects (e.g. habitat impacts) related to non-human biota are assessed in the EIS.

Figure 1-1 compares the scope of the DecomSA to the EIS and how they tie together.

Figure 1-1 Comparison of DecomSA to the EIS Document

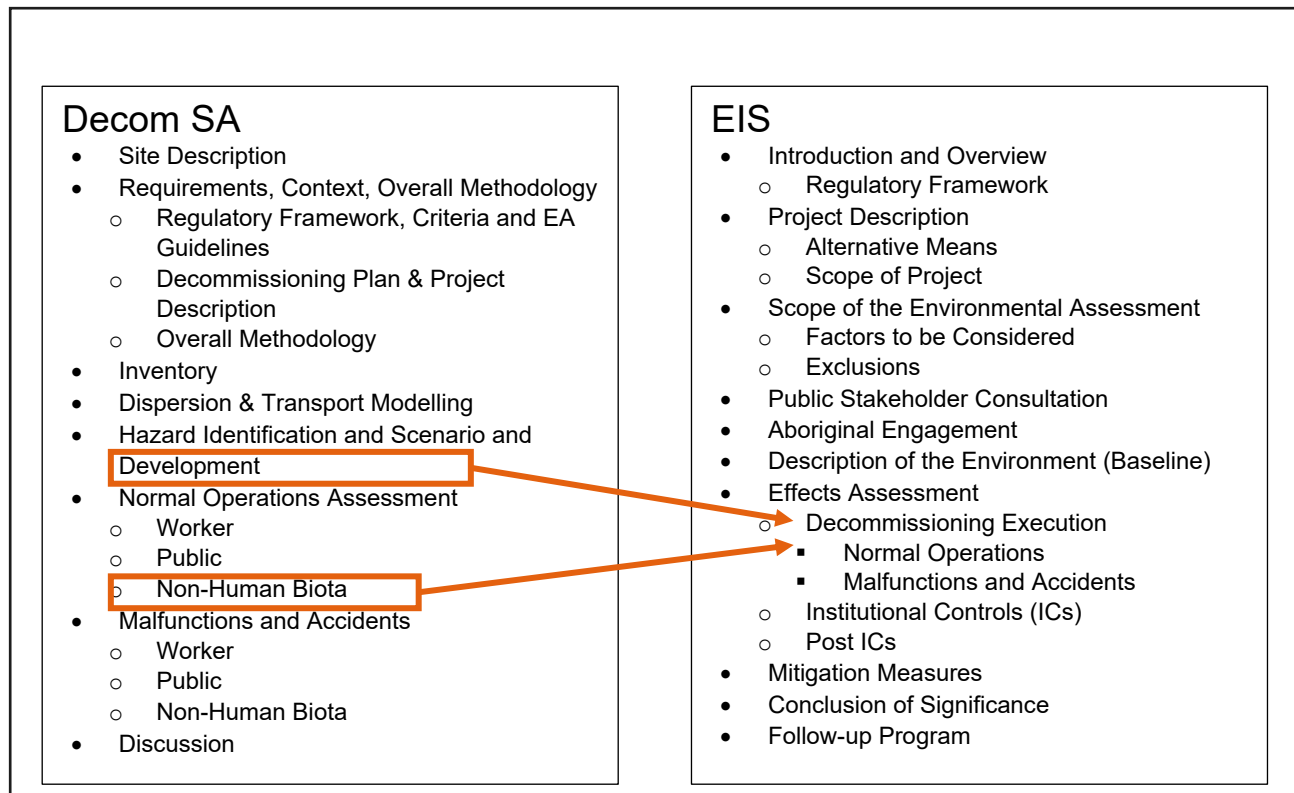
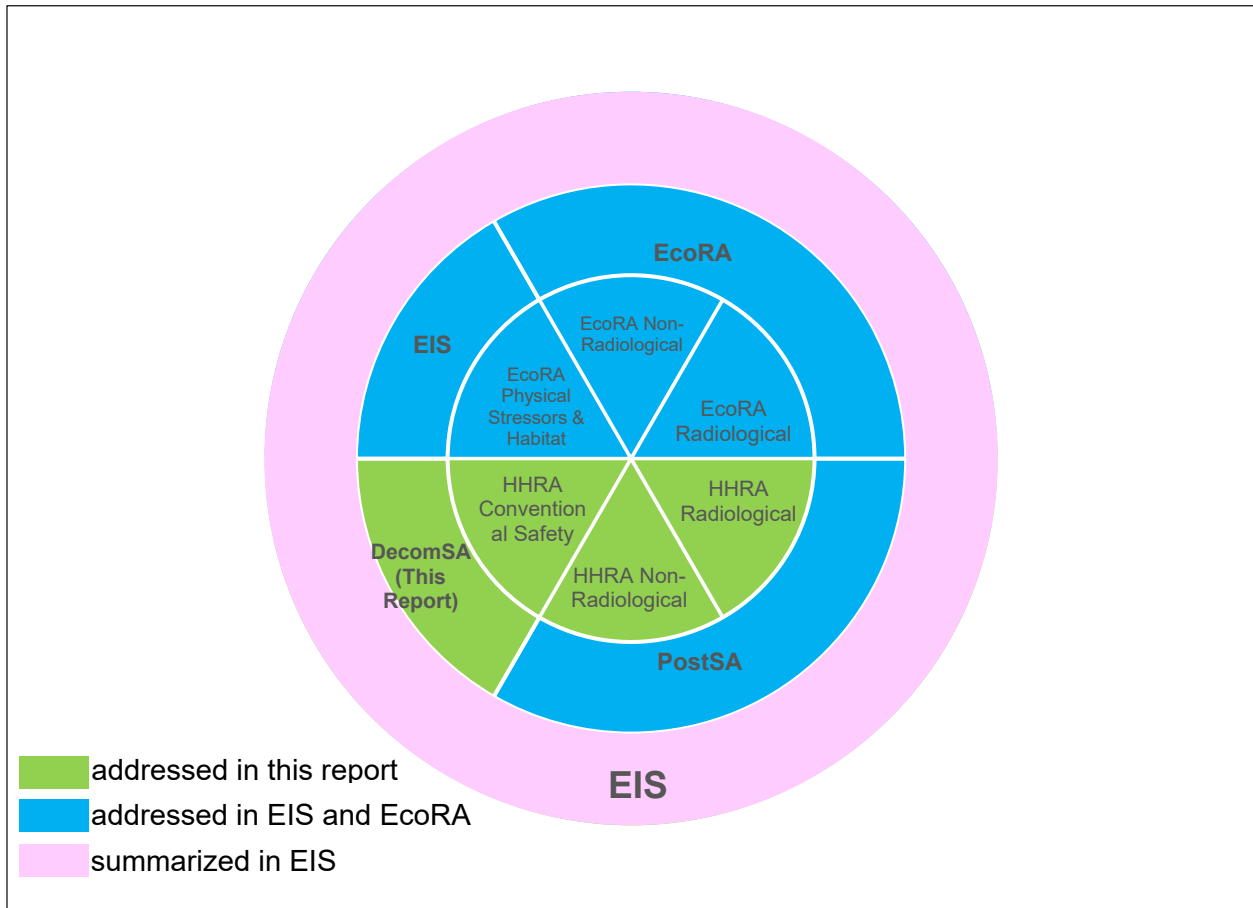


Figure 1-2 outlines the various effects that are assessed as part of the larger project scope, and, the documents where these effects assessment can be found. The centre segments represent the various assessment components, whereas the middle ring indicates the TSDs in which they are documented. The outer ring represents that all information is incorporated in the EIS. An outline of the project documents (e.g. EIS, EcoRA, DecomSA etc.) and their relationships was provided earlier, in the preamble of this report.

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Figure 1-2 Effects Assessments for Various Receptors and Stressors



Notes:
HHRA – Human Health Risk Assessment

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1.3 Report Breakdown

The main report sections are as follows:

Section 1.0: Presents background information for context, and briefly outlines the scope of this report.

Section 2.0: Acknowledges key CNL references used in this report.

Section 3.0: Describes the site, its location, and the main structures/features.

Section 4.0: Provides context for the DecomSA, including: regulatory framework, guidance documents, acceptance criteria, overview of the decommissioning plan, prior/existing facility safety assessments, an overview of the safety assessment methodology proposed, and relevant human receptors.

Section 5.0: Presents information on the radiological and non-radiological inventory of the facility.

Section 6.0: Presents information on dispersion and transport modelling methods used later in the assessment.

Section 7.0: Identifies hazards associated with the planned decommissioning activities, and uses the identified hazards to develop scenarios representing normal operations, and, potential accidents or malfunctions. Also, reviews the resulting hazard events to develop a reduced list of bounding scenarios.

Section 8.0: Assesses the safety of the relevant scenarios associated with normal operations.

Section 9.0: Assesses the risks associated with the bounding accident scenarios.

Section 10.0: Discussion of results and conclusions from the DecomSA.

Section 11: Discusses uncertainties, conservative assumptions used, and robustness of the DecomSA.

Section 12.0: Discusses quality aspects.

Section 13.0: Presents references.

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2.0 KEY CNL REFERENCE DOCUMENTS

The following list outlines key CNL reference material used in the development of the DecomSA:

- Detailed Decommissioning Plan - Nuclear Power Demonstration Waste Facility (Aikens 2019);
- Project Description (Titterington, 2016);
- Safety Analysis Report (SAR) (for the Storage with Surveillance (SwS) stage of the NPD facility) (Athauda-Arachchige, 2015);
- Procedure – Hazard Identification (Johnston 2016);
- Storage with Surveillance Plan (Luiz, 2016);
- Industrial Hygiene Survey Report – Hazard Assessment (AECL, 2015);
- Nuclear Power Demonstration Effluent Monitoring Plan (De Waele, 2016);
- Fire Hazard Analysis/Assessment (Dunfield & Glennie, 2012);
- Waste Management Plan (Gillespie, 2016);
- Building Arrangements for Reactor Process Area (Harris, 1958);
- Arrangement of Hatch Cover (Harris, 1960);
- The Radiochemical Characterization of the NPD Concrete Core Sections (Krasznai, 1991);
- Life Management Program for NPD Structures (Milman, 2004);
- Interim End-State Report (Seto, 2015);
- Operational Incidents and Accidents in NPD (Seto, 2014);
- Calculated Radioactive Inventory of NPD (Smith, 1988);
- Licence Conditions Handbook WFDL-LCH-W4-342.00/2034 Prototype Waste Facilities - Waste Facility Decommissioning Licence Nuclear Power Demonstration Waste Facility WFDL-LCH-W4-342.00/2034 (Phillips, 2019);
- NPDWF Emergency Procedure (Ingram, 2017);
- Annual Compliance Report for Prototype Waste Facilities (Primeau, 2016);
- CRL Ottawa River Sediment Remediation Assessment (Silke *et al*, 2014);
- Liquid Samples from NPD Stack and Septic Systems (McMillan, 2014);
- Current Groundwater Quality at NPD (Killey, 2014);
- Derived Release Limits for NPD Site (Chouhan & Scheier, 2011);
- Atmospheric Dilution Factors Used for NPD's Derived Release Limits (Chouhan, 2016a);
- River Dilution Factors Used for NPD's Derived Release Limits (Chouhan, 2016b);
- NPD Biodiversity Report (Morin & Carr, 2015);
- Gamma Spectrometry of NPD Room 405 (Adams, 2016);

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- Radiological Work Plan/Procedure: Reactor Vault Access, Concrete Coring in the Fueling Machine Room 405 (AECL 2016a,b);
- Radiological Work Plan/Procedure: Characterization Sampling, Moderator and Primary Heat Transport System (AECL 2017);
- Industrial Hygiene Survey Report – Hazard Assessment (AECL 2015);
- Lead (Pb) Survey Report (AECL 2012);
- NPD-2 Design Description (AECL 1960);
- Results of Sampling Effluent Streams from CNL's Prototype Reactor Decommissioning Sites (Audet, 2016);
- Zoning Plans – Radiological Safety Zone Plan for Nuclear Power Demonstration Waste Management Facility (McVeigh, 2016a);
- Facility Rooms and Area Plan at EL 420' and Various Lower Elevations (as marked) General Arrangement (Kittel, 2003);
- Standard Assumptions and Input Parameters for the Calculation of On-Site and Off-Site Doses following Hypothetical Accidental Atmospheric Radioactive Release from Facilities at CRL (Lundie, 2014);
- Historical Site Assessment Report for the Nuclear Demonstration Waste Management Facility (ORAU, 2016);
- Gamma Spectrometry of Waste Bag, HEPA Filter and Trailer at NPD (Reynard, 2015);
- Follow-Up to NPD PCB Survey Report (Vickerd, 2014);
- Inventories and location of Hazardous Substances in the NPD Facility (Schruder and Vickerd, 2017);
- 3D Model of NPD (CNL 2016b);
- Assessment of Hydrogen Generation from Aluminum-Grout Interaction at the NPD Site (Hongqiang, 2017);
- Edwards G (2017). C-14 in the NPD Channel End Fittings, 64-505100-400-000, April 2017;
- Edwards, G., and Adams, F. 2019. Calculations of the Current NPD Reactor Vault Activation Source Term. NPD Decommissioning. CNL No. 64-505100-ANL-001. R.0. February;
- McVeigh A (2017), Characterization Report for the NPDWF Primary Heat Transport and Moderator Systems, 64-509410-002, April 2017;
- McVeigh, A. (2018a). NPD Building Characterization Report. NPD Decommissioning. CNL No. 64-509410-REPT-011. R.0. November;
- McVeigh, A. (2018b). NPD Balance of Site Characterization Report, NPD Decommissioning, CNL No. 64-509410-REPT-009, R.0, April;
- McVeigh, A. (2019). Characterisation Report for NPDWDF Primary Heat Transport and Moderator Systems. CNL No. 64-509410-REPT-002. Rev.1. October;

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- McVeigh, A. (2020). Nuclear Power Demonstration Waste Facility (NPDWF) Waste Inventory Report. Document No. 64-508600-REPT-001. Revision 0. April.
- CNL. (2019). NPD Radiological Inventory for Arcadis May. CNL No. 64-509410-021-000. May;
- NMNTI (2017). Final Report for the Characterization of the NPD Reactor using TruPro® Technology. NMNTICNLFR01, May 2017;
- Trottier A and Edwards GWR (2012). Verification of the WM Smith Memorandum “Calculated Radioactive Inventory of the NPD”, AECL report 64-505100-401-000-0001, December 2012.

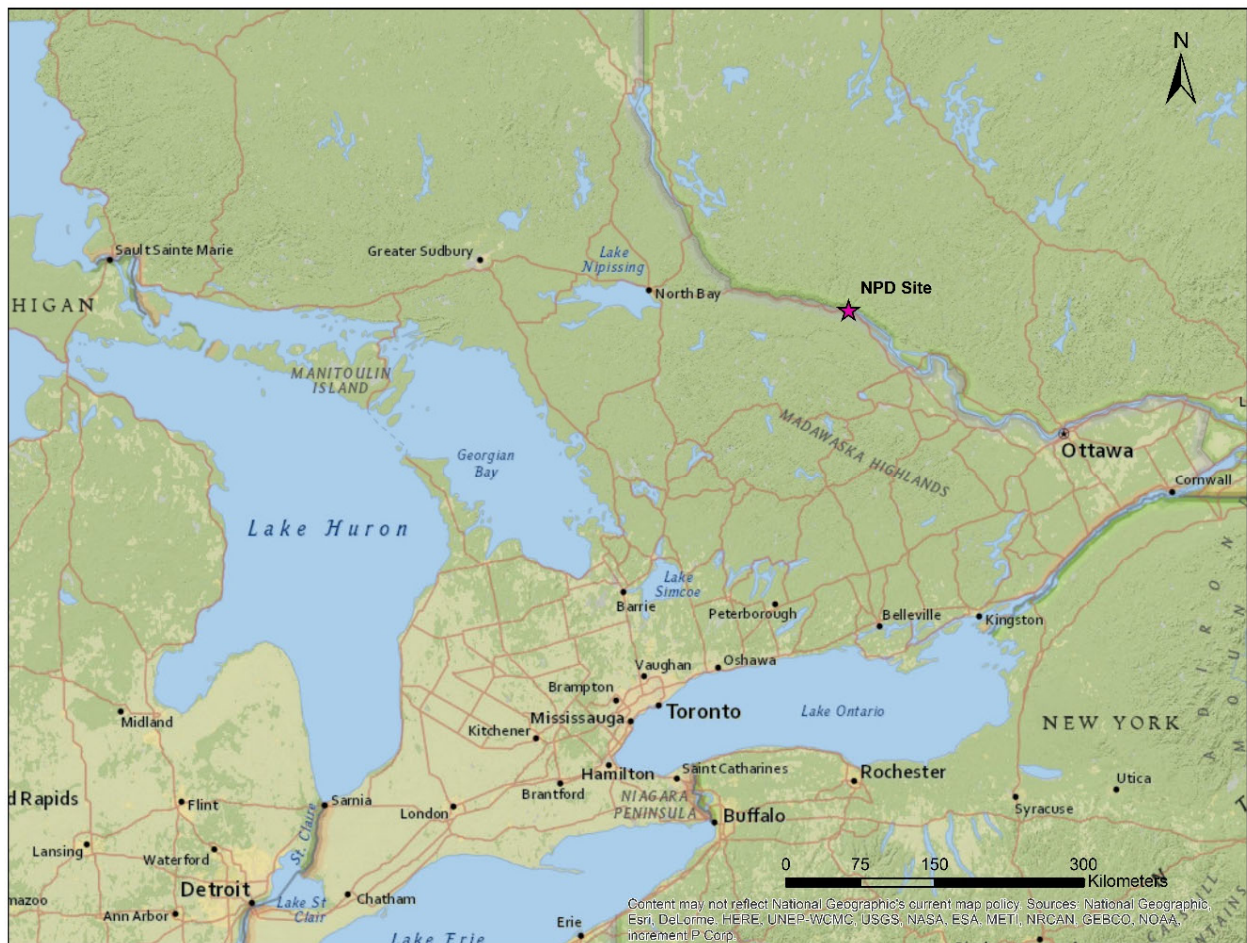
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3.0 SITE DESCRIPTION

3.1 Location

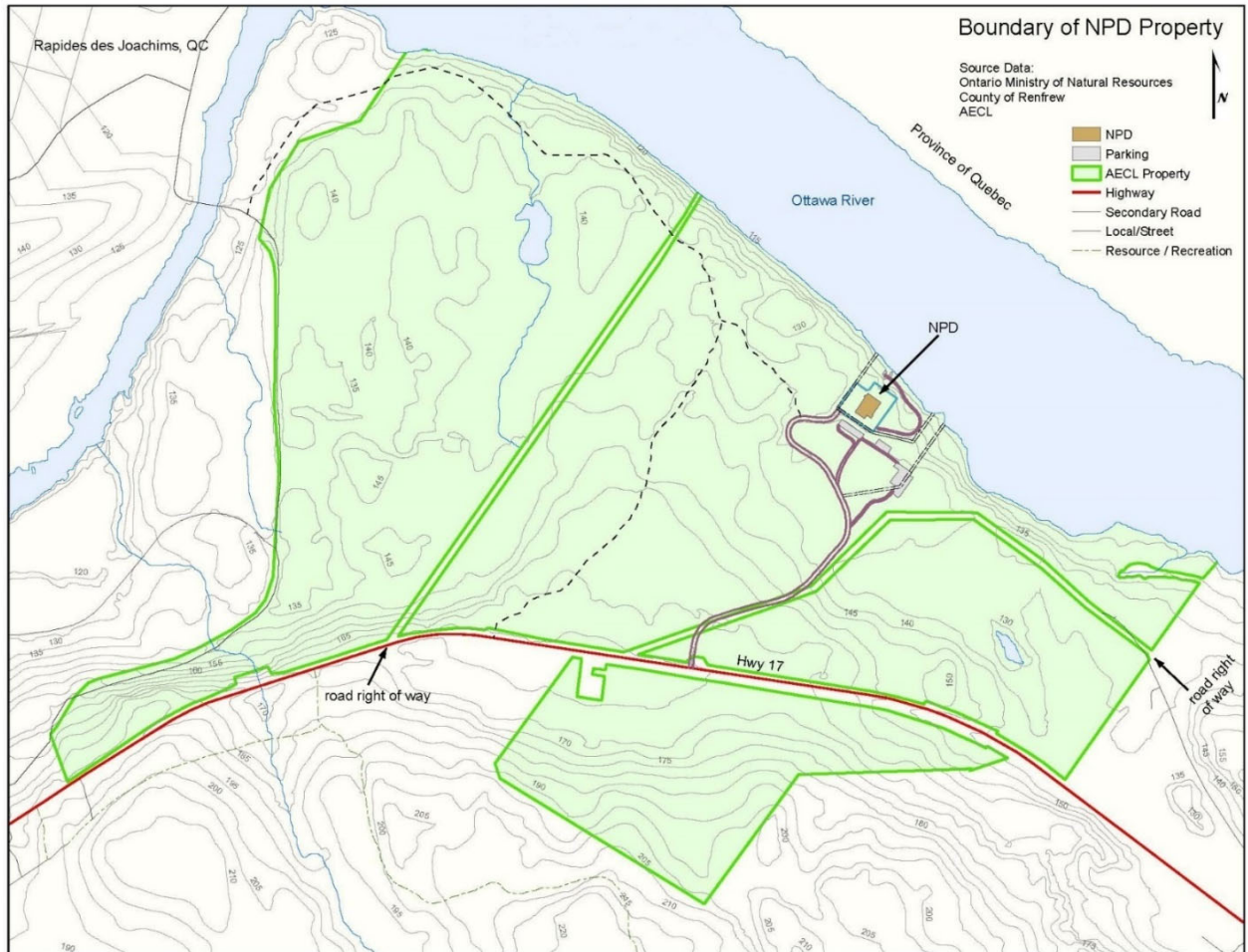
The NPD site is located near Rolphton, in Rolph Township, in the Town of Laurentian Hills in Renfrew County, Ontario, Canada. It is situated on the south bank of the Ottawa River, approximately 3 km downstream of the Des Joachims Dam, and approximately 25 km upstream of the Chalk River Laboratories (CRL) site. On the northeast side of the river is the province of Quebec. The centre of the site is located at approximately latitude 46°11'12" N, and longitude 77°39'28" W. The NPD facility occupies a small percentage (i.e. less than 1 percent) of the total NPD site area. See Figure 3-1 and Figure 3-2.

Figure 3-1 NPD Site Location (Titterington 2016)
(based on National Geographic Base Layer and Titterington 2016)



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Figure 3-2 NPD Site Vicinity (Titterington 2016)



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3.2 Site & Main Structures / Facilities

The current layout of buildings and foundations is discussed in the Project Description (Titterington 2016) and illustrated in Figure 3-3 and Figure 3-4. The current permanent structures at the NPD site are:

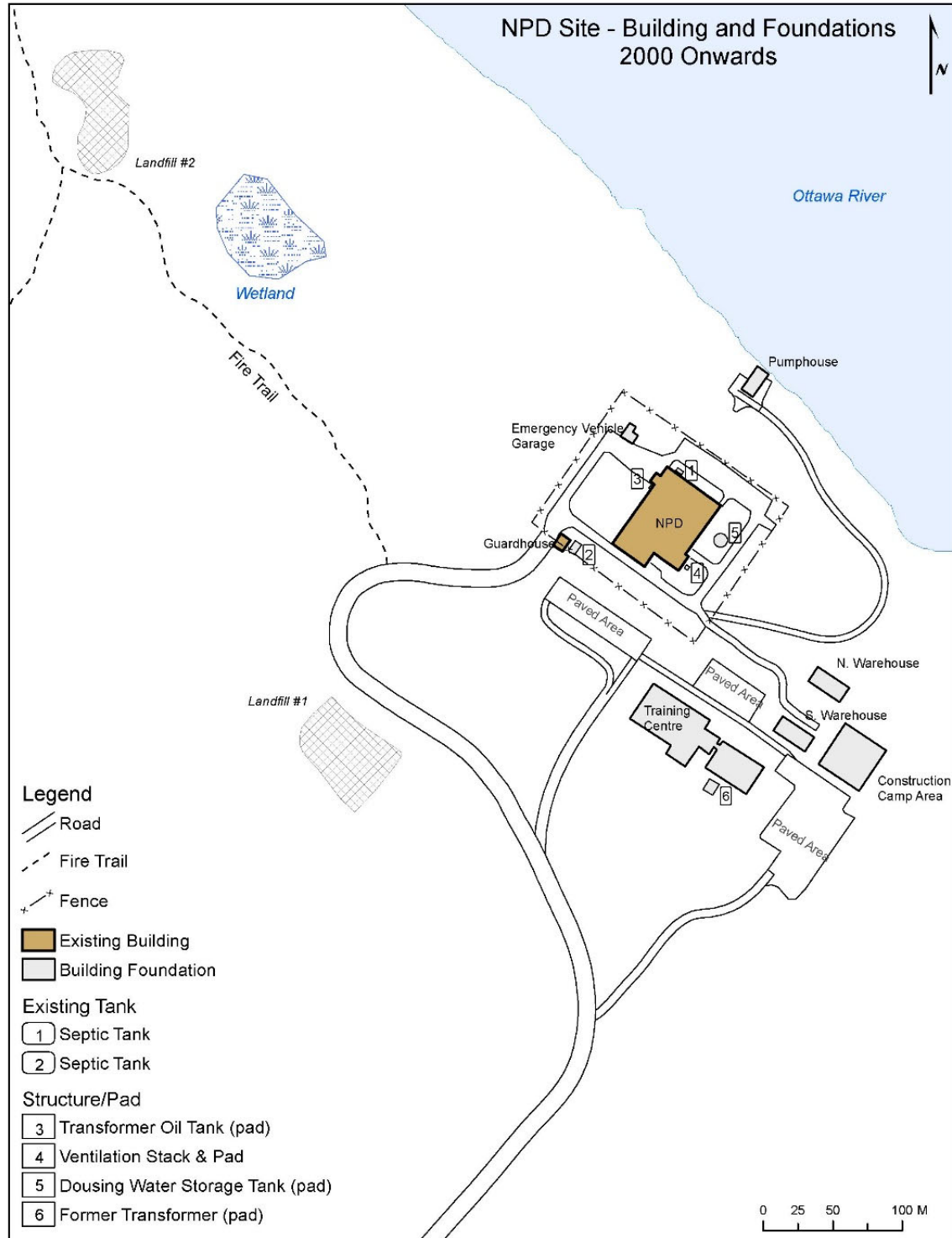
- Main Building – The purpose of the Main Building substructure is to house the reactor, its associated equipment, and to provide shielding and containment. It has a one-storey above ground structure with five levels below grade, and has a building area of approximately 2,600 m².
- Ventilation stack – The purpose of the ventilation stack is to discharge airborne effluent from the Main Building. The stack is a reinforced concrete structure 45.7 m high.
- Guardhouse – The purpose of the Guardhouse is to serve as an access control point into the fenced licenced area of the site. It is a standalone building at the entrance to the fenced area. It is a one-storey above ground structure with a building area of 80 m².
- Pressure Relief Duct – The former purpose of the pressure relief duct was to provide an emergency relief for steam from the boiler package. It is a reinforced poured concrete construction that extends below grade level.
- Diesel Generator Enclosure – The enclosure houses a diesel-generator set which provides emergency power to mitigate power interruptions at the facility.

There are also temporary facilities onsite such as sea containers and portable trailers and washrooms. A monitored security fence surrounds the licenced area of the site, and access is controlled (Aikens 2019).

Foundations from the previously removed pump house, emergency vehicle garage, training center, construction camps, warehouses, dousing tank, transformer and an administration wing remain onsite.

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Figure 3-3 NPD Site with Structures & Features (Titterington 2016)



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Figure 3-4 Photograph of NPD Site (Titterington 2016)
(Photo taken during SwS stage)



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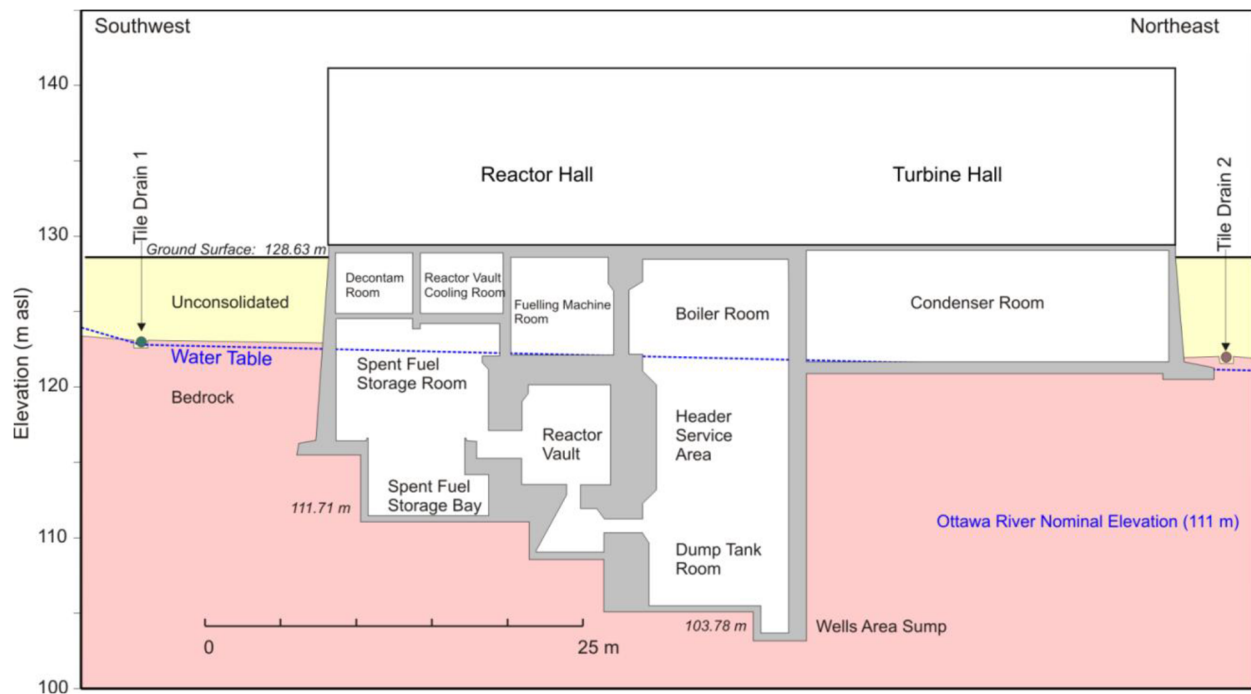
3.3 Main Facility – Construction

The NPD facility was constructed between 1956 and 1961. During construction, the landscape was significantly altered to create man-made terraces on which the buildings could be sited. The reactor building was constructed in a pit dug through the overburden and into bedrock. The concrete for the exterior walls was poured into a shuttered frame, leaving a gap between the rock/overburden and the exterior foundation walls of the facility. The gap between the building and rock/overburden was backfilled with lean concrete. Drains were constructed in the top surface of the bedrock to direct water away from the reactor building. In addition, a trench was excavated through the overburden, down to rockhead, for cooling water pipes that drew water from the river.

The main structure has one story above ground and five levels below ground. The above-ground portion consists of the reactor and turbine halls, flanked on the east by the service wing, and on the west by the control wing.

Figure 3-5 shows a cross-section view of the main structure, with elevation (note: two outer wings not shown).

Figure 3-5 Illustrative Cross-Section View of NPD Main Structure (Titterington 2016)



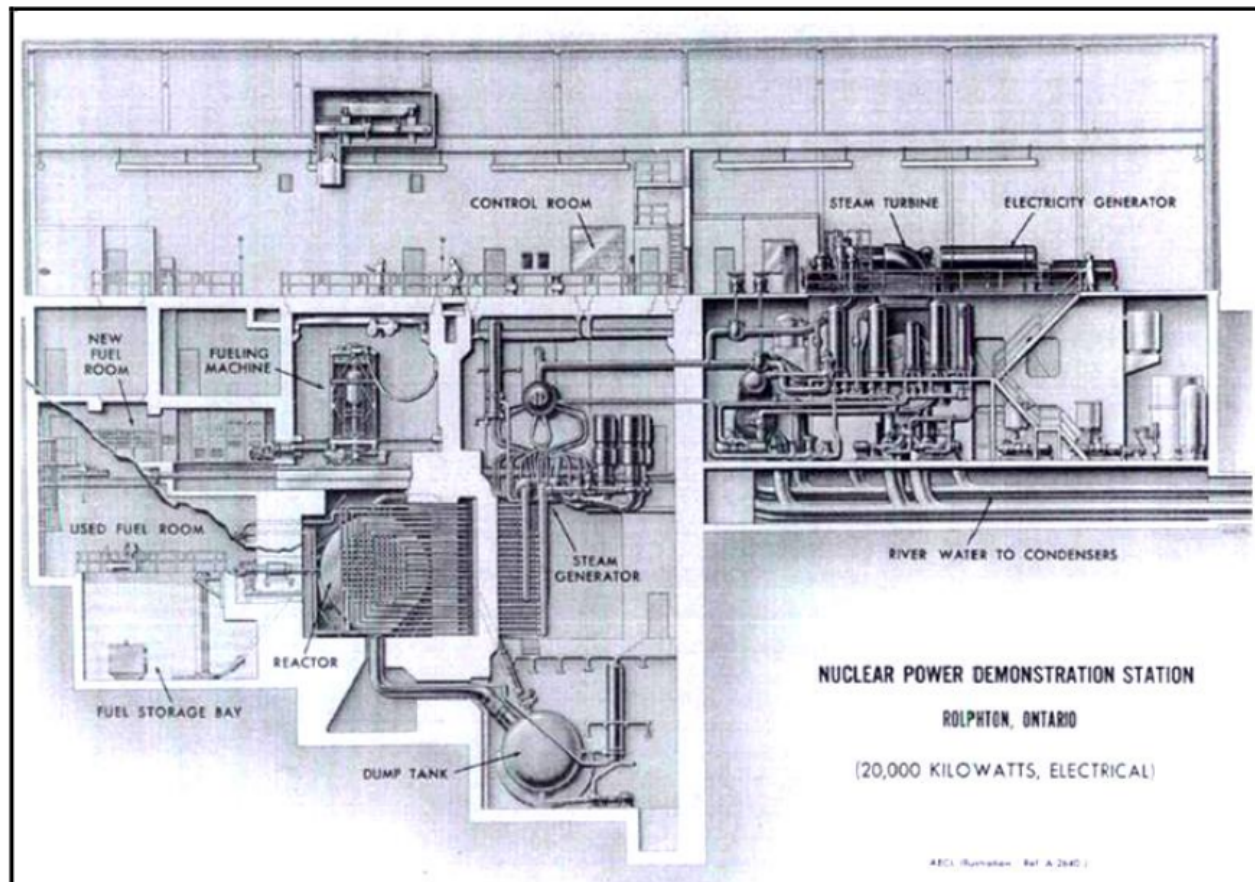
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3.4 Main Facility – Reactor Design

The reactor itself was a 20 MWe prototype for the CANDU reactor design, fueled primarily with natural uranium and was operated between 1962 and 1987. The reactor, heat transport system, turbine, and electrical power generator equipment are shown in Figure 3-6. The reactor core, or calandria, contains 132 horizontal pressure tubes in which fuel was inserted and was surrounded by the heavy water moderator. The calandria was constructed from aluminum and the fuel channels contained within are constructed of zircaloy with steel end fittings.

Figure 3-6 presents an illustrated cross-section of the facility, showing the main system components. Note the steam turbine, electricity generator and associated systems were removed during initial decommissioning activities (see Section 4.2 for more information).

Figure 3-6 NPD Cross Section Illustration Showing System Components



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4.0 REQUIREMENTS, CONTEXT, OVERALL METHODOLOGY

4.1 Regulatory Framework, Criteria, and EA Guidelines

4.1.1 Regulatory Framework

In brief, the NPD Closure Project (of which this DecomSA is a component) is undertaken to support completion of an EIS, as part of the Environmental Assessment (EA) process, under the *Canadian Environmental Assessment Act (CEAA)*. An EA under the *CEAA* is needed to obtain a decommissioning licence from the Canadian Nuclear Safety Commission (CNSC). The DecomSA supports the preparation of the DDP, which supports the licence amendment application. The CNSC communicates their requirements and expectations by way of regulatory guidance documents and EA Guidelines.

Further details regarding the licensing aspects of the NPD Closure Project can be found in the project's Licensing Plan (CNL 2016a).

4.1.2 CNSC Regulatory Guidance Documents

CNSC regulatory guidance documents are topic-specific technical documents that present general CNSC requirements and expectations, along with recommended approaches (methodologies) that can be followed to meet them.

Regulatory documents that are available from the CNSC on topics relevant to the DDP include:

- The June 2000 version of CNSC (2000a) Regulatory Guide G-219 – *Decommissioning Planning for Licensed Activities*.

Regulatory documents that are available from the CNSC on topics relevant to this DecomSA include:

- CNSC REGDOC-2.9.1, Version 1.1 (CNSC 2017) – *Environmental Protection: Environmental Policy, Assessments, and Protection Measures* (in particular, Appendix A.3.4 on Malfunctions & Accidents in the context of an EA).
- The May 2014 version of CNSC (2014) REGDOC-2.4.1 – *Deterministic Safety Analysis*.

- **REGDOC-2.9.1 Sec A.3.4:**
 - Assessment of radiological and non-radiological, health and environmental effects.
 - Description of postulated sequences leading to the release, considering, as appropriate:
 - internal events;
 - external events; and,
 - human-induced events.
 - Explanation of how these events were identified.
 - Description of frequencies.
 - Explanation of modeling.
 - Present mitigation measures.
 - Follow a bounding approach.

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Terminology – REGDOC-2.4.1

REGDOC-2.4.1 (CNSC 2014) groups events by frequency, into categories referred to as Anticipated Operational Occurrences (AOOs), Design-Basis Accidents (DBAs), and Beyond-Design-Basis Accidents (BDBs). Though terminology is different, the DecomSA's hazard identification process does include all events, using frequency ranks consistent with the facility SAR, which range from $> 3 \times 10^{-1}$ (i.e. corresponding to AOOs) to 10^{-6} (i.e. corresponding to BDBs). The identified hazard events (those shown in Appendix B) include AOOs, DBAs, and BDBs.

4.1.3 EA Guidelines

CNSC requirements and expectations are also communicated by way of issuing EA Guidelines. As part of the licensing process for EA-eligible projects, proponents submit a project description that undergoes review by the appropriate responsible authority; for the NPD Closure Project the responsible authority is the CNSC.

The CNSC has issued *Generic Guidelines for the Preparation of an Environmental Impact Statement* (CNSC 2016) to CNL for the NPD decommissioning project.

4.1.4 CSA Guidance

The primary CSA guidance document that has broad (high-level) applicability to the DecomSA is the June 2014 reaffirmed version of CSA (2009) N294 – *Decommissioning of Facilities Containing Nuclear Substances*. The CSA (2009) N294 standard provides high-level guidance on safety assessment in support of decommissioning, but provides valuable guidance for preparation of the DDP.

4.1.5 Radiological Dose Criteria / Acceptance Criteria

Normal Operations Assessment:

Dose/acceptance criteria for assessing normal operations are obtained from the relevant legislation (CNSC 2015); these are outlined in Table 4-1 below.

Table 4-1 Dose Acceptance Criteria – Normal Operations (CNSC 2015)

Application	Nuclear Energy Worker (NEW) Dose Criteria (Occupational)	Public Dose Criteria
Effective Dose	<ul style="list-style-type: none"> 50 mSv/yr; and, 100 mSv per 5 years. 	1 mSv/yr
Annual equivalent dose in:		
Lens of the eye	150 mSv	15 mSv
The Skin	500 mSv	50 mSv
The hands and feet	500 mSv	50 mSv

Note: for pregnant nuclear energy workers (NEWs), the annual effective dose limit is 4 mSv/yr.

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Accidents Assessment:

Dose/acceptance criteria for assessing accidents are obtained from the existing facility SAR (Athauda-Arachchige 2015); these are outlined in Table 4-2 below. These dose criteria depend on the frequency with which a receptor is exposed. Four event frequency ranges (with an associated dose band) define the accident. The upper bound of the dose band is considered as the safety goal, while the lower bound is considered as the safety target. Predicted doses below the safety target are acceptable, while doses above the safety target must be justified. Doses in excess of the safety goal are unacceptable.

Table 4-2 Dose Acceptance Criteria – Accidents (based on Athauda-Arachchige 2015)

Frequency Range (Events/year)	Description of Event Occurrence	Dose Range (mSv)	
		On-Site Personnel (Workers)	Off-Site Personnel (Public)
$>3 \times 10^{-1}$	Frequent ; Events that are expected to occur several times during the lifetime of the facility (e.g. frequency of approx. 1 every 3 years)	<1	<0.1
3×10^{-1} to 3×10^{-2}	Occasional ; Events may occur a few times during the lifetime of the facility. (e.g. frequency of approx. 1 every 3 years to 1 every 30 years)	1 to 5	0.1 to 0.5
$<3 \times 10^{-2}$ to 10^{-4}	Rare ; Events have slight chance of occurring during the lifetime of the facility. (e.g. frequency of approx. 1 every 30 years to 1 every 10,000 years)	>5 to 50	>0.5 to 5.0
$<10^{-4}$ to 10^{-6}	Extremely Rare ; Events are not expected to occur during the lifetime of the facility. (e.g. frequency of approx. 1 every 10,000 years to 1 every 1,000,000 years)	>50 to 100	>5 to 100

Note:

Frequency ranges for rare and extremely rare events have been adjusted to avoid overlapping of these frequency ranges.

Lifetime of the facility includes decommissioning, but excludes post-closure.

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4.1.6 Non-Radiological Benchmarks

The following non-radiological contaminants are identified for assessment of health effects on human receptors, based on information in Titterington (2016), the chemical inventory of the facility, and, on the nature of bounding scenario events (e.g. combustion products from fires):

- Lead;
- Mercury;
- Asbestos;
- PCBs (assumed >54%Cl);
- Dioxins and Furans (byproducts of PCBs combustion - *assessed for fire-related accident scenarios only*).

For non-radiological contaminants, calculated concentrations are compared to concentration criteria (outlined in the following subsections) to determine if adverse effects are anticipated. This is typically accomplished by dividing the concentration by the corresponding criterion, producing a value known as a screening index. Screening indices less than 1 indicate that the estimated concentration is less than the corresponding concentration criterion, and therefore adverse effects are not anticipated.

It is acknowledged that non-radiological criteria focus on airborne releases. This is due to the types of releases anticipated as part of normal decommissioning, the nature of the facility, and the exposures involved in normal operations and accidents (these topics are discussed in Sections 7.0, 8.0, and 9.0).

4.1.6.1 Criteria for Normal Operations Assessment:

Worker Receptors

For normal operations, Table 4-3 below presents the non-radiological criteria used to assess worker exposure to airborne levels of contaminants. These are based on the criteria recommended in the Canada Labour Code's *Canada Occupational Health and Safety Regulations* (Part 10.19(1)) [Government of Canada, 2019]. For all contaminants, the regulation recommends use of Threshold Limit Values (TLVs) from the American Conference of Governmental Industrial Hygienists (ACGIH).

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Table 4-3 Non-Radiological Criteria – Worker Receptors – Normal Operations

Chemical	Benchmark Value	Reference
Mercury	0.025 mg/m ³ [TLV for elemental and inorganic mercury; 8-hour Time Weighted Average (TWA)]	ACGIH 2017
PCB	0.5 mg/m ³ [TLV for chlorodiphenyl (54% chlorine) PCB; 8-hour TWA]	ACGIH 2017
Asbestos	0.1 fiber/cm ³ [Converted to mg/m ³ using 0.003 µg asbestos per 100 fibres (COEHHA 2009)]	ACGIH 2012
Lead	0.05 mg/m ³ [TLV for inorganic lead (as Pb); 8-hour TWA]	ACGIH 2017

Public Receptors

For normal operations, Table 4-4 below presents the non-radiological criteria used to assess public exposure to airborne levels of contaminants.

Due to the facility’s location near the border of Ontario and Quebec, ambient air quality criteria from the province of Quebec and the Province of Ontario were both considered. The Quebec (MELCC 2018) ambient air quality criterion for lead (i.e., 1.00E-04 mg/m³) is more conservative than the Ontario (MOE 2012) ambient air quality criterion for lead (i.e., 2.00E-04 mg/m³), therefore the more conservative MELCC (2018) air criterion was chosen.

Table 4-4 Non-Radiological Air Criteria – Public Receptors – Normal Operations

Chemical	Benchmark Value [mg/m ³]	Notes	Reference
Asbestos	1.20E-03*	Most conservative criterion: 0.04 fibres/cm ³ , 24-hour averaging time, protection of health	MOE (2012) Ambient Air Quality Criteria
Lead	1.00E-04	Most conservative criterion: 0.1 µg/m ³ , annual averaging time, protection of health	MELCC (2018) Ambient Air Quality Criteria

Notes:

Converted to mg/m³ using 0.003 µg asbestos per 100 fibres (COEHHA 2009)

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For normal operations, Table 4-5 below presents the non-radiological criteria used to assess public exposure to contaminants in soil.

Soil Criterion

In response to specific feedback on the 2017 version of the DecomSA, lead in airborne releases during normal operations is additionally assessed for potential soil deposition and accumulation. A soil criterion is therefore needed, such that a comparison can be made between estimated soil concentrations and a soil benchmark value. Table 4-5 below presents the soil criterion used to assess public exposure to lead concentrations in soil.

Note that soil criteria from the province of Quebec were also considered based on the information presented online at MELCC (2019). However, the MELCC (2019) soil criterion for lead (i.e. 500 µg/g) is less conservative than the Ontario (OMOE 2011) soil criterion for lead (i.e. 120 µg/g), therefore the more conservative OMOE (2011) soil criterion was chosen.

Table 4-5 Soil Criterion for Lead

Chemical	Benchmark Value [ug/g]	Notes	Reference
Lead	120	Soil (other than sediment) Residential/Parkland/Institutional/Industrial/ Commercial Community Property Use for properties within 30 m from a water body; For human health and ecological protection	Table 8 of OMOE (2011).

4.1.6.2 Criteria for Accidents Assessment:

Worker Receptors

For worker receptors, the chosen benchmarks (see Table 4-6 below) are the Immediately Dangerous to Life or Health (IDLH) values. Where IDLH values were unavailable, the public PAC-1 values, as described below, were used.

Table 4-6 Non-Radiological Criteria – Worker Receptors – Accidents

Chemical	Benchmark Value	Reference
Mercury Vapour	10 mg/m ³	IDLH (NIOSH 2016a)
PCB	13 mg/m ³	IDLH value not available. Public PAC-1 value used to fill gap.
Dioxins & Furans (as TCDD)	0.00013 mg/m ³	IDLH value not available. Public PAC-1 value used to fill gap.
Asbestos	0.05 mg/m ³	IDLH value not available. Public PAC-1 value used to fill gap.
Lead	100 mg/m ³	IDLH (NIOSH 2016b)

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Public Receptors

The benchmarks selected for assessing public receptors' short-term exposure to non-radiological substances during accident/emergency scenarios are the U.S. DOE Protective Action Criteria (PACs) (US DOE 2016). PACs are developed and maintained by the U.S. Department of Energy (DOE) / National Nuclear Security Administration (NNSA). PACs are a comprehensive set of *short-term public exposure guidelines for accident/emergency scenarios*, based on hierarchical selection of criteria from among U.S. Environmental Protection Agency AEGLs (Acute Exposure Guideline Levels), American Industrial Hygiene Association one-hour ERPGs (Emergency Response Planning Guidelines), or internal TEELs (Temporary Emergency Exposure Limits) where AEGLs or ERPGs are not available.

Three categories of PAC values are tabulated by the US DOE (PAC-1, PAC-2, PAC-3), with PAC-1 values correspond to the least severe effects. PAC-1 criteria are compiled from among AEGL-1, ERPG-1, and TEEL-1 values (depending on availability for a given substance). US DOE guidance is to use PAC values based on 1-hour AEGL values, where available. AEGL-1 values are airborne concentrations of a substance above which it is predicted that the general population, including susceptible individuals, could experience notable discomfort, irritation, or certain asymptomatic, nonsensory effects - however, these effects are not disabling and are transient and reversible upon cessation of exposure. In this assessment, PAC-1 values are chosen as the criteria for assessing short-term public exposures during accident scenarios. PAC-1 values are more protective than PAC-2 and PAC-3 values.

Table 4-7 presents the criteria for public receptors.

Table 4-7 Non-Radiological Criteria – Public Receptors - Accidents

Chemical	PAC-1 Criteria (US DOE 2016) [in mg/m ³]	Notes (US DOE2016)
Mercury^a	0.15	The PAC-1 value for mercury vapour is based on the AEGL-2/11 value.
PCBs^b	13	The PAC-1 value for PCBs is based on the TEEL-2/11 value.
Dioxins & Furans^c	0.00013	The PAC-1 value is based on TEEL-2/11 value for TCDD.
Asbestos	0.05	The PAC-1 value for asbestos is based on the PEL-STEL value.
Lead	0.15	PAC-1 value based on TLV-TWA x 3

Notes:

^a As mercury vapour; Hg₂O is not stable.

^b US DOE 2016 generic value for PCBs/Aroclor.

^c As 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD).

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Dioxins & Furans

Public (and worker) benchmark criteria for dioxins and furans are based on TCDD. Table 4-8 presents the toxic equivalence factors (TEQs) for other dioxin and furan congeners based on US EPA (2010). As shown in Table 4-8, TCDD has the highest toxic equivalent ratio (i.e. 1.0) among congeners. Therefore, it is conservative to use TCDD as the representative dioxin and furan compound.

Table 4-8 TEQs for Dioxin & Furan Congeners

Dioxins		Furans	
Congeners	Toxic Equivalence Factor	Congeners	Toxic Equivalence Factor
2,3,7,8-TCDD	1	2,3,7,8-TCDF	0.1
1,2,3,7,8-PeCDD	1	1,2,3,7,8-PeCDF	0.03
-	-	2,3,4,7,8-PeCDF	0.3
1,2,3,4,7,8-HxCDD	0.1	1,2,3,4,7,8-HxCDF	0.1
1,2,3,6,7,8-HxCDD	0.1	1,2,3,6,7,8-HxCDF	0.1
1,2,3,7,8,9-HxCDD	0.1	1,2,3,7,8,9-HxCDF	0.1
-	-	2,3,4,6,7,8-HxCDF	0.1
1,2,3,4,6,7,8-HpCDD	0.01	1,2,3,4,6,7,8-HpCDF	0.01
-	-	1,2,3,4,7,8,9-HpCDF	0.01
OCDD	0.0003	OCDF	0.0003

Notes:

A dioxin counterpart does not exist for every furan congener because the dioxin structure is more symmetric than the furan structure.

Soil Criterion

In response to specific feedback on the 2017 version of the DecomSA, lead in airborne releases during accident scenarios is additionally assessed for potential soil deposition and accumulation. A soil criterion is therefore needed, such that a comparison can be made between estimated soil concentrations and a soil benchmark value. The same soil criterion from normal operations is used for accidents - see earlier Table 4-5.

4.2 Decommissioning Plan & Project Description

CNL's project description (Titterington 2016) describes, at a high-level, the proposed decommissioning for the NPD site. Detailed descriptions are available in the project's Detailed Decommissioning Plan (DDP) (Aikens 2019).

The NPD site is being decommissioned in a phased manner. CNL has chosen a decommissioning strategy that is considered to minimize both the occupational radiation dose to staff, and the potential exposure of the public and the environment due to radioactive decay of

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short-live fission and activation products that remain on site. Conceptually, the process can be divided into three general phases:

- **Phase I** – Establishment of a Safe, Sustainable, Shutdown State;
- **Phase II** – Storage with Surveillance (the current facility state, pre-decommissioning); and,
- **Phase III** – Final Decommissioning. Including:
 - Execution Phase; and
 - Closeout Phases.

Brief descriptions of each phase are as follows.

Phase I: Establishment of a Safe, Sustainable, Shutdown State (Seto 2015)

The scope of Phase I decommissioning includes all work to achieve the SwS state and included the following major activities:

- Shutdown and drain all redundant process systems (including removal of all fuel and heavy water);
- Shutting down and disconnecting all services with the exception of those required for the SwS state such as electrical, ventilation, heating, and fire detection/alarm systems etc.;
- Decontamination of structures, systems and equipment when required;
- Removal of redundant systems, piping, wiring, conduit, structures and equipment (Non-Nuclear Area);
- Draining of the Spent Fuel Storage Bay pool water;
- Remediation of any impacted areas in the Non-Nuclear Area;
- Dismantling and removing redundant process equipment (Non-Nuclear Area);
- Demolishing redundant buildings;
- Segregating waste materials;
- Packaging and transferring decommissioning wastes to the CRL Waste Management Area (WMA) or other approved waste facilities for storage; and
- Perform interim end-state survey.

Phase I decommissioning was achieved by the early 1990s (Seto 2015).

Phase II: Storage with Surveillance

Phase II is a SwS period throughout which the remaining NPD site facilities are monitored and maintained prior to final decommissioning. Activities conducted during the SwS period consist primarily of maintaining services and systems (e.g. fire protection, alarm systems), routine inspections and monitoring, and pre-decommissioning preparatory work (e.g. conducting radiological surveys, removal of combustible material, improving the facility's industrial hygiene, etc.). More detail is provided in the facility's SwS Plan (Luiz, 2016).

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Phase III: Final Decommissioning

This DecomSA will support CNL's decommissioning of the site as part of Phase III, along with the projects DDP.

As outlined in the recent project description (Titterington 2016) and in the updated Alternative Means Assessment TSD (Garisto & McKee, 2019), ISD has been selected as the preferred method for carrying out Phase III final decommissioning. CNL's proposed ISD activities in Phase III generally include the following:

- Execution Phase:
 - Assembly and operation of grout batch mixing plant;
 - Grouting of lower areas of the below grade structures;
 - Demolition of above grade structures and emplacement within the below grade structures;
 - grouting in place; and,
 - Installation of a concrete cap and engineered barrier (resulting in an aboveground mound and underground monolith).
- Closeout Phases:
 - Final site restoration; and
 - Long-term care and maintenance activities.

The decommissioning plan concludes with execution and closeout on impacted lands, which will remain the property of Atomic Energy of Canada Limited (AECL).

4.3 Existing Safety Assessment Report & Safety Records

A safety analysis has been prepared for the NPD facility's current SwS state in Athauda-Arachchige (2015). The facility SAR (Athauda-Arachchige 2015) covers normal operations, AOOs, and accidents. It encompasses the existing buildings at the NPD site that are within the licensed area, including the main building, ventilation stack, guardhouse, diesel generator enclosure, and pressure relief duct. The events analyzed in this safety analysis include both internal events (e.g. operator error, equipment failure and internal fire) as well as external events (e.g., earthquake, extreme weather conditions and external fire).

It is important to note however, that the facility SAR (Athauda-Arachchige 2015) is based on the operations and activities of the SwS state, and therefore, it does *not* cover decommissioning activities.

Nevertheless, the facility SAR (Athauda-Arachchige 2015) contains site-specific information on topics such as meteorology, extreme weather conditions, hydrology, geology and seismicity, and, forest fires that are relevant for this report. It also outlines CNL's dose acceptance criteria.

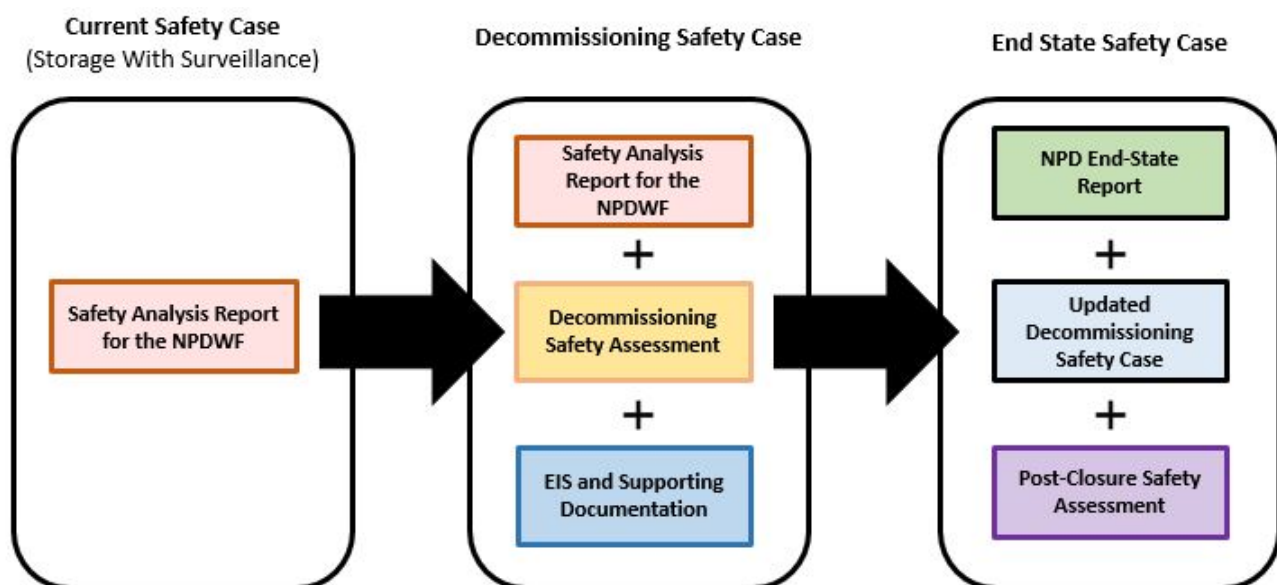
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Also available as a source of safety information is the Seto (2014) *Operational Incidents and Accidents in NPD* report. Seto (2014) documents a high-level review of facility annual reports, significant event reports, event notifications, and operation records from throughout the NPD SwS period and compiles a list (with brief descriptions) of any notable leaks, spills, fires, or other incidents that may have resulted in the release or spread of non-radiological/radioactive contamination. It also contains a list of notable historical events from 1962 to 2013 (i.e. encompassing the operating phase of the NPD facility) involving fuel failures, fuel damage, and leaks of oil, light and heavy water. However, it is important to note that the Seto (2014) list is not exhaustive and there may be events not detailed or identified in Seto (2014).

Relationship Between Safety Assessments

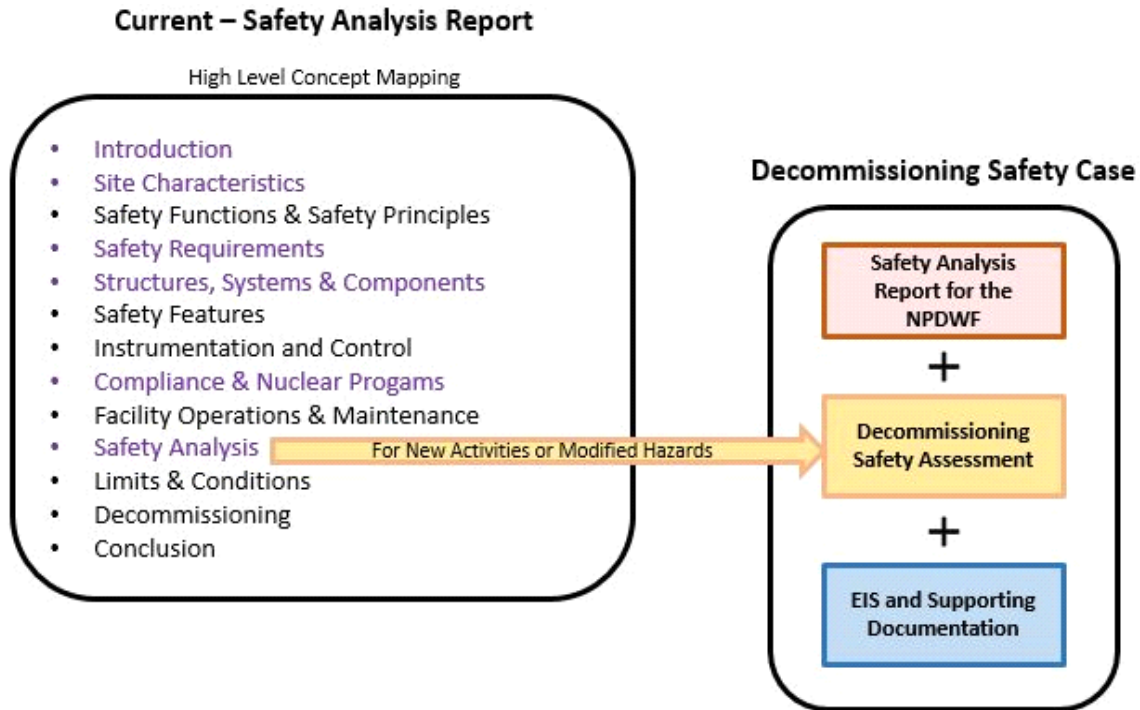
The facility SAR (Athauda-Arachchige, 2015; referred to as the ‘facility SAR’) includes an analysis of the NPD facility in its current SwS state, and associated activities (which could be considered ‘baseline safety’). The DecomSA (this report) addresses the new proposed decommissioning activities. The DecomSA is not intended to be a replacement of the facility SAR, rather it complements the facility SAR by focusing on the new circumstances created by decommissioning activities that would not otherwise be covered by the facility SAR analyses, and, to incorporate new information available since the release of the facility SAR. In this way, the DecomSA could be considered ‘incremental activities safety analysis’. Figure 4-1 and Figure 4-2 provide a schematic representation of the relationship between the facility SAR and the DecomSA, along with some key areas covered. Appendix G provides a table comparing the scenarios assessed in the facility SAR versus those assessed in this DecomSA.

Figure 4-1 Overview of the NPD Safety Case



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Figure 4-2 Closer Look at Decommissioning Safety Case



It is acknowledged that the DecomSA does overlap the facility SAR in some areas, this occurs because certain events, components, or hazards are present in the SwS state and in the decommissioning state, but these require re-evaluation focusing on decommissioning in particular. A key item for decommissioning is that many of the safety related systems credited in the facility SAR will be deactivated and removed as part of planned decommissioning (examples include deactivation of the ventilation system, removal of the fire detection system, and deactivation of alarms as power is disconnected from the facility). Overall, the DecomSA's analyses help to ensure that the safety of the planned decommissioning activities is within the overall safety envelope defined by the facility SAR. The facility SAR is updated periodically to ensure that it reflects the conditions of the facility and its surroundings, such as once the decommissioning end state is achieved.

4.4 Requirements for the Decommissioning Safety Assessment

The following list outlines key information that is required for successful completion of the DecomSA. These are largely documents that outline any *site-specific* requirements that the DecomSA must meet, the activities that the DecomSA must encompass, and the response capabilities available at the site.

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1. Project Description

The project description provides a high-level overview of the main aspects of the project, and is provided to regulators for review. CNL's project description (Titterington 2016) provides broad descriptions of the proposed in-situ disposal for the NPD site, such as context, project objectives, and brief high-level outline of physical project works.

2. CNSC EA Guidelines for the NPD Closure Project

EA guidelines are issued by the CNSC in response to a proponent's project description submittal. While EA guidelines are issued primarily to outline requirements for the EIS, some of these requirements will be relevant to (or need to be addressed by) the DecomSA.

3. Detailed Decommissioning Plan

The DDP for the facility contains crucial information for the DecomSA because it outlines what decommissioning activities are planned, what they involve, where they occur, and how they are to be executed. These are the activities that the DecomSA must assess. Hazardous events, scenarios, and all resulting assessment information is derived ultimately from the activities described in the DDP. The list of planned activities in Table 7-2 and Table 7-3 are the tasks assessed in the DecomSA. The DDP was prepared in parallel with the DecomSA in an iterative manner.

4. Design Documents

Design documents for the facility are the preferred source for geometries and dimensions, though a 3D model was also prepared. These are useful, for example, to understand room volumes, heights, and clearances. They also provide reference information on engineered safety systems, barriers, or containment structures.

5. Inventories (Radiological and Non-Radiological)

The radiological and non-radiological (e.g. PCBs, mercury, lead, etc.) inventory of the facility is of great importance for this safety assessment. The location(s) of the inventory are also important because this would be combined with information on the planned decommissioning activities to obtain an understanding of material handling doses by-location. Information on other substances - not only designated substances - and their quantities is also important, for example, fuel tanks for equipment.

6. Equipment

Information on anticipated equipment, vehicles, and machinery is also important for the DecomSA because these will affect hazard identification and subsequent scenarios. This includes for example, information on trucks, forklifts and cranes.

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7. Facility Ventilation

Information on facility ventilation is important for the DecomSA because there may be the need to calculate the concentration of airborne releases inside the facility. The influence of air exchanges, and any air filtration capabilities, would need to be incorporated.

8. Emergency Response or Incident Response Capabilities

It is important to understand the response capabilities that will be available for decommissioning because these will likely have important preventative or mitigative influence on accidents. Information includes for example, emergency/incident response plans, response times, response equipment (and its location), fire suppression systems/capabilities, etc.

4.5 Overall Methodology, Key Models & Codes

4.5.1 Key Models

Common tools (models) and technical guidance documents used in performing accident assessment and general quantitative risk assessment are summarized in Appendix A.

For normal operations, the same models are applied (namely, dispersion models) but with parameter values appropriate for normal operations (e.g. dispersion factors and acceptance criteria).

4.5.2 Key Codes (Software)

In addition to the models outlined in Section 4.5.1 above, the following codes (i.e. computer software) are acknowledged as key tools for use in this DecomSA.

AERMOD

AERMOD is a steady state Gaussian plume dispersion model developed by the AMS/EPA Regulatory Model Improvement Committee (AERMIC). AERMOD can be used to assess pollutant concentrations from a wide variety of complex industrial settings including multiple stacks, fugitive emissions, and building wake effects. The AERMOD model is the regulatory model currently recommended by the U.S. EPA and the MOECC for simulating short-term air quality impacts from industrial complexes. The AERMOD Modelling System consists of two pre-processors (AERMET and AERMAP) and the dispersion model AERMOD. In AERMOD, basic boundary layer parameters are calculated from the raw upper air data and are used to control the vertical travel of the pollutant plume. The stability is described by the Monin-Obukhov (M/O) length. The M/O length is a function of the surface roughness, the surface albedo (reflectivity) and surface soil moisture content as well as the upper air data.

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AERMOD is used to model the dispersion of atmospheric releases (according to its capabilities above), in order to derive atmospheric dispersion factors. AERMOD is also used to perform air quality assessment aspects.

CALPUFF

CALPUFF is an advanced meteorological and air quality modeling system developed by Earth Tech Inc. and Exponent Inc.'s scientists (<http://www.src.com/calpuff/calpuff1.htm>). CALPUFF is a multi-layer, multi-species, non steady-state Lagrangian puff dispersion model that can simulate the effects of temporally and spatially varying meteorological conditions on pollutant transport. Dispersion is simulated for discrete "puffs" of species emitted from modeled sources. The puffs are tracked until they have left the modelling domain while calculating dispersion, transformation and removal along the way. CALPUFF can be applied on scales of tens to hundreds of kilometers. It includes algorithms for subgrid scale effects (such as terrain impingement), as well as, longer range effects (such as pollutant removal due to wet scavenging and dry deposition, chemical transformation, and visibility effects of particulate matter concentrations). CALPUFF is maintained by the model developers and distributed by Exponent. The model has been adopted by the U.S. Environmental Protection Agency (USEPA) in its Guideline on Air Quality Models as the preferred model for assessing long range transport of pollutants and their impacts on Federal Class I areas and on a case-by-case basis for certain near-field applications involving complex meteorological conditions.

CALPUFF is used as a supplementary tool to model the dispersion of atmospheric releases (according to its capabilities above), in order to derive atmospheric dispersion factors.

Microsoft Excel

Microsoft Excel is used to perform the majority of source term release and dose calculations in this DecomSA. Calculations in Excel also integrate outputs from other models (e.g. from air modelling), organize hazard scenarios based on consequence and frequency scores, and calculate corresponding risk results.

MCNP

MCNP is a general-purpose Monte Carlo code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. Specific areas of application include, but are not limited to, radiation protection and dosimetry, radiation shielding, and medical physics.

In the DecomSA, MCNP is used to perform a dose modelling calculation for drilling (described in Appendix D).

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4.5.3 Overall Methodology

The DecomSA methodology involves two main components: assessment of normal decommissioning operations; and, assessment of accidents that could potentially occur during decommissioning.

For assessing accidents, the methodology involves (at a high level – consistent with Section 4.5.1) identifying hazards and associated scenarios, and assessing the risk from these scenarios by accounting for both their frequency and their potential consequences.

For assessing normal operations, the methodology involves (at a high level) identifying scenarios representing normal operations, estimating doses (radiological and non-radiological), and comparing these estimates to corresponding benchmarks/limits.

It is also important to understand that this DecomSA is prepared to support an EIS and for the NPD closure project under the Canadian Environmental Assessment Act (CEAA), and, to support the parallel preparation of the DDP. EISs under the CEAA contain specific sections to address ‘malfunctions and accidents’ (M&As). Therefore, the accidents assessment in this DecomSA involves – to the extent possible - the CEAA EIS methodology for addressing malfunctions and accidents.

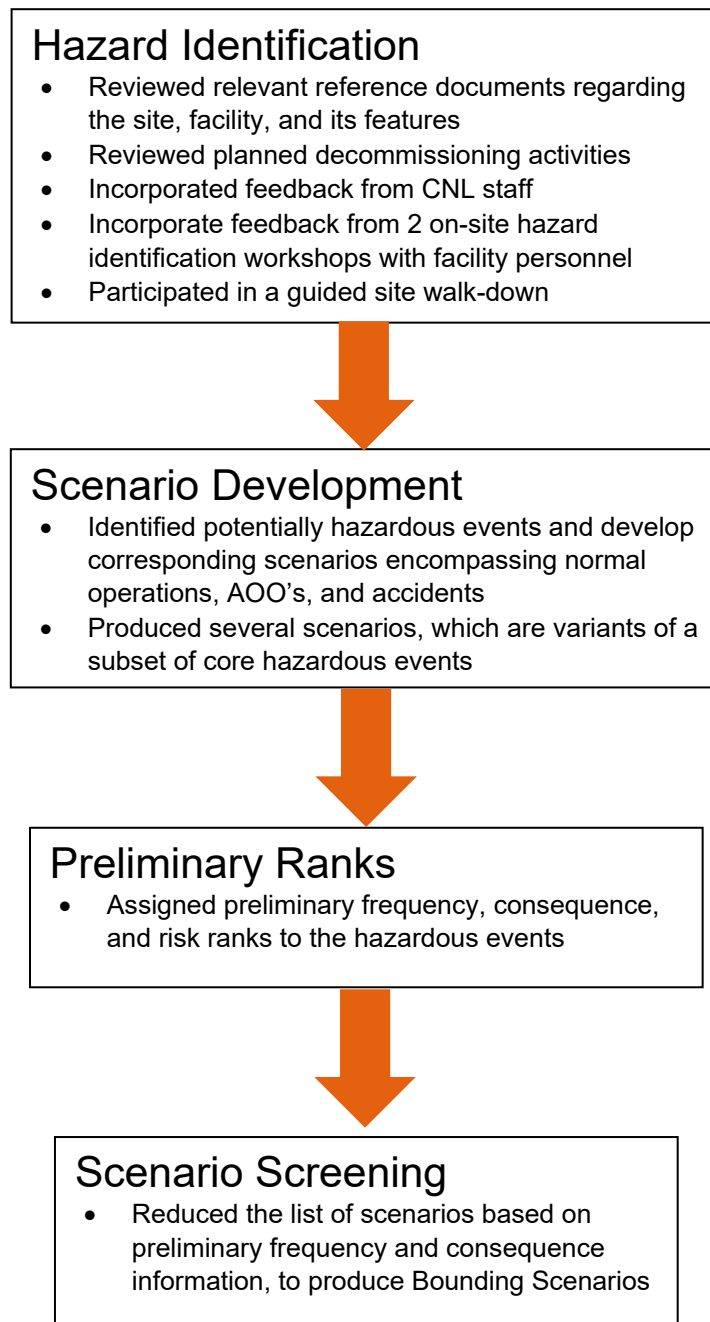
This results in the following overall methodology (outlined below). Additional detail (such as detailed descriptions, detailed methods, justifications, etc.) is provided in subsequent sections of this report).

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1. Hazard Identification & Scenario Development:

Figure 4-3 describes the process used for hazard identification and scenario development.

Figure 4-3 Hazard Identification and Scenario Development Process



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2. Normal Operations Assessment (for applicable normal operating scenarios). Which included:

- a. Outlining receptors and environmental components/media, and potential types of effects;
- b. Outlining study boundaries;
- c. Estimating releases and corresponding doses (radiological and non-radiological) to receptors;
- d. Identifying dose benchmarks/limits; and,
- e. Comparing dose estimates to dose benchmarks/limits.

3. Accidents Assessment (including AOOs) (for applicable bounding accident scenarios):

a. Scoping Stage. Which included:

- i. Characterize receptors and potential types of effects;
- ii. Identify corresponding initiating events (for bounding scenarios); and,
- iii. Outline study boundaries.

b. Analysis Stage. Which included:

- i. Frequency Assessment

Frequency assessment involved quantitatively defining frequencies for each identified bounding scenario (encompassing initiating event frequency and conditional probabilities, where possible).

- ii. Consequence Assessment

Consequence assessment involved performing source term characterization for the identified bounding scenarios, defining consequence criteria (those in Sections 4.1.5 and 4.1.6), and quantitatively estimating the resulting doses to receptors for applicable bounding scenarios.

c. Mitigation Stage. Which included:

- i. Preventative Measures

Involved identifying and outlining relevant preventative measures, and linking these measures to corresponding risk results such that their influence can be understood.

- ii. Mitigation Measures

Involved identifying and outlining relevant mitigation measures, and linking these measures to corresponding risk results such that their influence can be understood.

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d. Significance Stage. Which included:

- i. Performing risk calculations;
- ii. Defining risk criteria; and,
- iii. Comparing risk results to risk criteria, to determine significance.

e. Follow-Up Stage. Which included:

- i. Identify and describing any applicable follow-up actions.

4.6 Human Receptors

Human receptors assessed in this DecomSA include workers and members of the public.

Worker Receptors:

It is assumed that all worker receptors (including contractors) that perform work within the fenced licensed area are Nuclear Energy Workers (NEWs).

Public Receptors:

Public receptor locations were obtained from the existing site *Derived Release Limit* (DRL) Report (Chouhan 2016b), and, from information on nearby land users, obtained from NPD site staff.

Receptor locations from the DRL (Chouhan 2016b) included: Rapides des Joachims residential, Point Stewart residential, Cottage, Rolphton residential, Mackey beef farm, and Bass Lake beef farm. The remaining receptor locations include: Residential (R1), Residential (R2), Residential (R3), Recreational (R4), and the Guardhouse. Note that Residential R1 to R3 and Recreational R4 were added to represent additional nearby properties and a recreational area. The Guardhouse was added to represent the fenced boundary of the licensed area within the NPD property.

Table 4-9 outlines these receptors, as well as their locations, distance, and direction from the NPD Facility. Figure 4-4 shows the receptor locations graphically.

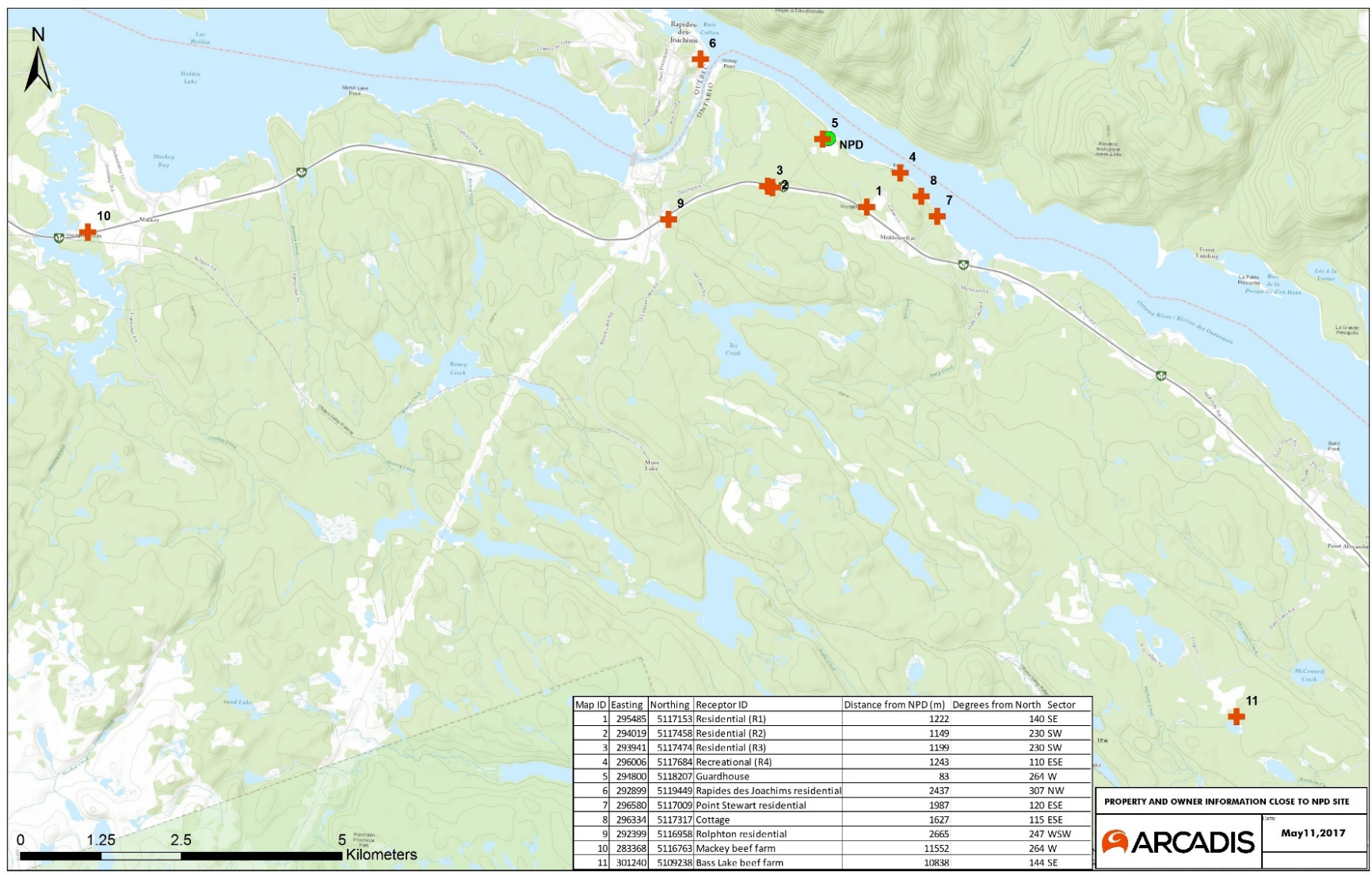
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Table 4-9 Receptor Locations

Discrete Receptors			Location relative to the NPD Facility		
Easting (m)	Northing (m)	Receptor ID	Distance from NPD (m)	Direction	
				Degrees from North	Sector
295485	5117153	Residential (R1)	1222	140	SE
294019	5117458	Residential (R2)	1149	230	SW
293941	5117474	Residential (R3)	1199	230	SW
296006	5117684	Recreational (R4)	1243	110	ESE
294800	5118207	Guardhouse	83	264	W
292899	5119449	Rapides des Joachims residential	2437	307	NW
296580	5117009	Point Stewart residential	1987	120	ESE
296334	5117317	Cottage	1627	115	ESE
292399	5116958	Rolphon residential	2665	247	WSW
283368	5116763	Mackey beef farm	11552	264	W
301240	5109238	Bass Lake beef farm	10838	144	SE

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Figure 4-4 Receptor Locations



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5.0 INVENTORY

5.1 Radionuclides

This section describes the radioactive materials present within the NPD Facility.

As discussed in Section 4.2, following permanent shutdown of NPD, all process systems not required during safe storage were drained and shut down, including the heavy water moderator and heat transport system. A discussion of past incidents (e.g. spills/leaks) and their relevance to decommissioning can be found in the DDP. Spent fuel has been transferred to fuel storage facilities at the CRL site. Any mobile materials such as demineralizer equipment was removed for re-use and the entire turbine system, control room and support facilities were cleared out and demolished where possible. Any redundant buildings and non-nuclear systems were removed (i.e., power house components). The NPD facility currently consists of a limited number of structures including the main building storing the reactor and its associated systems, a diesel-generator, the ventilation stack and the guardhouse. At the time of permanent shutdown, the preferred decommissioning strategy for the station, was one of deferred decommissioning. A deferment period allowed for significant reduction of radiation fields emanating from the reactor and associated process systems as a result of the decay of radioactive isotopes.

The most recent estimates of the facility's radiological inventory (as of 2020) are described in detail in the subsections below.

5.1.1 Activation Products

5.1.1.1 Reactor Vault

The Reactor Vault inventory includes activated reactor components and structures such as the:

- concrete biological shield;
- carbon steel liner;
- aluminum Calandria vessel and Calandria tubes;
- Carbon steel feeder tubes;
- zircaloy pressure tubes; and,
- stainless-steel end fittings and components.

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Modelling & Measurements

The previous version of the DecomSA, provided in 2017 as part of the EIS submission package, obtained reactor inventory estimates from the 2017 PostSA (Arcadis & Quintessa, 2017), which in turn derived its estimated inventory from ORIGEN modelling results in Smith (1988). The calculations of Smith (1988) were verified independently by Trottier & Edwards (2012), specifically focusing on the pressure tube and calandria tube inventories. Edwards and Adams (2019) have since recalculated the activity of some NPD reactor components. This re-calculation, again using the ORIGEN code, replaced the 2-D neutron transportation code used by Smith [1988] with MCNP, a 3-D solver, and provided a detailed examination of potential impurities and uncertainties in the material compositions (see Table 5-1 below). This calculation supersedes the previous work which was originally performed soon after shutdown in 1988 and subsequently verified in 2012.

The NPD Closure Project also completed sampling of the various activated reactor materials to build confidence in the calculated inventory. This included sampling and laboratory analysis of the activated inner concrete of the Reactor Vault walls, carbon steel vault liner, aluminum Calandria vessel and a Calandria tube as well as the zircaloy from a pressure tube. Sampling of the Calandria was undertaken by New Millennium Nuclear Technologies Incorporated (NMNTI). Collection of a sample of the stainless-steel components was not possible. These sample results, NMNTI [2017], used the empirical data, as well as re-estimates of the various reactor material masses from 3D modeling (based on original design drawings), to validate the activation product inventory modelled by Smith [1988], Edwards [2017] and subsequently, Edwards and Adams [2019]. A comparison of the results indicates that:

- The total activation product inventory estimated using Edwards and Adams [2019] ($7.51\text{E}+13$ Bq) is conservative in comparison to the total activation product inventory estimated by sample results alone ($2.07\text{E}+13$ Bq) in NMNTI [2017].
- The modelled activation product inventory of the NPD reactor components appears to be largely conservative for the aluminium and zircaloy reactor components (with the exception of some radionuclides where sample data is used in preference for conservatism – see Table 5-1, for example: Sr-90, Cs-137).
- Tritium was overestimated in the aluminium components by Edwards and Adams [2019] and underestimated in the concrete. The total tritium inventory estimated by sampling results was approximately 20 times lower than Edwards and Adams [2019].
- Except in the case of tritium where there is confidence in the use of the lower results by sample, the higher activity of either the sampled or calculated results have been used to form a composite total activity and provide the most conservative source term (reflected in Table 5-3).
- Edwards and Adams [2019] underestimates C-14 by 4 orders of magnitude in the bioshield concrete. This discrepancy is potentially due to errors in the starting N-14 composition or impurities in reactor materials. However, the total C-14 inventory estimated by Edwards

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and Adams [2019] is still approximately 20 times higher than the total inventory determined by sampling results.

Table 5-1 provides a comparison of the sample results obtained, NMNTI [2017], and the most up-to-date modelling results Edwards and Adams [2019]. Where sample results were not obtained, stainless steel, the comparator used is the verification work undertaken in 2017 which looked specifically at the NPD end fitting components, Edwards [2017].

In assessing sample results, NMNTI [2017] provided an implied inventory for fission product/actinide contamination of the pressure tubes and other components within the reactor vault (see Table 5-2). The fission product/actinide results are considered to be captured, or rather bounded by, the revised inventory for the reactor components in Edwards and Adams [2019], and are not considered contaminants due to fuel failures but products of activation and fission of impurities within reactor components. Transportation and deposition of contaminants due to fuel failure and activation/corrosion product distribution throughout the Primary Coolant System are deemed to be suitably bounded by the inventory captured in the Primary Heat Transport and Moderator Systems. however, a more applicable inventory for assigned fuel failure contamination within the reactor vault is derived from intrusive samples obtained from the remote entry to the Reactor Vault which are then applied over the surface area applicable to the room [McVeigh 2020]. These results are provided to supersede the NMNTI [2017] results (see comparison in Table 5-2).

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Table 5-1 Comparison of ORIGEN Neutron Flux calculations [Edwards 2017, Edwards and Adams 2019] and Sampling Data [NMNTI 2017]

Radionuclide	Aluminium		Concrete		Carbon Steel		Stainless Steel		Zircalloy		Composite Total Activity by Radionuclide (Bq)
	NMNTI (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	Edwards (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	
	(Bq) ¹										
H-3	9.13E+09	3.10E+13	1.41E+12	9.48E+03	2.35E+08	3.35E+07	-	2.04E+09	2.11E+11	7.36E+11	2.16E+12
C-14	2.97E+08	1.00E+11	2.40E+10	2.70E+06	8.13E+07	1.25E+09	5.55E+09	1.05E+11	5.30E+10	1.36E+12	1.59E+12
Cl-36	1.21E+07	4.58E+09	1.74E+08	7.17E+06	1.09E+07	-	-	2.64E+05	3.43E+07	2.50E+10	2.98E+10
Ca-41	-	9.21E+08	7.62E+09	3.56E+07	-	5.80E+06	-	3.28E+08	-	1.25E+09	1.01E+10
Co-60	4.16E+10	5.28E+11	3.18E+11	2.58E+08	1.17E+10	1.61E+11	3.04E+11	1.34E+13	2.79E+11	2.63E+12	1.71E+13
Ni-59	8.49E+08	2.17E+09	-	1.68E+06	-	8.37E+08	2.09E+09	1.54E+11	-	2.16E+11	3.73E+11
Ni-63	1.55E+11	5.22E+11	6.83E+10	1.55E+08	4.39E+09	3.96E+10	1.94E+11	1.44E+13	6.93E+12	3.36E+13	4.86E+13
Se-79	-	1.06E+04	-	2.06E+00	-	6.08E+05	-	1.77E+07	-	1.04E+05	1.84E+07
Sr-90	3.11E+09	2.97E+09	-	1.01E+06	2.91E+6	1.68E+08	-	3.55E+10	2.32E+10	2.55E+10	6.43E+10
Zr-93	-	2.76E+06	-	2.80E+03	-	3.67E+03	-	2.06E+06	2.90E+10	2.40E+11	2.40E+11
Nb-93m	-	4.97E+06	-	2.25E+03	-	2.55E+07	-	1.41E+09	-	1.94E+11	1.95E+11
Nb-94	-	0.00E+00	-	1.62E+05	-	5.84E+07	-	4.40E+09	1.85E+08	1.13E+10	1.58E+10
Tc-99	-	2.17E+06	-	3.94E+02	-	7.53E+06	-	4.12E+08	-	1.45E+08	5.67E+08
Ag-108m	-	3.42E+08	-	3.96E+03	-	8.63E+08	-	7.74E+10	-	2.16E+10	1.00E+11
Sn-121m	-	6.19E+07	-	1.60E+02	-	1.94E+06	-	7.56E+07	-	2.08E+11	2.08E+11
Sn-126	-	5.66E+04	-	3.32E+00	-	0.00E+00	-	3.71E+05	-	6.86E+05	1.11E+06
Sb-125	-	2.67E+07	-	1.55E+01	-	1.15E+06	-	2.52E+07	2.69E+10	9.05E+10	9.06E+10
I-129	-	3.76E+03	-	0.00E+00	-	0.00E+00	-	3.94E+04	-	5.25E+04	9.56E+04
Cs-135	-	6.68E+04	-	3.86E+01	-	1.79E+03	-	1.34E+06	-	7.45E+05	2.15E+06
Cs-137	6.91E+9	6.39E+09	-	1.07E+06	-	1.87E+08	-	4.82E+10	6.08E+10	7.79E+10	1.33E+11
Sm-151	-	4.71E+08	-	5.51E+05	-	3.07E+08	-	2.25E+09	-	7.60E+07	3.11E+09
Eu-152	2.76E+08	7.78E+09	1.23E+11	3.85E+07	5.92E+07	1.87E+07	-	1.26E+08	3.48E+09	7.51E+04	1.34E+11
U-234	-	7.04E+05	-	4.35E+05	-	2.76E+07	-	1.18E+07	-	1.35E+05	4.07E+07
U-235	-	2.08E+04	-	2.02E+04	-	1.26E+06	-	2.45E+05	1.55E+3	0.00E+00	1.55E+06
U-236	-	0.00E+00	-	1.02E+01	-	0.00E+00	-	1.51E+05	-	1.85E+04	1.70E+05
U-238	1.21E+05	4.68E+05	-	4.40E+05	-	2.79E+07	-	6.04E+06	7.74E+04	9.24E+04	3.49E+07
Np-237	-	0.00E+00	-	0.00E+00	-	0.00E+00	-	2.97E+04	-	3.09E+04	6.06E+04
Pu-238	8.96E+07	7.33E+07	8.30E+08	0.00E+00	-	7.26E+02	-	3.27E+08	6.27E+08	1.05E+09	2.30E+09

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Radionuclide	Aluminium		Concrete		Carbon Steel		Stainless Steel		Zircalloy		Composite Total Activity by Radionuclide (Bq)
	NMNTI (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	Edwards (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	
	(Bq) ¹										
Pu-239	6.44E+07	1.47E+07	2.06E+07	1.98E+05	-	1.08E+08	-	1.49E+09	4.22E+08	1.54E+08	2.10E+09
Pu-240	-	4.24E+07	-	2.29E+01	-	1.39E+05	-	9.71E+08	-	4.80E+08	1.49E+09
Pu-241	-	1.12E+09	-	0.00E+00	-	1.50E+04	-	1.30E+10	8.05E+09	1.56E+10	2.96E+10
Pu-242	-	6.73E+05	-	0.00E+00	-	0.00E+00	-	3.57E+05	-	1.11E+07	1.21E+07
Am-241	-	1.36E+08	-	0.00E+00	-	0.00E+00	-	1.88E+09	1.28E+09	1.80E+09	3.82E+09
Am-242m	-	3.37E+05	-	0.00E+00	-	0.00E+00	-	7.91E+06	-	3.39E+06	1.16E+07
Am-243	-	9.67E+06	-	0.00E+00	-	0.00E+00	-	3.48E+05	-	1.64E+08	1.74E+08
Cm-243	-	5.45E+05	-	-	-	-	-	3.10E+05	-	9.27E+06	1.01E+07
Cm-244	-	9.95E+08	-	0.00E+00	-	0.00E+00	-	1.19E+06	-	1.58E+10	1.67E+10
Be-10	-	1.26E+05	-	0.00E+00	-	0.00E+00	-	5.14E+04	-	5.62E+04	2.34E+05
Al-26	-	4.18E+06	-	0.00E+00	-	0.00E+00	-	0.00E+00	-	0.00E+00	4.18E+06
P-32	-	3.20E+04	-	1.47E-01	-	4.80E+01	-	2.06E+03	-	4.80E+05	5.14E+05
Si-32	-	3.15E+04	-	0.00E+00	-	0.00E+00	-	1.76E+03	-	4.80E+05	5.13E+05
Ar-39	-	2.73E+07	-	3.28E+04	-	6.97E+04	-	5.85E+05	-	1.80E+08	2.08E+08
Fe-55	2.34E+10	8.77E+10	7.84E+10	9.91E+07	1.73E+10	1.46E+10	5.10E+10	3.15E+12	1.79E+11	1.25E+11	3.51E+12
Fe-60	-	7.25E+04	-	0.00E+00	-	0.00E+00	-	1.80E+05	-	1.74E+05	4.27E+05
Co-60m	-	7.25E+04	-	0.00E+00	-	0.00E+00	-	1.80E+05	-	1.74E+05	4.27E+05
Kr-85	-	1.08E+08	-	2.82E+04	-	5.41E+06	-	1.35E+09	-	7.82E+08	2.24E+09
Rb-87	-	0.00E+00	-	3.29E+04	-	0.00E+00	-	0.00E+00	-	0.00E+00	3.29E+04
Y-90	-	2.97E+09	-	1.01E+06	-	1.73E+08	-	7.09E+10	-	2.55E+10	9.96E+10
Nb-91	-	2.91E+04	-	0.00E+00	-	4.07E+05	-	1.39E+07	-	7.84E+06	2.21E+07
Mo-93	-	3.71E+06	-	0.00E+00	-	3.50E+07	-	1.93E+09	-	6.84E+08	2.65E+09
Ru-106	-	2.27E+01	-	4.62E-04	-	9.79E-02	-	1.22E+02	-	3.46E+02	4.91E+02
Pd-107	-	2.78E+04	-	0.00E+00	-	0.00E+00	-	1.07E+05	-	4.74E+05	6.08E+05
Ag-108	-	2.98E+07	-	3.44E+02	-	7.34E+07	-	6.73E+09	-	1.08E+09	8.71E+09
Ag-109m	-	3.00E+03	-	2.61E-07	-	1.01E+02	-	3.08E+04	-	3.06E+05	3.40E+05
Cd-109	-	3.00E+03	-	2.61E-07	-	1.01E+02	-	3.08E+04	-	3.06E+05	3.40E+05
Cd-113m	-	4.13E+07	-	2.15E+01	-	6.28E+08	-	2.21E+09	-	2.71E+07	2.90E+09
Sn-121	-	4.80E+07	-	1.24E+02	-	1.53E+06	-	5.87E+07	-	1.61E+11	1.61E+11
Te-125m	-	6.53E+06	-	3.79E+00	-	2.62E+05	-	6.14E+06	-	2.22E+10	2.22E+10
Sb-126m	-	5.66E+04	-	3.32E+00	-	0.00E+00	-	3.71E+05	-	6.86E+05	1.11E+06

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Radionuclide	Aluminium		Concrete		Carbon Steel		Stainless Steel		Zircalloy		Composite Total Activity by Radionuclide (Bq)
	NMNTI (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	Edwards (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	
	(Bq) ¹										
Ba-133	-	1.02E+09	-	1.57E+06	-	0.00E+00	-	1.37E+03	-	1.19E+04	1.03E+09
Ba-137m	-	5.86E+09	-	1.01E+06	-	8.50E+07	-	4.55E+10	-	7.37E+10	1.25E+11
Cs-134	-	5.57E+05	-	2.89E-03	-	4.33E+00	-	3.60E+05	-	6.70E+06	7.62E+06
La-137	-	2.92E+05	-	1.18E+01	-	2.38E+05	-	1.41E+07	-	0.00E+00	1.46E+07
Pm-145	-	2.47E+08	-	4.60E+03	-	0.00E+00	-	0.00E+00	-	0.00E+00	2.47E+08
Pm-146	-	1.83E+05	-	0.00E+00	-	0.00E+00	-	2.16E+02	-	0.00E+00	1.84E+05
Pm-147	-	7.80E+06	-	9.03E+02	-	1.44E+06	-	1.60E+08	-	2.44E+07	1.93E+08
Sm-151	-	4.71E+08	-	5.51E+05	-	3.07E+08	-	2.25E+09	-	7.60E+07	3.11E+09
Eu-154	-	2.51E+10	-	1.38E+06	-	8.78E+05	-	6.75E+08	-	1.16E+09	2.69E+10
Eu-155	-	1.90E+09	-	1.25E+04	-	6.57E+04	-	3.18E+07	-	8.38E+07	2.01E+09
Tb-157	-	4.24E+07	-	1.46E+03	-	0.00E+00	-	0.00E+00	-	0.00E+00	4.24E+07
Tb-158	-	8.26E+06	-	0.00E+00	-	0.00E+00	-	0.00E+00	-	0.00E+00	8.26E+06
Ho-166m	-	3.73E+07	-	0.00E+00	-	0.00E+00	-	0.00E+00	-	0.00E+00	3.73E+07
Hf-182	-	0.00E+00	-	0.00E+00	-	0.00E+00	-	2.69E+03	-	4.44E+06	4.44E+06
Ta-182	-	3.17E+02	-	0.00E+00	-	1.36E-01	-	2.93E+03	-	4.44E+06	4.44E+06
Re-186	-	2.33E+03	-	0.00E+00	-	6.63E-01	-	8.64E+03	-	1.20E+06	1.21E+06
Re-186m	-	2.06E+03	-	0.00E+00	-	0.00E+00	-	7.91E+03	-	1.20E+06	1.21E+06
Pt-193	-	2.24E+06	-	0.00E+00	-	0.00E+00	-	0.00E+00	-	7.92E+08	7.94E+08
Tl-208	-	3.13E+05	-	1.13E+05	-	3.26E+06	-	4.98E+06	-	0.00E+00	8.66E+06
Pb-205	-	2.79E+04	-	0.00E+00	-	0.00E+00	-	1.26E+04	-	2.53E+05	2.93E+05
Pb-209	-	0.00E+00	-	2.25E+02	-	1.32E+04	-	1.24E+06	-	0.00E+00	1.26E+06
Pb-210	-	0.00E+00	-	3.67E+01	-	0.00E+00	-	0.00E+00	-	0.00E+00	3.67E+01
Pb-212	-	9.11E+05	-	3.14E+05	-	9.69E+06	-	1.38E+07	-	1.90E+03	2.48E+07
Bi-210	-	4.02E+01	-	3.67E+01	-	0.00E+00	-	0.00E+00	-	4.86E+02	5.63E+02
Bi-211	-	0.00E+00	-	2.96E+01	-	7.68E+03	-	1.97E+05	-	0.00E+00	2.05E+05
Bi-212	-	9.11E+05	-	3.14E+05	-	9.69E+06	-	1.38E+07	-	1.90E+03	2.48E+07
Bi-213	-	0.00E+00	-	2.25E+02	-	1.32E+04	-	1.24E+06	-	0.00E+00	1.25E+06
Po-210	-	4.02E+01	-	3.67E+01	-	0.00E+00	-	1.02E+00	-	4.86E+02	5.64E+02
Po-212	-	5.84E+05	-	2.01E+05	-	5.81E+06	-	8.87E+06	-	0.00E+00	1.55E+07
Po-213	-	0.00E+00	-	2.20E+02	-	1.29E+04	-	1.21E+06	-	0.00E+00	1.23E+06
Po-215	-	0.00E+00	-	2.96E+01	-	7.68E+03	-	1.97E+05	-	0.00E+00	2.05E+05

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Radionuclide	Aluminium		Concrete		Carbon Steel		Stainless Steel		Zircalloy		Composite Total Activity by Radionuclide (Bq)
	NMNTI (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	Edwards (2017)	Edwards and Adams (2019)	NMNTI (2017)	Edwards and Adams (2019)	
	(Bq) ¹										
Po-216	-	9.11E+05	-	3.14E+05	-	9.41E+06	-	1.38E+07	-	1.90E+03	2.45E+07
At-217	-	0.00E+00	-	2.25E+02	-	1.32E+04	-	1.24E+06	-	0.00E+00	1.26E+06
Fr-221	-	0.00E+00	-	2.25E+02	-	1.32E+04	-	1.24E+06	-	0.00E+00	1.26E+06
Rn-220	-	9.11E+05	-	3.14E+05	-	9.33E+06	-	1.38E+07	-	1.90E+03	2.44E+07
Ra-224	-	9.11E+05	-	3.14E+05	-	9.32E+06	-	1.38E+07	-	1.90E+03	2.44E+07
Ra-225	-	0.00E+00	-	2.25E+02	-	1.32E+04	-	1.24E+06	-	0.00E+00	1.26E+06
Ra-228	-	3.28E+04	-	3.14E+05	-	9.17E+06	-	1.98E+06	-	0.00E+00	1.15E+07
Ac-225	-	0.00E+00	-	2.25E+02	-	1.32E+04	-	1.24E+06	-	0.00E+00	1.26E+06
Ac-228	-	3.28E+04	-	3.14E+05	-	9.15E+06	-	1.98E+06	-	0.00E+00	1.15E+07
Th-228	-	9.11E+05	-	3.14E+05	-	9.21E+06	-	1.38E+07	-	1.90E+03	2.43E+07
Th-229	-	0.00E+00	-	2.25E+02	-	1.32E+04	-	1.24E+06	-	0.00E+00	1.26E+06
Th-230	-	0.00E+00	-	3.15E+03	-	9.66E+04	-	2.59E+04	-	0.00E+00	1.26E+05
Th-231	-	2.08E+04	-	2.02E+04	-	1.26E+06	-	2.45E+05	-	0.00E+00	1.55E+06
Th-232	-	3.28E+04	-	3.14E+05	-	9.19E+06	-	1.98E+06	-	0.00E+00	1.15E+07
Th-234	-	4.68E+05	-	4.40E+05	-	2.79E+07	-	6.04E+06	-	9.24E+04	3.49E+07
Pa-234	-	0.00E+00	-	7.03E+02	-	4.33E+04	-	9.66E+03	-	0.00E+00	5.37E+04
Pa-234m	-	4.68E+05	-	4.40E+05	-	2.79E+07	-	6.04E+06	-	9.24E+04	3.49E+07
U-232	-	8.52E+05	-	0.00E+00	-	1.33E+03	-	1.15E+07	-	1.84E+03	1.24E+07
U-233	-	1.52E+06	-	5.72E+04	-	8.26E+06	-	3.13E+08	-	0.00E+00	3.23E+08
U-237	-	2.75E+04	-	1.84E-06	-	3.69E-01	-	3.18E+05	-	3.82E+05	7.27E+05
Np-237	-	0.00E+00	-	0.00E+00	-	0.00E+00	-	2.97E+04	-	3.09E+04	6.06E+04
Am-242		3.35E+05		0.00E+00		0.00E+00		7.87E+06		3.37E+06	1.16E+07
Am-242m		3.37E+05		0.00E+00		0.00E+00		7.91E+06		3.39E+06	1.16E+07
Cm-242		2.77E+05		0.00E+00		0.00E+00		6.51E+06		2.79E+06	9.58E+06
Cm-245		1.14E+05		0.00E+00		0.00E+00		0.00E+00		1.83E+06	1.94E+06
Cm-246		3.64E+05		0.00E+00		0.00E+00		0.00E+00		5.25E+06	5.61E+06

Red Font: indicates higher of measured vs modelled value, for each radionuclide.

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Table 5-2 Comparison of Assigned Fuel Failure Contamination Inventory and Measured Results

Radionuclide	Assigned 1 st PostSA Inventory	Assigned 2 nd PostSA Inventory [NMNTI 2017]	Assigned 3 rd PostSA Inventory CNL Sampling and Application [McVeigh 2020]
	(Bq)		
H-3	-	-	7.62E+08
C-14	-	-	2.97E+09
C-36	-	-	2.79E+07
Fe-55	-	-	1.53E+08
Co-60	-	-	2.52E+08
Ni-63	-	-	1.05E+09
Se-79	6.20E+04	-	-
Sr-90	5.14E+09	2.63E+10	2.68E+10
Zr-93	3.06E+05	-	-
Nb-93	3.44E+04	-	-
Nb-94	1.96E+01	-	-
Tc-99	2.31E+06	-	1.76E+07
Ru-106	2.27E-01	-	-
Pd-107	1.23E+04	-	-
Cd-113	5.11E+05	-	-
Sn-121	1.07E+04	-	-
Sn-126	7.60E+04	-	-
Sb-125	6.70E+04	2.69E+10	-
I-129	4.54E+03	-	-
Cs-134	1.65E+04	-	-
Cs-135	1.12E+05	-	-
Cs-137	6.79E+09	6.77E+10	4.11E+10
Pm-147	1.32E+06	-	-
Sm-151	3.45E+07	-	-
Eu-152	3.74E+05	-	-
Eu-154	2.57E+07	-	1.60E+08
Eu-155	1.53E+06	-	-
Ho-166	1.14E+01	-	-
U-232	6.85E+01	-	-
U-234	6.29E+04	-	-
U-235	5.60E+03	1.55E+03	-
U-236	4.58E+04	-	-
U-238	6.13E+04	1.98E+05	-
Np-237	1.37E+04	-	-
Pu-238	5.28E+07	1.55E+09	1.47E+08
Pu-239	6.20E+07	5.07E+08	9.98E+08 ^[1]
Pu-240	9.84E+07	-	See Pu239
Pu-241	2.03E+09	8.05E+09	-
Pu-242	1.22E+05	-	-
Am-241	1.53E+08	1.28E+09	1.49E+09
Am-242m	1.06E+06	-	-
Am-243	2.19E+05	-	-
Cm-243	1.34E+05	-	-
Cm-244	1.17E+06	-	-

[1] Combined activity for ^{239/240}Pu.

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Based on the considerations outlined above, a composite total inventory was chosen to represent the reactor vault, derived by using the higher of the results for each component by radionuclide (shown in Table 5-1), except in the case of tritium where the most reliable figure is used. The resulting composite total inventory is presented in Table 5-3 below.

Table 5-3 Composite Total Reactor Vault Inventory [Bq]

Radionuclide	Aluminium	Concrete	Carbon Steel	Stainless Steel	Zircalloy	Contamination
	(Bq)					
H-3	9.13E+09	1.41E+12	2.35E+08	2.04E+09	7.36E+11	7.62E+08
C-14	1.00E+11	2.40E+10	1.25E+09	1.05E+11	1.36E+12	2.97E+09
Cl-36	4.58E+09	1.74E+08	1.09E+07	2.64E+05	2.50E+10	2.79E+07
Ca-41	9.21E+08	7.62E+09	5.80E+06	3.28E+08	1.25E+09	-
Co-60	5.28E+11	3.18E+11	1.61E+11	1.34E+13	2.63E+12	2.52E+08
Ni-59	2.17E+09	1.68E+06	8.37E+08	1.54E+11	2.16E+11	-
Ni-63	5.22E+11	6.83E+10	3.96E+10	1.44E+13	3.36E+13	1.05E+09
Se-79	1.06E+04	2.06E+00	6.08E+05	1.77E+07	1.04E+05	-
Sr-90	3.11E+09	1.01E+06	1.68E+08	3.55E+10	2.55E+10	2.68E+10
Zr-93	2.76E+06	2.80E+03	3.67E+03	2.06E+06	2.40E+11	-
Nb-93m	4.97E+06	2.25E+03	2.55E+07	1.41E+09	1.94E+11	-
Nb-94	0.00E+00	1.62E+05	5.84E+07	4.40E+09	1.13E+10	-
Tc-99	2.17E+06	3.94E+02	7.53E+06	4.12E+08	1.45E+08	1.76E+07
Ag-108m	3.42E+08	3.96E+03	8.63E+08	7.74E+10	2.16E+10	-
Sn-121m	6.19E+07	1.60E+02	1.94E+06	7.56E+07	2.08E+11	-
Sn-126	5.66E+04	3.32E+00	0.00E+00	3.71E+05	6.86E+05	-
Sb-125	2.67E+07	1.55E+01	1.15E+06	2.52E+07	9.05E+10	-
I-129	3.76E+03	0.00E+00	0.00E+00	3.94E+04	5.25E+04	-
Cs-135	6.68E+04	3.86E+01	1.79E+03	1.34E+06	7.45E+05	-
Cs-137	6.91E+09	1.07E+06	1.87E+08	4.82E+10	7.79E+10	4.11E+10
Sm-151	4.71E+08	5.51E+05	3.07E+08	2.25E+09	7.60E+07	-
Eu-152	7.78E+09	1.23E+11	5.92E+07	1.26E+08	3.48E+09	-
U-234	7.04E+05	4.35E+05	2.76E+07	1.18E+07	1.35E+05	-
U-235	2.08E+04	2.02E+04	1.26E+06	2.45E+05	0.00E+00	-
U-236	0.00E+00	1.02E+01	0.00E+00	1.51E+05	1.85E+04	-
U-238	4.68E+05	4.40E+05	2.79E+07	6.04E+06	9.24E+04	-
Np-237	0.00E+00	0.00E+00	0.00E+00	2.97E+04	3.09E+04	-
Pu-238	8.96E+07	8.30E+08	7.26E+02	3.27E+08	1.05E+09	1.47E+08
Pu-239	6.44E+07	2.06E+07	1.08E+08	1.49E+09	4.22E+08	9.98E+08
Pu-240	4.24E+07	2.29E+01	1.39E+05	9.71E+08	4.80E+08	-
Pu-241	1.12E+09	0.00E+00	1.50E+04	1.30E+10	1.56E+10	-
Pu-242	6.73E+05	0.00E+00	0.00E+00	3.57E+05	1.11E+07	-
Am-241	1.36E+08	0.00E+00	0.00E+00	1.88E+09	1.80E+09	1.49E+09
Am-242m	3.37E+05	0.00E+00	0.00E+00	7.91E+06	3.39E+06	-
Am-243	9.67E+06	0.00E+00	0.00E+00	3.48E+05	1.64E+08	-
Cm-243	5.45E+05	-	-	3.10E+05	9.27E+06	-
Cm-244	9.95E+08	0.00E+00	0.00E+00	1.19E+06	1.58E+10	-
Be-10	1.26E+05	0.00E+00	0.00E+00	5.14E+04	5.62E+04	-
Al-26	4.18E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-
P-32	3.20E+04	1.47E-01	4.80E+01	2.06E+03	4.80E+05	-

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Radionuclide	Aluminium	Concrete	Carbon Steel	Stainless Steel	Zircalloy	Contamination
	(Bq)					
Si-32	3.15E+04	0.00E+00	0.00E+00	1.76E+03	4.80E+05	-
Ar-39	2.73E+07	3.28E+04	6.97E+04	5.85E+05	1.80E+08	-
Fe-55	8.77E+10	7.84E+10	1.73E+10	3.15E+12	1.79E+11	1.53E+08
Fe-60	7.25E+04	0.00E+00	0.00E+00	1.80E+05	1.74E+05	-
Co-60m	7.25E+04	0.00E+00	0.00E+00	1.80E+05	1.74E+05	-
Kr-85	1.08E+08	2.82E+04	5.41E+06	1.35E+09	7.82E+08	-
Rb-87	0.00E+00	3.29E+04	0.00E+00	0.00E+00	0.00E+00	-
Y-90	2.97E+09	1.01E+06	1.73E+08	7.09E+10	2.55E+10	-
Nb-91	2.91E+04	0.00E+00	4.07E+05	1.39E+07	7.84E+06	-
Mo-93	3.71E+06	0.00E+00	3.50E+07	1.93E+09	6.84E+08	-
Ru-106	2.27E+01	4.62E-04	9.79E-02	1.22E+02	3.46E+02	-
Pd-107	2.78E+04	0.00E+00	0.00E+00	1.07E+05	4.74E+05	-
Ag-108	2.98E+07	3.44E+02	7.34E+07	6.73E+09	1.08E+09	-
Ag-109m	3.00E+03	2.61E-07	1.01E+02	3.08E+04	3.06E+05	-
Cd-109	3.00E+03	2.61E-07	1.01E+02	3.08E+04	3.06E+05	-
Cd-113m	4.13E+07	2.15E+01	6.28E+08	2.21E+09	2.71E+07	-
Sn-121	4.80E+07	1.24E+02	1.53E+06	5.87E+07	1.61E+11	-
Te-125m	6.53E+06	3.79E+00	2.62E+05	6.14E+06	2.22E+10	-
Sb-126m	5.66E+04	3.32E+00	0.00E+00	3.71E+05	6.86E+05	-
Ba-133	1.02E+09	1.57E+06	0.00E+00	1.37E+03	1.19E+04	-
Ba-137m	5.86E+09	1.01E+06	8.50E+07	4.55E+10	7.37E+10	-
Cs-134	5.57E+05	2.89E-03	4.33E+00	3.60E+05	6.70E+06	-
La-137	2.92E+05	1.18E+01	2.38E+05	1.41E+07	0.00E+00	-
Pm-145	2.47E+08	4.60E+03	0.00E+00	0.00E+00	0.00E+00	-
Pm-146	1.83E+05	0.00E+00	0.00E+00	2.16E+02	0.00E+00	-
Pm-147	7.80E+06	9.03E+02	1.44E+06	1.60E+08	2.44E+07	-
Sm-151	4.71E+08	5.51E+05	3.07E+08	2.25E+09	7.60E+07	-
Eu-154	2.51E+10	1.38E+06	8.78E+05	6.75E+08	1.16E+09	1.60E+08
Eu-155	1.90E+09	1.25E+04	6.57E+04	3.18E+07	8.38E+07	-
Tb-157	4.24E+07	1.46E+03	0.00E+00	0.00E+00	0.00E+00	-
Tb-158	8.26E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-
Ho-166m	3.73E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-
Hf-182	0.00E+00	0.00E+00	0.00E+00	2.69E+03	4.44E+06	-
Ta-182	3.17E+02	0.00E+00	1.36E-01	2.93E+03	4.44E+06	-
Re-186	2.33E+03	0.00E+00	6.63E-01	8.64E+03	1.20E+06	-
Re-186m	2.06E+03	0.00E+00	0.00E+00	7.91E+03	1.20E+06	-
Pt-193	2.24E+06	0.00E+00	0.00E+00	0.00E+00	7.92E+08	-
Tl-208	3.13E+05	1.13E+05	3.26E+06	4.98E+06	0.00E+00	-
Pb-205	2.79E+04	0.00E+00	0.00E+00	1.26E+04	2.53E+05	-
Pb-209	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-
Pb-210	0.00E+00	3.67E+01	0.00E+00	0.00E+00	0.00E+00	-
Pb-212	9.11E+05	3.14E+05	9.69E+06	1.38E+07	1.90E+03	-
Bi-210	4.02E+01	3.67E+01	0.00E+00	0.00E+00	4.86E+02	-
Bi-211	0.00E+00	2.96E+01	7.68E+03	1.97E+05	0.00E+00	-
Bi-212	9.11E+05	3.14E+05	9.69E+06	1.38E+07	1.90E+03	-
Bi-213	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-
Po-210	4.02E+01	3.67E+01	0.00E+00	1.02E+00	4.86E+02	-
Po-212	5.84E+05	2.01E+05	5.81E+06	8.87E+06	0.00E+00	-

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Radionuclide	Aluminium	Concrete	Carbon Steel	Stainless Steel	Zircalloy	Contamination
	(Bq)					
Po-213	0.00E+00	2.20E+02	1.29E+04	1.21E+06	0.00E+00	-
Po-215	0.00E+00	2.96E+01	7.68E+03	1.97E+05	0.00E+00	-
Po-216	9.11E+05	3.14E+05	9.41E+06	1.38E+07	1.90E+03	-
At-217	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-
Fr-221	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-
Rn-220	9.11E+05	3.14E+05	9.33E+06	1.38E+07	1.90E+03	-
Ra-224	9.11E+05	3.14E+05	9.32E+06	1.38E+07	1.90E+03	-
Ra-225	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-
Ra-228	3.28E+04	3.14E+05	9.17E+06	1.98E+06	0.00E+00	-
Ac-225	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-
Ac-228	3.28E+04	3.14E+05	9.15E+06	1.98E+06	0.00E+00	-
Th-228	9.11E+05	3.14E+05	9.21E+06	1.38E+07	1.90E+03	-
Th-229	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-
Th-230	0.00E+00	3.15E+03	9.66E+04	2.59E+04	0.00E+00	-
Th-231	2.08E+04	2.02E+04	1.26E+06	2.45E+05	0.00E+00	-
Th-232	3.28E+04	3.14E+05	9.19E+06	1.98E+06	0.00E+00	-
Th-234	4.68E+05	4.40E+05	2.79E+07	6.04E+06	9.24E+04	-
Pa-234	0.00E+00	7.03E+02	4.33E+04	9.66E+03	0.00E+00	-
Pa-234m	4.68E+05	4.40E+05	2.79E+07	6.04E+06	9.24E+04	-
U-232	8.52E+05	0.00E+00	1.33E+03	1.15E+07	1.84E+03	-
U-233	1.52E+06	5.72E+04	8.26E+06	3.13E+08	0.00E+00	-
U-237	2.75E+04	1.84E-06	3.69E-01	3.18E+05	3.82E+05	-
Np-237	0.00E+00	0.00E+00	0.00E+00	2.97E+04	3.09E+04	-
Am-242	3.35E+05	0.00E+00	0.00E+00	7.87E+06	3.37E+06	-
Am-242m	3.37E+05	0.00E+00	0.00E+00	7.91E+06	3.39E+06	-
Cm-242	2.77E+05	0.00E+00	0.00E+00	6.51E+06	2.79E+06	-
Cm-245	1.14E+05	0.00E+00	0.00E+00	0.00E+00	1.83E+06	-
Cm-246	3.64E+05	0.00E+00	0.00E+00	0.00E+00	5.25E+06	-

Uncertainties

Information on activation products within the reactor vault materials is considered to be of good quality.

The work by NMNTI [2017] provides valuable additional information on the radionuclide content of structures within the Reactor Vault. Comparison of these results with the new activation product inventory estimated by Adams and Edwards [2019] suggests that the latter may be an overestimate by a factor of two, and significantly greater for some key radionuclides such as Ni-59. Though, measurement data are also not available for Ag-108m, a particularly important radionuclide.

Some radionuclides also appear to have been underestimated when calculated by modelling, most notably tritium and C-14 in concrete and steels. This is likely to be due to the assumed composition of the materials.

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Overall, whilst there remain uncertainties in the inventory, stemming from the modelling results, the measurements strongly suggest that the modelled inventory is significantly conservative. Whilst there remain these uncertainties, the modelling estimates together with the measured results form a conservative, composite reference inventory.

5.1.1.2 Boiler Room

At the time of shutdown, the total activity estimated to have been deposited in the primary heat transport and moderator systems had been estimated to be 8.5×10^{11} Bq [Presley 1988]. This estimate was derived from a diminutive amount of data thus resulting in significant uncertainties.

More recently, characterization of the primary heat transport and moderator systems has involved an initial intrusive sampling campaign coupled with a qualitative survey intended to provide information on the general distribution of radionuclides as held-up contamination throughout the system. Planning inputs were established based on achieving an upper confidence level of 80% of the mean radioactivity concentration. The established concentration of each system was then applied over the calculated surface area of the respective system achieving a further level of conservatism based on distribution. The estimated total radionuclide inventory for the primary heat transport and moderator system can be found in Table 5-4 below, which is an excerpt from McVeigh (2019). Additionally, minor or subsidiary systems have been characterized McVeigh [2019] either through direct sampling or by conservative application of the primary heat and moderator systems radionuclide fingerprint derived in McVeigh [2017]. These data are found in Table 5-5 below and reflect the inventory of the following systems:

- Reactor Vault Ventilation Cooling System (RVCS);
- Moderator Helium System (MHS);
- Moderator Demineraliser (MD);
- Reflector Circuit (RC);
- Heat Transport System Collection (HTSCo);
- Heat Transport System Emergency Injection (HTSEI);
- Heat Transport System Demineraliser (HTSD);
- Heat Transport System Charging (HTSCh);
- Heat Transport System Standby Cooling (HTSSC).

With the intention that the inventory estimate be bounding, the total radioactivity for the boiler room inventory, which was derived prior to the completion of characterization activities, was set at 40 times the combined activity of the primary heat transport and moderator systems used in prior assessments to account for those systems yet to be examined. The radioactive inventory of the boiler room now reflects the other systems summarized in Table 5-4 and when summed this represents a slight increase of approximately 2.5 times the previous inventory total.

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Table 5-4 Total Radionuclide inventory for Primary Heat Transport and Moderator Systems (McVeigh 2019)

Radionuclide	Radioactivity (Bq)	
	Moderator System	Primary Heat Transport System
Am-241	6.68E+07	4.50E+10
Cs-137	4.43E+08	1.76E+10
Pu-238	9.74E+05	4.13E+09
Pu-239/240	4.56E+07	4.25E+10
Pu-241	4.65E+08	3.42E+11
Sr-90	6.09E+06	1.18E+10
C-14	3.54E+07	3.66E+07
Co-60	5.83E+08	2.35E+11
Eu-154	-	4.70E+09
Eu-155	-	1.18E+09
Ni-63	7.64E+09	1.62E+11
H-3	2.87E+10	6.88E+09
Total	3.80E+10	8.73E+11

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Table 5-5 Total Radionuclide Inventory for Other Systems (McVeigh 2020)

Radionuclide	Other Systems									Radionuclide Totals
	RVCS	MHS	MD	RC	HTSCo	HTSD	HTSEI	HTSch	HTSSC	
H-3	4.42E+06	9.77E+06	5.37E+08	5.76E+05	4.20E+04	1.64E+09	5.62E+08	1.98E+08	2.18E+08	3.17E+09
C-14	9.23E+03	1.17E+05	6.61E+05	1.38E+03	1.68E+02	8.75E+06	2.99E+06	1.05E+06	1.16E+06	1.47E+07
Cl-36	3.67E+04	-	-	-	-	-	-	-	-	3.67E+04
Co-60	-	-	3.39E+06	5.44E+03	4.59E+02	3.98E+09	2.48E+07	1.75E+09	1.04E+09	6.80E+09
Ni-63	9.68E+03	-	4.45E+07	6.82E+03	2.82E+03	2.73E+09	1.70E+07	1.20E+09	7.11E+08	4.70E+09
Sr-90	-	-	1.14E+05	-	3.32E+04	2.81E+09	9.62E+08	3.38E+08	3.72E+08	4.48E+09
Tc-99	-	-	-	-	-	-	-	-	-	0.00E+00
Cs-137	2.01E+04	9.08E+03	2.58E+06	-	2.26E+04	2.99E+08	1.86E+06	1.31E+08	7.77E+07	5.12E+08
Eu-154	-	-	-	-	-	7.96E+07	4.95E+05	3.49E+07	2.07E+07	1.36E+08
Eu-155	-	-	-	-	-	1.99E+07	1.24E+05	8.73E+06	5.18E+06	3.39E+07
Pu-238	-	-	5.67E+04	-	2.11E+01	6.99E+07	4.35E+05	3.07E+07	1.82E+07	1.19E+08
Pu-239/240	-	-	2.65E+05	-	2.30E+02	7.19E+08	4.47E+06	3.16E+08	1.87E+08	1.23E+09
Pu-241	-	-	2.70E+06	-	4.83E+01	5.80E+09	3.61E+07	2.54E+09	1.51E+09	9.89E+09
Am-241	-	-	3.89E+05	-	1.66E+02	7.61E+08	4.74E+06	3.34E+08	1.98E+08	1.30E+09
System Totals	4.50E+06	9.90E+06	5.92E+08	5.90E+05	1.02E+05	1.89E+10	1.62E+09	6.88E+09	4.36E+09	3.24E+10

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5.1.1.3 Fueling Machine Room

As discussed in 5.1.1.2 above, the characterization of other minor or subsidiary systems was conducted in 2018/2019, with McVeigh [2020] providing activities by system. The fueling system was sampled and resulting activities applied appropriately to derive a system total activity, summarized in Table 5-6. The separate radiological inventory of the twenty-seven legacy waste drums within the Fueling Machine Room is estimated in Adams [2016] and is described later, in Section 5.1.4.

Table 5-6 Estimated Inventory of the Fuel Handling System (McVeigh 2020)

Radionuclide	Activity (Bq)			
	Sample Lines	Drain Lines	Fuel Handling System	Total
H-3	2.42E+08	1.03E+09	9.34E+06	1.28E+09
C-14	1.29E+06	5.50E+06	2.05E+04	6.81E+06
Co-60	8.26E+09	3.32E+07	2.82E+06	8.30E+09
Ni-63	5.68E+09	2.28E+07	1.00E+07	5.71E+09
Sr-90	4.14E+08	3.32E+07	1.17E+08	5.64E+08
Tc-99	-	-	1.12E+05	1.12E+05
Cs-137	6.20E+08	3.32E+07	2.06E+08	8.59E+08
Eu-154	1.65E+08	6.63E+05	4.35E+05	1.66E+08
Eu-155	4.13E+07	1.66E+05	-	4.15E+07
Pu-238	1.45E+08	7.76E+06	2.24E+06	1.55E+08
Pu-239/240	1.49E+09	7.99E+07	9.94E+06	1.58E+09
Pu-241	1.20E+10	6.44E+08	4.98E+06	1.26E+10
Am-241	1.58E+09	8.45E+07	1.49E+07	1.68E+09
Total	3.06E+10	1.97E+09	3.78E+08	3.29E+10

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5.1.1.4 Fuel Storage Room

The fuel storage room contains no significant radiological inventory aside from facility structural contamination. This area was a discrete survey unit during the building characterization campaign reported in McVeigh [2018a]. Table 5-7 provides the summary activity assigned to this room.

Table 5-7 Summary of Radiological Inventory of the Fuel Storage Room

Radionuclide	Activity Concentration (Bqg ⁻¹)	Activity (Bq)
H-3	1.44E+02	5.7E+09
C-14	6.74E-01	1.3E+07
Cl-36	2.50E-02	4.9E+05
Co-60	9.74E-04	1.9E+04
Sr-90	2.45E-02	4.8E+05
Tc-99	1.55E-02	3.1E+05
Cs-137	8.29E-01	1.6E+07
Pu-238	2.52E-02	5.0E+05
Pu-239/240	2.12E-02	4.2E+05
U-235	7.63E-03	1.5E+05
U-238	4.49E-02	8.9E+05
Total		3.76E+08

5.1.1.5 Above-Grade Structure

Stevenson *et al.* [2016] provides volumes and weight estimates for demolition waste from the above-grade NPD building. It also provides recommendations on how to place the demolition waste in the available space in the below grade structure. It confirms it is possible to place all above-grade demolition material into the condenser room.

Sampling and analysis have been conducted for concrete floor and lower walls in various rooms and summarized in McVeigh [2018a]. The Non-Nuclear Areas were classified into three classes and the mean value of each class is presented in McVeigh [2018a]. Tritium is the predominant radionuclide in the samples however elevated concentrations of Cs-137 and Co-60 were also noted in a few samples from the Non-Nuclear Area. A total radiological inventory for the above-grade structure has been determined from these results and is outlined in Table 5-8. Note that activity concentrations are the maximum of the mean values of three classes whereas the total activities are for all Non-Nuclear Areas.

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Table 5-8 Total Radiological Inventory in the Non-Nuclear, Above-grade Structure Concrete

Radionuclide	Activity Concentration (Bqg ⁻¹)	Activity (Bq)
Am-241	1.96E-03	1.44E+06
C-14	1.00E+00	2.72E+08
Cs-137	3.90E-02	1.39E+06
Cl-36	6.38E-02	2.49E+07
Co-60	8.78E-04	3.63E+05
Ni-63	2.98E-02	1.18E+07
Pu-238	4.14E-03	2.78E+06
Pu-239/240	4.58E-03	9.92E+05
Sr-90	1.36E-02	4.79E+06
Tc-99	7.31E-03	1.52E+06
H-3	2.41E+02	8.25E+10
U-235	4.13E-03	1.77E+06
U-238	3.19E-02	2.56E+07
Total		8.28E+10

In addition to structural material there is also asbestos waste that has been removed from the boiler room. This asbestos waste is radiologically contaminated from operational incidents and accidents. The estimated radiological inventory of the 175 m³ of asbestos waste, presented in Table 5-9, is determined by the previous laboratory analysis which indicated tritium as the only radionuclide present in detectable levels Kinectrics [2015].

Table 5-9 Total Radiological Inventory from Generated Asbestos Waste

Radionuclide	Concentration (Bq/g)	Total Estimated Radioactivity (Bq)
H-3	1.0E+03	4.21E+11

Following demolition, the asbestos waste currently stored outside the facility in steel containers will be emplaced in the control wing for final grouting and disposal.

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Uncertainties

The objective of the wider NPDWF sampling and characterization plan was written to limit the upper bound of the uncertainty of radionuclide inventories. The objective was 80% Upper Confidence Limit (UCL) of the mean concentration as results were utilized for waste disposition as opposed to a clearance decision. Although the distribution of radioactive contaminants varies dependent on their physical form, mobility, location, etc., the appropriate UCLs were generated using the results of sampling for the building and systems. At 80% confidence the average difference between the estimated mean and the UCL is less than 2 and at 95% this rises to 3.5 for the Nuclear Area structure (3 for the Non-Nuclear Area). A factor of 3 is applied in the balance of the radioactive inventory to ensure the source term is appropriately bounded.

Screening

The above-grade inventory is screened against Unconditional Clearance Levels from the Nuclear Substances and Radiation Devices Regulation (SOR/2000-207) (CNSC 2000b). Radionuclides with activity concentrations that are less than their corresponding unconditional clearance levels are screened out (removed from further assessment).

Table 5-10 Above-Grade Inventory & Screening Outcomes

Inventory of Above-Grade Structure (from Table 5-8)			Unconditional Clearance Level* (Bq/g)	Screening Decision
Rad.	Activity Concentration (Bq/g)	Total Activity (Bq)		
H-3	2.41E+02	8.25E+10	1.0E+02	IN
Cs-137	3.90E-02	1.39E+06	1.0E-01	OUT
Co-60	8.78E-04	3.63E+05	1.0E-01	OUT
Am-241	1.96E-03	1.44E+06	1.0E-01	OUT
C-14	1.00E+00	2.72E+08	1.0E+00	IN
Cl-36	6.38E-02	2.49E+07	1.0E+00	OUT
Ni-63	2.98E-02	1.18E+07	1.0E+02	OUT
Pu-238	4.14E-03	2.78E+06	1.0E-01	OUT
Pu-239/240	4.58E-03	9.92E+05	1.0E-01	OUT
Sr-90	1.36E-02	4.79E+06	1.0E-01	OUT
Tc-99	7.31E-03	1.52E+06	1.0E+00	OUT
U-235	4.13E-03	1.77E+06	1.0E+00	OUT
U-238	3.19E-02	2.56E+07	1.0E+00	OUT
Total		8.28E+10		

* Nuclear Substances and Radiation Devices Regulation (SOR/2000-207) (CNSC 2000b).

Based on Table 5-10, H-3 and C-14 screen in, and their inventory values need to be carried forward in the assessment. The remaining radionuclides will not be carried forward for assessment since, comparatively, they will have negligible impacts on dose.

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5.1.1.6 Below-Grade Structure

Sampling and analysis have been conducted for concrete floor and lower walls in various rooms and summarized in McVeigh [2018a]. Whereas the Non-Nuclear area inventory has been assigned to the Above-Grade Structure, Section 5.1.1.5, the balance of the facility structure is captured here and comprises the Nuclear area. Tritium and C-14 are the predominant radionuclides in the samples however elevated concentrations of Cs-137, Am-241, Co-60 and Sr-90 were also noted in a few samples from the Nuclear Area. In order to provide a conservative estimate of radiological inventory as a result of contaminated facility structures, the following inputs or assumptions were used:

- The total surface areas within the below-grade Non-Nuclear and Nuclear Areas were summed.
- A maximum depth of 15 mm was assumed for the depth of contamination in the structure (for tritium this figure was doubled to account for its greater expected penetration depth).
- For each radionuclide, the mean concentration was calculated for the respective Non-Nuclear or Nuclear Area data.
- All radionuclide concentrations were applied over 100% of the available surface area and to the corresponding mass of material dependent on depth, resulting in a significantly conservative margin.

Table 5-11 Total Radiological Inventory in Below-grade Facility Structure Concrete

Radionuclide	Activity Concentration (Bqg ⁻¹)	Activity (Bq)
Am-241	2.21E-03	7.62E+05
C-14	1.84E+02	7.82E+10
Cs-137	9.64E-02	4.60E+07
Cl-36	9.42E-02	1.69E+07
Co-60	9.64E-03	3.23E+06
Ni-63	6.66E-02	7.12E+06
Pu-238	3.02E-02	9.70E+06
Pu-239/240	1.14E-02	2.15E+06
Sr-90	5.29E-02	1.21E+07
Tc-99	1.75E-02	3.39E+06
H-3	2.27E+03	1.75E+12
U-235	7.41E-03	1.93E+06
U-238	7.33E-02	3.12E+07
Total		1.83E+12

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5.1.2 Reactor Vault Concrete Core Measurement Data

In addition to the modelled activation product activities above, select measurement data are available from laboratory analysis of concrete cores obtained from the walls of the reactor vault. These measurement data are presented in Table 5-12. This data has been decayed to the levels expected in 2018.

Table 5-12 Radionuclide Concentrations (Bq/g) Measured in Concrete Cores (Decayed from Krasznai (1991))

Radionuclide	Vault End (0-24 cm) Bq/g	Boiler Room End (24-130 cm) Bq/g
H-3	1.25E+02	8.55E+02
C-14	1.60E+01	2.95E+02
Ca-41	2.00E+00	Not measured
Mn-54	0.00E+00	0.00E+00
Co-60	3.40E+01	0.00E+00
Ni-63	2.00E+00	Not measured
Cs-137	2.00E+00	1.00E+00
Cs-134	0.00E+00	0.00E+00
Ce-144	0.00E+00	0.00E+00
Eu-152	1.10E+01	0.00E+00
Eu-154	1.00E+00	0.00E+00

5.1.3 Tritium-in-Air Measurement Data

Select bounding scenario calculations require information on the concentration of tritium in indoor facility air. Table 5-13 presents air concentrations of tritium from 2010 to 2015 based on Primeau (2015), converted to Bq/m³ from DACs (1 DAC is equal to 3.7x10⁵ Bq/m³).

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Table 5-13 Tritium Concentrations in Indoor Air (Primeau 2015)

Sample Time			Bq/m ³							
Start	Stop	Days	R-742 (Reactor Hall)	R-607 (Ventilation Service)	R-745 (Fan Room)	C-506 (Corridor)	R-103 (Dump Tank Room)	R-306 (Spent Fuel Storage Room)	R-408 (New Fuel Room)	ST-5 (Stairwell)
2010 Jun 15	2010 Nov 08	115	7.40E+03	2.96E+05	3.70E+04	7.40E+04	7.77E+05	1.85E+05	4.81E+05	5.18E+05
2010 Nov 09	2011 Jun 06	209	3.70E+03	7.40E+04	3.70E+04	7.40E+04	3.70E+05	7.40E+04	3.70E+04	1.48E+05
2011 Jun 06	2011 Nov 15	162	3.70E+03	2.59E+05	3.70E+04	1.85E+05	1.04E+06	1.48E+05	5.18E+05	5.55E+05
2011 Nov 16	2012 Jun 12	209	3.70E+03	7.40E+04	3.70E+04	7.40E+04	3.70E+05	7.40E+04	7.40E+04	2.22E+05
2012 Jun 06	2012 Nov 06	153	3.70E+03	7.40E+04	3.70E+04	1.48E+05	6.29E+05	1.11E+05	1.48E+05	3.33E+05
2012 Nov 06	2013 Jun 17	222	0.00E+00	3.70E+04	0.00E+00	3.70E+04	1.48E+05	3.70E+04	3.70E+04	7.40E+04
2013 Jun 17	2013 Nov 06	141	3.70E+03	3.70E+04	3.70E+04	3.70E+04	2.22E+05	3.70E+04	7.40E+04	1.48E+05
2013 Nov 5	2014 May 6	182	3.70E+03	5.55E+04	2.59E+04	1.11E+04	NC	3.33E+04	1.11E+04	3.55E+05
2015 Apr 10	2015 Jun 11	62	0.00E+00	3.33E+04	1.11E+04	3.33E+04	2.18E+05	1.85E+04	4.81E+04	1.22E+05
2015 Jun 12	2015 Sep 15	95	0.00E+00	1.85E+04	3.70E+03	0.00E+00	1.85E+05	2.22E+04	0.00E+00	1.67E+05
2015 Sep 15	2015 Dec 15	91	4.07E+04	5.55E+04	7.40E+03	1.48E+04	2.81E+05	1.48E+04	1.41E+05	5.18E+04
Average:			6.39E+03	9.22E+04	2.46E+04	6.26E+04	4.24E+05	6.86E+04	1.43E+05	2.45E+05
95th Percentile			2.41E+04	2.78E+05	3.70E+04	1.67E+05	9.19E+05	1.67E+05	5.00E+05	5.37E+05

NC – Not Calculated.

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5.1.4 Drummed Waste in the Fueling Machine Room

The Fueling Machine Room houses 27 legacy waste drums containing metal conduit and piping from process systems, filters, concrete rubble, personal protective equipment (PPE) wastes, and one drum of sludge from the Bay Area sump cleanup, as well as several empty drums with internal surface contamination from heavy water storage. The drums were repackaged into 55-gal overpacks which is the configuration they can be currently found in.

Out of the twenty-seven drums in the Fueling Machine Room, only four drums have a gamma dose rate of any significance – drum #5 (Bay Sump Sludge), drum #6 (Metal and Piping), drum #7 (Protective Clothing) and drum #23 (Filter) (Vickerd 2017). In 2016, in-situ gamma spectroscopy was performed, on drum #5 and drum #7. Table 5-14 shows the measured spectroscopy results for Drum #7 as presented in (Adams 2016).

Table 5-14 Drum #7 Spectroscopy Results

Using NaI*		Using CZT**	
Nuclide	Activity (Bq)	Nuclide	Activity (Bq)
Cs-137	7.81E+06	Cs-137	6.12E+06
Co-60	9.10E+05	Co-60	1.23E+06

* NaI = Sodium Iodide (See Adams 2016)

** CZT = Cadmium-Zinc-Telluride (see Adams 2016)

For the purpose of developing a bounding source term inventory estimate, the fingerprint of radionuclides in the primary heat transport system (see 5.1.1.2) is conservatively applied to the drums. The resulting extrapolated inventory is shown in Table 5-15 below.

Table 5-15 Summary of the Radiological Inventory of Fueling Machine Room Drums (Vickerd 2017)

Source	Dominant Radionuclide	Inventory (Bq)
27 drums historically generated first phase of decommissioning (e.g., PPE&C, metal conduit & pipes, concrete rubble)	Cs-137, Sr-90, Co-60	4.19E+09

Drum #7 is of particular interest in this study because of the combustible nature of this drum’s contents, which could be involved in fire events occurring as part of bounding scenarios 8 and 9 in the fueling machine room (see Section 9.2 for further information on source terms for fire scenarios).

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5.1.5 Stack Water Concentrations

Table 5-16 shows the concentrations of radioactive material in water present at the base of the stack and has been decayed to 2018. The values for the bottom of the stack were used because they show the highest concentrations.

Table 5-16 Concentrations of Radioactive Material in the Stack Water (Decayed to 2018) (McMillan 2014)

Location	Tritium (Bq/L)	Co-60 (Bq/L)	Cs-137 (Bq/L)
NPD Stack Surface	6.47E+06	1.18E+00	9.14E-01
NPD Stack Middle	6.39E+06	1.18E+00	9.14E-01
NPD Stack Bottom	7.03E+06	1.18E+00	9.14E-01

5.1.6 Stack Concrete Contamination

Measured data are available for contamination of the stack concrete, from McVeigh (2018a).

Other than tritium and C-14, all other radionuclides detected above the reported method detection limit (MDL) were of natural origin, i.e. Naturally Occurring Radioactive Material (NORM) including and descending from the Uranium/Thorium decay series and typically found in masonry and building materials. As such their concentrations are excluded from the summary table below. (McVeigh 2018a)

These data are shown in Table 5-17 below.

Table 5-17 Radiological Inventory in the Stack Concrete (McVeigh 2018a)

Radionuclide	Activity (Bq)
H-3	6.50E+07
C-14	4.00E+07

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5.2 Non-Radiological Compounds

This section presents the non-radioactive hazardous chemicals present within the system. The non-radiological (chemical) inventory consists of following:

- Lead;
- Mercury;
- Asbestos;
- PCBs; and,
- Petroleum hydrocarbons (PHCs).

Varying amounts of mould have also been identified within the facility (e.g. AECL 2013, 2015; CNL 2018a), and as such, mould will be considered as part of future detailed work planning. The NPD Closure Project will apply PPE during activities where exposure is possible, or clean up the area if required.

5.2.1 Lead

Lead paint exists throughout facility. Additionally, there are large quantities of lead bricks, shielding material, and other sources of encased lead. Table 5-18 presents the estimated inventory of lead based on information in McVeigh (2020).

Table 5-18 Quantity & Location of Lead (Pb) During Decommissioning (McVeigh 2020)

Room	Quantity of Lead
Fueling Machine Room (Room 405)	<ul style="list-style-type: none"> • Solid lead, encased within Shielded Room walls: 88,990 kg (<i>i.e. 44,495 kg for each of the two rooms</i>) • Lead shot in the roof of the Shielded Rooms: 15,848 kg (<i>i.e. 7,924 kg for each of the two rooms</i>) • Two shield gates in Fueling Room floor: 45,704 kg (<i>i.e. 22,852 kg in each of the two gates</i>)
New Fuel Room	23,148 kg, lead shielding bricks
Reactor Vault	25,000 kg, encased in steel
(Spent) Fuel Storage Room	4,500 kg, encased in steel
Boiler Room	18,797 kg, encased in steel
Active Auxiliaries Room (Room 307)	2,800 kg, exposed lead shield wall
Lead Paint (Above-Grade)	335 kg During decommissioning this lead paint is located throughout the above-grade structure. After decommissioning (i.e. into postclosure) this lead paint will be located in the Turbine Room since this is where the above-grade building rubble will be emplaced for final grouting and disposal.
Paint (Below-Grade)	397 kg

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5.2.2 Mercury

Residual mercury in the boiler room is the only anticipated source of mercury throughout the facility. Overall, it is estimated that there is <0.01 kg of mercury remaining in the boiler room, based on residual levels measured in the wells area sump (McVeigh 2020).

5.2.3 Asbestos

Asbestos is present in a variety of forms such as pipe insulation, floor tiles and building cladding. Removal of asbestos pipe insulation and equipment insulation from the non-nuclear areas was completed in 1991 and has been removed from the site. In 2014, the first phase of asbestos abatement began in the nuclear areas. Asbestos was removed from all accessible areas in the nuclear area, with the exception of the boiler room. In 2017, a large asbestos removal campaign was completed in the Boiler Room and only small quantities of asbestos remain. The asbestos waste is packaged and staged to ensure safe interim storage at the NPD site until the safety case for disposal within the facility is approved, at which time the plan is to emplace the asbestos within the facility (e.g. in the control wing basement) and grout in-place as part of facility grouting.

Asbestos estimates from McVeigh (2020) are presented in Table 5-19, along with corresponding locations.

Table 5-19 Estimated Asbestos Inventory (McVeigh 2020)

Location at Start of Decommissioning	Location-Compartment at Time of Closure
Sealand container outside facility (5) – 165 m ³	Basement of Control Wing – 175 m ³
Inside walls in above grade structure – 20 m ³	Turbine Room (Condenser Pit) – 20 m ³
Inside reactor vault – 5 m ³	Inside reactor vault – 5 m ³
Inside Boiler Room – 30 m ³	Inside Boiler Room – 30 m ³
Exterior Transite panels – 10 m ³	

Using a density of 2.4 g/cm³ for chrysotile-form asbestos (NIOSH 2016c), and a total volumetric inventory of 230 m³, this produces a total (bounding) estimated inventory of 552,000 kg of asbestos, by mass.

5.2.4 PCBs

The primary source of PCBs in the NPD facility is light ballasts. Transformers can also contain PCBs; however, the transformers present on site have been found to be free of PCBs (Vickerd, 2014).

To facilitate decommissioning of the NPD facility, CNL's plan is to remove all light ballasts, verify if they are PCB containing, and disposition according to CNL's Hazardous Waste Program

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(Schruder and Vickerd, 2017), before decommissioning of the facility begins. However, there is a small possibility that a select few ballasts (e.g. 3 or 4 most likely in the condenser pit and turbine hall) might be safer to remove while decommissioning is underway. In such an event, these remaining light ballasts will be removed once some grouting activities have taken place and effectively raised the level of the floor, allowing safe access. Once these light ballasts have been removed, grouting will resume. Ultimately, all PCB-containing light ballasts will have been removed from the facility by the time decommissioning is complete.

The following table presents the estimated quantities, and locations, of PCB-containing light ballasts at present, at the time decommissioning activities begin, and at the time decommissioning is complete and the NPD facility is closed.

Table 5-20 Estimated PCB Inventory

Present Count & Location <i>As of April 2021</i>	Location at Start of Decommissioning	Location/Compartment at Time of Closure
Boiler Room – 68 ballasts	Boiler Room – zero	Boiler Room – zero
Condenser Pit – 56 ballasts	Condenser Pit – zero (<i>possibly select few remaining</i>)	Condenser Pit – zero

Given that there is uncertainty in whether or not all PCBs will be removed from the facility before decommissioning begins, this assessment has chosen a conservative approach and assumes that the bounding number of light ballasts (i.e. 68, Boiler Room) will be present at the time decommissioning begins and are removed as part of the decommissioning activities.

Schruder & Vickerd (2017) also addresses the potential for PCBs to be present in paint and caulking in the NPD facility by noting that paint and caulking samples collected at Whiteshell facilities - of similar vintage - all contained less than the regulated level of 50 mg/kg of PCBs in solids. CNL has sampled the paint and caulking in the NPD Facility for the potential for PCBs to be present, and all samples contained less than the regulated level of 50 mg/kg of PCBs in solids. As such, PCB containing paint and caulking do not warrant further assessment. (McVeigh 2018)

5.2.5 Petroleum Hydrocarbons (PHCs)

For PHC contamination, evidence of a historical oil leak was found in the tile drains and remediation was undertaken. Historic unauthorized surface dumpsites have been observed to include oil cans, anti-freeze containers, tires, miscellaneous cans, and at one location, an empty 45 gallon drum. Therefore, the empty waste containers may have contained hydrocarbons and/or other industrial chemicals that may have leaked. There was no evidence of the presence of radionuclides of concern (ROCs) in waste items, though data are limited to Cs-137. (PostSA TSD)

Athauda-Arachchige (2015) mentions that PHC contamination exists near the facility due to a leak from an underground diesel fuel storage tank in 1992. About 270 m³ of contaminated soil was excavated and removed from the site. Monitoring wells were subsequently installed and

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groundwater samples were analyzed for total petroleum hydrocarbons, along with a number of measurements related to soil. As outlined in Killey (2014), PHC analysis from these groundwater wells found decreasing levels over the time (1993 to 2011), with the most recent analyses for PHCs detecting 70 µg/L of hydrocarbons with carbon contents of greater-than 10 carbon atoms per molecule, in samples from nearby wells. None of the samples contained total PHC concentrations that exceed the 200 µg/L concentration recommended in the Environment Canada guideline for high- sensitivity sites.

For PHCs related to decommissioning activities, it is assumed that fuel quantities involve vehicle fuel tanks, and day tanks of diesel fuel for daily refueling of equipment. Therefore, any potential spill of PHCs would be small (i.e. less than 100 L). Spill response procedures for the site would address soil contamination from accidental fuel spills of this nature. The facility is located approximately south-west of the river, with access roads further south-west (i.e. further from the river), and therefore, direct pathways to river surface water are unlikely, for spills of 100 L or less. Pathways to workers would be limited to inhalation of vapours, which is negligible.

Therefore, on these bases, PHCs do not warrant further assessment.

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6.0 DISPERSION & TRANSPORT MODELLING

This section describes the dispersion and transport modelling methods used to estimate contaminant concentrations in air and water. Overall, three types of dispersion modelling are used:

- **Short-Distance Airborne Dispersion Model:** to estimate air concentrations from releases that occur inside a room and do not escape the building envelope;
- **Long-Distance Airborne Dispersion Model:** to estimate outdoor air concentrations from releases that occur outdoors (or indoors but subsequently escape the building envelope); and,
- **River Dilution Model:** to estimate the concentration of contaminants in river surface water, from releases that enter the river.

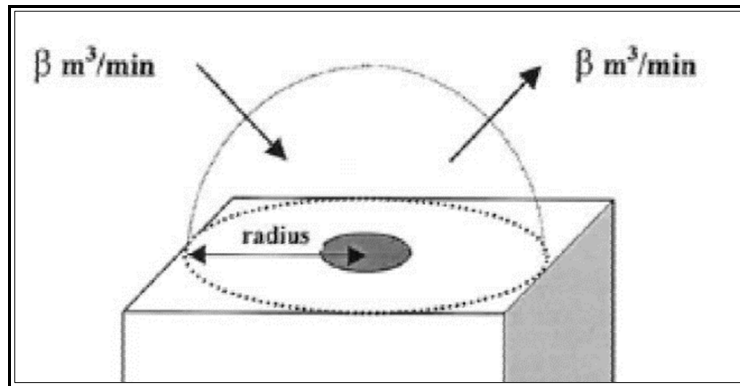
6.1 Short-Distance Airborne Dispersion Model

A short-distance dispersion model is used to calculate indoor dispersion, and outdoor dispersion for nearby worker receptors within the licensed area. The simplest model used to estimate airborne concentrations from releases in an enclosed area is the steady-state room concentration model, which assumes that the emitted contaminant is uniformly dispersed in the entire room. However, an important drawback of this model is that the higher concentrations experienced in close proximity to the emission point are overlooked. As such, if a receptor is located near the source of the release, this model would under-estimate the air concentration to which the receptor is exposed. To avoid this drawback, a more complex model is used based on a two-dispersion-zone pattern as described below, based on Keil *et al.* (2009).

In the Keil *et al.* (2009) two-zone model, a room is considered to contain two zones – a near field zone surrounding the emission source, and a far-field zone comprising the remainder of the room. The air in each zone is completely mixed but with a limited air exchange between the two zones. Figure 6-1 presents an illustration of the two-zone model. The radius of the hemisphere is selected to contain the breathing zone of the worker whose exposure level is to be estimated. The flow (β) into and out of the near field is calculated as a rate in m^3/s . The room supply and exhaust air flow (F) is also calculated as a rate in m^3/s .

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Figure 6-1 Two-Zone Model Concept



For a source term emission rate of 'QR' (in Bq/s, or g/s), the concentrations in near field (C_{NF}) and far field (C_{FF}) are calculated as follows:

$$C_{NF} = QR/F + QR/\beta \quad (\text{in Bq/m}^3 \text{ or g/m}^3)$$

$$C_{FF} = QR/F \quad (\text{in Bq/m}^3 \text{ or g/m}^3)$$

In a room with low air velocity, or for large rooms, the near field concentration is much larger than far field concentration. As room size increases, β decreases relative to F. Therefore, the two-zone model predicts relatively higher exposure values near the emission source compared to a room model relying on uniform mixing.

The value of β is calculated as follows: using the values of the near field radius (R) in meters, room volume (V) in m^3 , and F as follows:

$$\beta = 0.48 F \times V / R^3$$

Where,

β = flow between near-field and far-field (in m^3/s);

F = room air supply/ventilation flow (in m^3/s);

V = total room air volume (in m^3);

R = chosen near-field radius (in m).

Table 6-1 presents the values used for R, V, and F parameters.

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Table 6-1 Two-Zone Model - Parameter Values

Parameter	Value	Units	Notes
<i>R</i> (Near-Field radius)	2	m	Considered to be approximately the height of the worker (i.e. 2 m), such that the near field includes the worker receptor breathing zone.
<i>V</i> (Room Volume – Indoor Scenarios)	807 (FM Room)	m ³	For some indoor scenarios, the approximate dimensions of the fueling machine room, (above the reactor vault) are used. The volume of the fueling machine room is based off interpretation of drawings NA25-F-2254, Na25-F-2329 and 201E284 R3. For other indoor scenarios, the approximate dimensions of the boiler room are used.
	4200 (Boiler Room)	m ³	
<i>V</i> (Room Volume – Outdoor Scenarios)	1,000,000	m ³	For bounding scenarios occurring outdoors (i.e. Bounding Scenarios 1 to 5, and 12) a volume of 100 m x 100 m x 100 m is assumed, in order to represent a large virtual room volume.
<i>F</i> (Air Flow – Indoor Scenarios)	0.1	Air Exchanges per Hour	Though the ventilation system will be deactivated during decommissioning activities, natural ventilation/air-exchange will still occur. For typical above-ground structures a natural air exchange rate of 1 (i.e. one exchange per hour) can be used. However, given that many of the facility's rooms are interior rooms, without windows, and are located underground, a more conservative value of 0.1 (i.e. 10% of the normal value) is used.
	0.0224 (FM Room)	m ³ /s	Based on the room volume of the fueling machine room (see above), this produces an air flow of 0.0224 m ³ /s.
	0.0117 (Boiler Room)	m ³ /s	Based on the room volume of the boiler room (see above), this produces an air flow of 0.0117 m ³ /s.
<i>F</i> (Air Flow – Outdoor Scenarios)	72	Air Exchanges per Hour	Based on an outdoor wind speed of 2 m/s, multiplied by the 100 m x 100 m area (m ²), to obtain m ³ /s; for air exchanges convert to m ³ /hour then divided by the total outdoor 'room' volume to obtain air exchanges per hour.
	20,000	m ³ /s	

Table 6-2 presents the resulting dispersion factors for unit release (1 Bq/s or 1 g/s as applicable).

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Table 6-2 Two-Zone Model – Unit Dispersion Factors

[resulting air concentrations per unit release of 1 Bq/s or 1 g/s, as applicable]

Location	Two-Zone: Near-Field	Two-Zone: Far-Field	Units
Outdoor	5.00E-5	5.0E-5	Bq/m ³ per Bq/s release
	5.00E-5	5.0E-5	g/m ³ per g/s release
Indoor – Fueling Machine Room	4.55E+01	4.46E+01	Bq/m ³ per Bq/s release
	4.55E+01	4.46E+01	g/m ³ per g/s release
Indoor – Boiler Room	8.61E+00	8.57E+00	Bq/m ³ per Bq/s release
	8.61E+00	8.57E+00	g/m ³ per g/s release

6.2 Long-Distance Airborne Dispersion Model

Select bounding scenarios involve airborne releases with the potential to escape the building envelope (or, involve outdoor air releases). For such scenarios, it is necessary to calculate the air concentration at distance (i.e. at public receptor locations), accounting for atmospheric dispersion. This is accomplished by multiplying the released quantity (i.e. the source term) by an atmospheric dispersion factor (ADF). ADFs are derived using air dispersion models - accounting for conditions such as meteorology and topography - and represent the conversion from a release rate (e.g. mass per time) to an air concentration at a particular location (e.g. mass per volume):

$$C_{\text{air}} = \text{ER} \times \text{ADF}$$

Where,

C_{air} = air concentration at location (in Bq/m³ or µg/m³);

ER = emission Rate (in Bq/s or µg/s);

ADF = atmospheric dispersion factor (in g/m³ per g/s, or equivalent units).

ERs are described in greater detail in Section 6.2.1 below. ADFs are described in greater detail in Section 6.2.2 below.

6.2.1 Emission Rate

For releases from *non-fire* bounding scenarios (i.e. bounding scenarios 3,4, 5, 8, 9, and 12) the emission rate (ER) is calculated by dividing the source term (Q) by the duration of the release (T_{REL}):

$$\text{ER} = \text{Q} / T_{\text{REL}}$$

Where,

ER = emission rate (in Bq/s or g/s);

Q = source term (in Bq or g) [presented in Section 9.2.1];

TREL = release time (s, hr, or a) [presented in Table 6-3 below].

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Table 6-3 Release Times for Non-Fire Bounding Scenarios

Bounding Scenario No.	Brief Description	Release Time (T _{REL})
3	Tornado (Rad.)	1 hour
4	Tornado (Non.-Rad.)	1 hour
5	Flood (Rad.)	24 hours
8	Exposure (Drilling; Rad.) [variants a & b]	a) 32 hours; for increased drilling time b) 16 hours; for increased source term
9	Exposure (Drilling; Non.-Rad.)	Not Calculated – no MAR is present (see Table 9-6).
12	Stack Collapse & Release (Rad.)	Instantaneous (1 min)

For releases from *fire* bounding scenarios (i.e. bounding scenarios 1, 2, 10, and 11), the ER is calculated based on the source term (Q) and the duration of the fire (T_{FD}):

$$ER = Q / T_{FD}$$

Where,

ER = emission Rate (in Bq/s or g/s);

Q = source term (in Bq or g) [presented in Section 9.2.1];

T_{FD} = fire duration (s, or a) [presented in Table 6-4 below].

Table 6-4 Release Times for Fire Bounding Scenarios

Bounding Scenario No.	Brief Description	Release Time (T _{REL})
1	Forest Fire (Rad.)	1 hour
2	Forest Fire (Non.-Rad.)	1 hour
10	Indoor Fire (Rad.)	1 hour
11	Indoor Fire (Non.-Rad.)	1 hour

6.2.2 Atmospheric Dispersion Factor

This section provides a brief description of the ADFs available for this study.

Accident Scenario ADFs from CALPUFF Modelling

ADFs for accident scenarios were derived by performing atmospheric dispersion modelling using CALPUFF (Scire *et al.* 1990, 2000) to simulate unit releases from the NPD facility for fire events, and, for non-fire events. The CALPUFF model has an option of using the area buoyancy source, and is therefore applicable for fire and non-fire simulations. A brief overview is discussed below, with resulting ADFs; additional information on CALPUFF modelling is presented in Appendix C.

Meteorological conditions vary from hour-to-hour, but are assumed to be uniform throughout the modelling domain within any give hour. Meteorological data from Ottawa were used to perform

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the modelling, with a separate case modelled using supplementary wind and temperature data from CRL where available.

A tiered grid was used for receptor placement, ranges from 20 m to 500 m. In addition, discrete sensitive receptors - including residential and recreational locations in vicinity of the NPD facility, as well as the airborne human receptors from the (Chouhan & Scheier, 2011) DRL - were also incorporated.

Modelling results for fire scenarios are presented in Table 6-5 as ADFs (in g/m^3 per g/s) and 1-hour concentrations (in $\mu\text{g}/\text{m}^3$) at discrete receptor locations. Modelling result for non-fire scenarios are presented in Table 6-6 also as ADFs (in g/m^3 per g/s) and 1-hour concentrations (in $\mu\text{g}/\text{m}^3$) at discrete receptor locations. ADF results that incorporate CNL measured wind data were chosen for use in calculations.

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Table 6-5 ADFs for Fire Scenarios

Receptors	Location relative to the NPD Facility		Fire Scenario			
	Distance from NPD (m)	Sector	CALPUFF-Ottawa Meteorology		CALPUFF-CNL Wind	
Receptor ID			Dilution factor (g/m ³ per g/s)	Max 1-h Conc. (µg/m ³)	Dilution factor (g/m ³ per g/s)	Max 1-h Conc. (µg/m ³)
Residential (R1)	1222	SE	3.6E-07	0.4	3.5E-07	0.3
Residential (R2)	1149	SW	3.7E-07	0.4	3.5E-07	0.3
Residential (R3)	1199	SW	3.6E-07	0.4	4.0E-07	0.4
Recreational (R4)	1243	ESE	2.9E-07	0.3	3.2E-07	0.3
Guardhouse	83	W	9.4E-06	9.4	5.2E-06	5.2
Rapides des Joachims residential	2437	NW	2.5E-07	0.2	2.9E-07	0.3
Point Stewart residential	1987	ESE	2.5E-07	0.3	2.6E-07	0.3
Cottage	1627	ESE	2.5E-07	0.2	2.8E-07	0.3
Rolphon residential	2665	WSW	3.7E-07	0.4	3.9E-07	0.4
Mackey beef farm	11552	W	7.3E-08	0.07	1.2E-07	0.1
Bass Lake beef farm	10838	SE	1.7E-07	0.2	2.1E-07	0.2

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Table 6-6 ADFs for Non-Fire Scenarios

Receptors	Location relative to the NPD Facility		Non-Fire Scenario			
	Distance from NPD (m)	Sector	CALPUFF-Ottawa Meteorology		CALPUFF-CNL Wind	
			Dilution factor (g/m ³ per g/s)	Max 1-h Conc. (µg/m ³)	Dilution factor (g/m ³ per g/s)	Max 1-h Conc. (µg/m ³)
Receptor ID						
Residential (R1)	1222	SE	2.5E-04	254.8	3.5E-04	347.8
Residential (R2)	1149	SW	4.1E-04	413.8	3.3E-04	328.9
Residential (R3)	1199	SW	2.6E-04	258.0	2.9E-04	289.7
Recreational (R4)	1243	ESE	2.5E-04	246.3	2.9E-04	292.1
Guardhouse	83	W	1.5E-02	15317.0	1.5E-02	15291.0
Rapides des Joachims residential	2437	NW	1.2E-04	120.1	1.1E-04	111.5
Point Stewart residential	1987	ESE	1.2E-04	115.3	9.2E-05	92.4
Cottage	1627	ESE	1.6E-04	155.5	2.0E-04	202.3
Rolphton residential	2665	WSW	9.2E-05	92.1	8.4E-05	83.7
Mackey beef farm	11552	W	9.9E-06	9.9	1.6E-04	163.2
Bass Lake beef farm	10838	SE	9.9E-06	9.9	5.6E-06	5.6

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Overall, the ADFs derived from CALPUFF modelling (i.e. those above) are used preferentially for air dispersion calculations; though ADFs from CNL (i.e. those described below) are shown in normal operations for comparison.

Normal Operations ADFs from AERMOD and CALPUFF Modelling

ADFs for normal operations were derived by performing atmospheric dispersion modelling using AERMOD (U.S. EPA 2001) and CALPUFF (Scire *et al.* 1990, 2000) to simulate a unit release from the NPD facility. A brief overview is discussed below, with resulting ADFs; additional information on modelling is presented in Appendix C.

The AERMOD model is the regulatory model currently recommended by the U.S.EPA and the Ontario Ministry of Environment & Climate Change (OMOECC) for simulating short-term air quality impacts from industrial complexes. The AERMOD model is a steady-state Gaussian Plume model. The model accepts meteorological data records to define the conditions for plume rise, transport and dispersion, and estimates the concentration or deposition value for each source-receptor combination, as well as short-term and long-term averages.

The meteorological data set used was the regional data for Ottawa (applicable for the Eastern region), prepared by the OMOECC, for forested land use, for the year 2000. In addition, select meteorological data were provided by CNL from the Chalk River Laboratories site for the period 2009 to 2015.

A tiered grid was used for receptor placement, which ranged from 20 m to 500 m (based on recommendations provided by OMOECC). In addition to the OMOECC grid, discrete sensitive receptors - including receptor locations in vicinity of the NPD facility - were also included.

AERMOD modelling results for normal operations are available in Appendix C.2.

As mentioned, ADFs for normal operation were also re-derived using CALPUFF. In contrast to AERMOD, CALPUFF is a multi-layer, gridded non-steady-state puff dispersion model that can simulate the effects of temporally and spatially varying meteorological conditions on pollutant transport. In addition, CALPUFF can remove pollutants through dry and wet deposition processes and transform pollutant species through chemical reaction. CALPUFF can also use three-dimensional meteorological fields.

CALPUFF modelling used the same regional meteorological data for Ottawa as was used in AERMOD, with the same combined CNL wind and temperature data. Meteorological conditions were assumed to vary from hour-to-hour, but were assumed to be uniform throughout the modeling domain within each given hour. A volume-source unit release was used, centred on the NPD facility (see Appendix C.2 for details).

CALPUFF modelling results for normal operations are shown in Table 6-7. A comparison of ADFs from AERMOD vs. CALPUFF shows that those derived by CALPUFF are more conservative. Therefore, CALPUFF-derived ADFs for normal operations are used in subsequent calculations.

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Table 6-7 ADFs for Normal Operations Scenarios

Receptors	Location relative to the NPD Facility		Atmospheric Dispersion Factors for Normal Operations	
	Distance from NPD (m)	Sector	CALPUFF using Ottawa Meteorology	CALPUFF using CNL Wind Data
Receptor ID			Dilution factor (g/m ³ per g/s)	Dilution factor (g/m ³ per g/s)
Residential (R1)	1222	SE	1.7E-06	4.8E-06
Residential (R2)	1149	SW	2.3E-06	5.3E-06
Residential (R3)	1199	SW	2.1E-06	4.9E-06
Recreational (R4)	1243	ESE	2.3E-06	6.3E-06
Guardhouse	83	W	6.1E-04	4.4E-04
Rapides des Joachims residential	2437	NW	4.4E-07	3.7E-06
Point Stewart residential	1987	ESE	7.7E-07	2.9E-06
Cottage	1627	ESE	1.2E-06	4.2E-06
Rolphon residential	2665	WSW	5.8E-07	1.6E-06
Mackey beef farm	11552	W	4.7E-08	9.1E-08
Bass Lake beef farm	10838	SE	3.8E-08	9.8E-08

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ADFs from Chouhan (2016a)

In addition to the CALPUFF-derived ADFs discussed above, alternative ADFs are available for NPD site from Chouhan (2016a). The Chouhan (2016a) ADFs are those used in the 2011 DRL (Chouhan & Scheier, 2011). Table 6-8 presents the Chouhan (2016a) ADFs for the 6 key receptor locations identified in the DRL.

Table 6-8 ADFs from Chouhan (2016a)

Potential Critical Group Receptor	Location Relative to NPD Stack			Dilution Factor (Bq/m ³ per Bq/s)
	Distance (m)	Direction		
		Degrees from North	Sector	
Rapides des Joachims residential	2437	307	NW	3.01E-07
Point Stewart residential	1987	120	ESE	2.41E-07
Cottage	1627	115	ESE	2.53E-07
Rolphton residential	2665	247	WSW	1.11E-07
Mackey beef farm	11552	264	W	2.35E-08
Bass Lake beef farm	10838	144	SE	2.18E-08

6.2.3 Dispersion for Tornado Scenarios

For bounding scenarios involving Tornado accidents, an estimate of the dilution is needed. Tornado ADF's used for this analysis are obtained from Weber and Hunter (US DOE 1996) for a tornado in the EF-2 to EF-3 range. The dispersion factors are based on the distance from the tornado, for unit releases of 1 g/s. Table 6-9 shows the dilution factors corresponding to the distance from the tornado.

Table 6-9 Distance and Corresponding Dilution Factor (US DOE 1996)

Distance (km)	Dilution (s/m ³)
2	1.00E-13
3	4.50E-06
4	5.00E-06
5	4.00E-07
6	3.80E-07
7	3.40E-07
8	3.00E-07
9	2.50E-07
10	2.00E-07
15	1.50E-07
20	1.00E-07
25	9.50E-08
30	9.00E-08
35	7.00E-08
40	5.00E-08
45	5.25E-08
50	5.50E-08
70	4.00E-08
100	3.00E-08

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Tornado ADFs were assigned to each receptor location based on the distance between the receptor location and the NPD site, assuming that the tornado strikes the NPD site directly. Table 6-10 shows how each receptor was categorized by distance, and, its resulting ADF. To avoid underestimating the resulting concentrations, a lower dilution factor category was applied (to be conservative). For example, if the receptor's distance was 2.7 km, then the ADF for 3 km was applied since it represents less dilution (higher concentrations) than the ADF for 2 km.

Table 6-10 Receptor Location and Corresponding ADF

Receptor	Distance from NPD (m) (see Section 4.6)	Distance from NPD (km)	Corresp. ADF Distance Interval (m)*	Corresp. ADF (g/m ³ per g/s)
Residential (R1)	1222	1.222	2	1.00E-13
Residential (R2)	1149	1.149	2	1.00E-13
Residential (R3)	1199	1.199	2	1.00E-13
Recreational (R4)	1243	1.243	2	1.00E-13
Guardhouse	83	0.083	2	1.00E-13
Rapides des Joachims residential	2437	2.437	3	4.50E-06
Point Stewart residential	1987	1.987	2	1.00E-13
Cottage	1627	1.627	2	1.00E-13
Rolphon residential	2665	2.665	3	4.50E-06
Mackey beef farm	11552	11.552	10	2.00E-07
Bass Lake beef farm	10838	10.838	10	2.00E-07

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6.3 Air-to-Soil Transferring Model

Airborne releases from the NPD facility can be transported through the air and deposited on the soil around the facility. This section describes the methods used to predict the concentration in soil resulting from airborne releases.

6.3.1 Normal Operation Scenarios

Soil concentrations depend on deposition velocity, the duration of deposition, and natural mechanisms that remove lead from the soil (e.g. soil erosion, leaching and surface run-off). For this assessment, the only soil removal mechanism considered is leaching, which is conservative.

Deposition from the atmosphere occurs both by washout during periods of precipitation and by interaction with the surface when precipitation is not falling. A combined wet and dry deposition velocity V_g (m/s) is calculated following Clause 6.3.3.1 in N288.1-14 (CSA 2018):

$$V_g = V_d + V_w$$

Where,

V_g	Combined deposition velocity (m/s);
V_d	Dry deposition velocity (m/s) [0.0014; CSA N288.1-14 (2018) Table 14];
V_w	Wet deposition velocity (m/s).

Wet deposition velocity is different for soil that is exposed to both snow and rain. In such cases deposition velocity can be calculated as follows (see CSA 2018, Clause 6.3.3.1):

$$V_w = f_{pj} \times W_r \times P$$

Where,

V_w	Wet deposition velocity (m/s);
f_{pj}	Fraction of the time precipitation falls when the wind blows from sector j (unitless);
W_r	Washout ratio (unitless);
P	Long-term average precipitation rate (m/s).

Table 6-11 Default Values for Deposition Velocity Calculation

Parameter	Value	Reference
f_{pj} (unitless)	0.36	CSA N288.1-14 (2018) Clause 6.3.3.3 the maximum value
W_r (unitless)	5.5E+06	CSA N288.1-14 (2018) Table 14 washout ratio (rain and snow) for all others
P (m/s)	3.03E-08	CSA N288.1-14 (2018) Clause 6.3.3.4 Value for Eastern Ontario.
V_w (m/s)	6E-02	= $f_{pj} \times W_r \times P$ (from values above)
V_d (m/s)	1.4E-03	CSA N288.1-14 (2018) Table 14 for all others
V_g (m/s)	0.0614	= $V_d + V_w$ (from values above)

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The soil loss constant from the soil due to leaching is calculated using the following equation, which merges equations 6-32 and 6-33 of CSA N288.1-14 (CSA 2018):

$$k_{leaching} = \frac{q_{infil}}{Z_{soil}[\theta + (\rho \times K_d)]}$$

Where,

$k_{leaching}$	Soil loss coefficient due to leaching (1/yr);
q_{infil}	Net infiltration rate of water through the soil (m/y) [0.32; CSA N288.1-14 (2018); Clause 6.3.6.3; value for Eastern Ontario soils];
Z_{soil}	Depth of the top mixed soil layer (m) [0.2; CSA N288.1-14 (2018) Clause 6.3.1.1];
ρ	Bulk soil density (kg/m ³) [1300; CSA N288.1-14 (2018) Clause 6.3.2.2; value for loam (loam soil type is recommended for eastern Ontario sites (CSA N288.1-14 (2018), Clause 6.3.1.2))];
θ	Soil water content (m ³ water/m ³ soil) [0.2, CSA N288.1-14 (2018) Clause 6.3.4.3; value for loam (loam soil type is recommended for eastern Ontario sites (CSA N288.1-14 (2018), Clause 6.3.1.2))];
K_d	Equilibrium distribution coefficient (m ³ /kg) [13 for Pb, IAEA 2010 Table 14, mean value for loam (loam soil type is recommended for eastern Ontario sites (CSA N288.1-14 (2018), Clause 6.3.1.2))].

Soil concentrations over the desired build-up period were estimated using the following equation:

$$C_{soil}(t) = C_{air} \times \frac{V_g}{Z_{soil} \times \rho} \times \left(\frac{1 - \exp(-kt)}{k} \right) \times \frac{1 \text{ kg}}{1000 \text{ g}} \times \frac{365 \text{ d}}{y} \times \frac{86400 \text{ s}}{d} \times \frac{10^6 \mu\text{g}}{1 \text{ g}}$$

where:

$C_{soil}(t)$	Soil concentration after t years (µg/g);
t	Build-up period (yr);
C_{air}	Average air concentration over the t-year time period due to air releases from the facility (g/m ³);
V_g	Deposition velocity for soil (m/s);
Z_{soil}	Depth of the top mixed soil layer (m);
ρ	Bulk soil density (kg/m ³);
k	Soil loss coefficient due to leaching (1/yr) [calculated $k_{leaching}$, as above].

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Table 6-12 Parameter Values for Soil Concentration Calculations

Parameter	Value	Reference
C_{air} (g/m ³)		Calculated separately for each scenario. See Section 8.0.
V_g (m/s)	0.0614	Calculated in Table 6-11 Default values for Deposition Velocity Calculation
ρ (kg/m ³)	1300	CSA N288.1-14 (2018) Clause 6.3.2.2
Z_{soil} (m)	0.2	CSA N288.1-14 (2018) Clause 6.3.1.1
t (yr)	Several	Determined separately for each scenario, based on their release durations. See Section 8.5.2 and Section 8.6.1 for normal operations.
k (1/yr)	5.59E-03	Calculated

6.3.2 Accident Scenarios

For accident scenarios, which occur over short periods of time, the total deposition to soil must be calculated using a different method than for normal operations. For accidents, air-to-soil deposition consists of dry deposition and wet deposition.

Dry deposition can be calculated as:

$$D_d = V_d C_{air} \Delta t$$

Where,

D_d Total dry deposition (g/m² or Bq/m²);

V_d Dry deposition velocity (m/s);

C_{air} Average air concentration at receptor site, over the time period Δt , due to air releases during the accident at the facility (g/m³ or Bq/m³);

Δt Time during which the plume is over the receptor site (s).

It is noted that there is no dry deposition for gases such as tritium (CSA N288.2-M91 2003).

Wet deposition rate is calculated using a washout ratio as described in CSA N288.1-14 (CSA 2018), making use of currently available air concentration data. It is important to note that this model is generally used for normal releases from a facility, and thus applying it to accidents is likely conservative. In this approach,

$$D_w = V_w C_{air} \Delta t$$

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Where,

D_w Total wet deposition (g/m² or Bq/m²);

V_w Wet deposition velocity (m/s) which in turn is given by

$$V_w = W_r p_s$$

Where,

W_r Washout ratio for rain (unitless);

p_s Precipitation rate (m/s)

The washout ratio W_r given in CSA N288.1-14 (CSA 2018) for rainfall only is used here. There is no wet deposition for noble gases.

Table 6-13 summarizes the parameters for dry and wet deposition.

Table 6-13 Values for Dry and Wet Deposition

Parameter	Value	Reference
V_d (m/s)	0.0014	CSA N288.1-14 (2018) Table 14 for all others
W_r (unitless)	6.30E+05	CSA N288.1-14 (2018) Table 14 washout ratio (for rain) for all others.
p_s (m/s)	8.23E-07	Government of Canada (2020), maximum extreme daily rainfall (71.1 mm) on August 2, 1965 at Chalk River AECL station, divided by 24 hours (86400 s). This is extremely conservative.
V_w (m/s)	0.52	= $W_r \times p_s$ (from values above)
C_{air} (g/m ³ or Bq/m ³)		Calculated separately for each scenario. See Section 9.0.
Δt (s)	3600	1 hour for forest fire, tornado and indoor fire, see Table 6-3 and Table 6-4.
	60	1 min for stack collapse & release, see Table 6-3.

The dry and wet deposition rates are summed and converted to mass concentration by the equation below:

$$C_{soil} = \frac{D_d + D_w}{Z_{soil} \times \rho} = \frac{V_d + W_r p_s}{Z_{soil} \times \rho} \times C_{air} \times \Delta t$$

Where

C_{soil} Soil concentration (µg/g or Bq/kg);

Z_{soil} Depth of the top mixed soil layer (0.2 m, CSA N288.1-14 (2018) Clause 6.3.1.1);

ρ Bulk soil density (1300 kg/m³, CSA N288.1-14 (2018) Clause 6.3.2.2)

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7.0 HAZARD IDENTIFICATION & SCENARIO DEVELOPMENT

7.1 Hazard Identification Methodology

Hazard identification involves the identification of materials, equipment, or processes that have the potential to expose workers or members of the public to potentially harmful materials or conditions.

The hazard identification methodology used in this study is outlined below. This methodology is based on hazard identification guidance from the Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AICE) *Guidelines for Chemical Process Quantitative Risk Analysis* (CCPS 2000). It is also consistent with guidance presented in Johnston (2016) *Procedure – Hazard Identification*, and with general safety assessment guidance from the CSA (2014a) N294-09 standard.

The hazard identification methodology includes:

1. Dividing the project into Work Breakdown Structures (WBSs) according to the decommissioning plan (consistent with Canadian Standards Association (CSA) N294-09 standard on *Decommissioning of Facilities Containing Nuclear Substances* (CSA 2014a)).
2. Identifying activities associated with each WBS (and accounting for key location-specific activities). [see Section 7.2]
3. For each activity, identifying associated hazards based on:
 - a) Reviewing available project/site documentation, namely:
 - Athauda-Arachchige (2015) *Safety Analysis Report* (for the pre-decommissioning SwS state);
 - Titterington (2016) *Project Description*;
 - Aikens (2019) *Detailed Decommissioning Plan - Nuclear Power Demonstration Waste Facility*;
 - Dunfield & Glennie (2012) *Fire Hazard Analysis/Assessment*;
 - Gillespie (2016) *NPD Waste Management Plan*;
 - Ingram (2017) *Emergency Procedure*;
 - De Waele (2016) *Effluent Monitoring Plan* (for the pre-decommissioning SwS state);
 - Reynard (2015) *Gamma Spectrometry of Waste Bag, HEPA Filter and Trailer at NPD*;
 - McVeigh (2016a) *Zoning Plans – Radiological Safety Zone Plan for NPDWMF*;
 - Milman (2004) *Life Management Program for NPD Structures*;
 - AECL (2015) *Industrial Hygiene Survey Report – Hazard Assessment*; and,
 - Accident records from Seto (2014) “*Operational Incidents and Accidents in NPD*”;

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- b) An understanding of the location of the site and its surroundings;
 - c) An understanding of existing measures/safeguards;
 - d) Participating in interactive HI Workshops with NPD site staff (May 2016; March 2017); and
 - e) Visual observations of the site, in its pre-decommissioning SwS state.
4. Recording the hazards, by activity, using Hazard Identification Tables (HAZID Tables) (see Appendix B).
5. Characterizing the hazards (in the HAZID Tables) by noting their corresponding:
- Location;
 - Hazard category (e.g. radiological hazard, non-radiological hazard);
 - Hazardous agent (e.g. hazardous chemicals, radionuclides, physical hazard);
 - Hazardous event (e.g. Spill of construction material, fire, flood);
 - Consequence (e.g. exposure to radionuclides, exposure to hazardous chemicals); and,
 - Existing and planned safeguards.
6. Assigning *preliminary* severity, frequency, and risk ranks, by:
- Considering the location and nature of each event, the safeguards in place, and the potential consequence;
 - Incorporating relevant findings from previously conducted studies (e.g. the facility SAR);
 - Incorporating feedback from site staff; and,
 - Adopting an overall attitude towards conservatism and caution (in other words, erring on the side of greater consequence and greater frequency when assigning ranks).

An example of a HAZID Table is shown in Table 7-1 below. A full set of tables presenting the identified hazards, with details, is provided in Appendix B.

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Table 7-1 Example HAZID Table
(Detailed tables are provided in Appendix B)

No.	Project Activity	Hazard Category	Hazardous Agent	Hazardous Event	Consequence	Ranking			Existing Safeguards	Action Req.
						S*	F**	R***		
1	General	Entire site	Hydrocarbons	Fuel spill from mobile storage tank or during fueling activities	Site contamination	S0	F3	R0	1 – Spill response plan in place. 2 – Fuel spill kits will be required for on-site vehicles with large fuel tanks. 3 – Secondary containment structures will be used to prevent spills from storage tanks or during refueling activities where applicable. 4 – PHC and Spill Plans (CNL 2012; CNL 2013). 5 - Routine maintenance checks on equipment. 6 – Contractors’ H&S plan is reviewed by supply chain management and meets CNL’s requirements.	-

Notes:

- * Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.
- ** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.
- *** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

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7.2 Project Work Packages & Activities

Detailed descriptions of the planned decommissioning tasks are documented in the DDP (CNL 2020). For this DecomSA, the project was divided into WBSs according to the DDP (CNL 2020), to allow greater consistency with CSA N294 (2014a). The WBS relevant to this DecomSA are outlined in Table 7-2 below.

Table 7-2 Work Breakdown Structure

WBS Code	WBS Name
8	Nuclear Power Demonstration Closure Project
8.1	NPD Enabling Works
8.1.001	Mobilization & Interim Baseline Until 31/3/16
8.1.002	Temporary Facilities, Power & IT Upgrades
8.1.003	Decommissioning Works
8.1.003.24962	Grout Solution Mobilization
8.2	Nuclear Systems Disposition
8.2.001	No longer applicable – covered by WBS items 8.2.005 and 8.3.001
8.2.002	No longer applicable – covered by WBS items 8.2.005 and 8.3.001
8.2.003	No longer applicable – covered by WBS items 8.2.005 and 8.3.001
8.2.004	No longer applicable – covered by WBS items 8.2.005 and 8.3.001
8.2.005	Tank and Pipe Penetrations
8.3	Building Disposition
8.3.001	Bldg. Characterization & Work Planning
8.3.001.24973	Building Grout, Demolition and Stack Work Package
8.3.002	No longer applicable – covered by WBS items 8.3.001 and 8.3.007
8.3.003	No longer applicable – covered by WBS items 8.3.001 and 8.3.007
8.3.004	No longer applicable – covered by WBS items 8.3.001 and 8.3.007
8.3.005	No longer applicable – covered by WBS items 8.3.001 and 8.3.007
8.3.006	Above-Grade Demolition
8.3.006.24987	Demolition Mobilization & Preps
8.3.006.24988	Demolish Above-Grade Facilities
8.3.007	Facility Preparation Activities
8.3.007.00001	Structural Penetrations
8.3.007.00002	External Penetration Seals
8.3.007.00004	Electrical Isolation
8.3.007.00005	Salvage Equipment for Re-use
8.4	Balance of Site Disposition
8.4.001	Characterization & Work Planning
8.4.001.24989	Balance of Site Characterization
8.4.002	No Longer Applicable – the ventilation stack will now be left on site as a source of Chimney Swift habitat (Aikens 2019)
8.4.003.24999	Stack Equipment Removal
8.4.004	No longer applicable – covered by WBS item 8.4.006
8.4.005	Site Restoration
8.4.005.25029	Concrete Cap and Engineered Barrier Documentation
8.4.005.25030	Concrete Cap Installation
8.4.005.25031	Engineered Barrier Installation
8.4.006	Site Demobilization

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WBS Code	WBS Name
8.4.006.25027	Site Restoration and Demobilization
8.5	Regulatory and Licensing Activities
8.5.001	Detailed Decommissioning Plan
8.5.002	Safety Case
8.5.003	Environmental Assessment
8.5.004	Other Regulatory Requirements
8.5.005	Licensing Process
8.6	Common Elements
8.6.001	Health, Safety, Environment & Quality
8.6.002	Operations & Maintenance
8.6.003	Project Management
8.6.004	Waste Management
8.6.005	Licensing & Permits

The WBS from Table 7-2 is further divided into specific decommissioning activities. The list of decommissioning activities is outlined in Table 7-3 below (along with corresponding WBS numbers for the various activities), based on CNL (2020).

Table 7-3 Decommissioning Activities (CNL 2020)

Activity No.	Project Activity	Corresponding WBS #
1	Batch Mixing Plant	
1.1	Designate footprint, create access, temporary fencing (south side of the facility, in the footprint of the prior training center).	8.1.003.24962
1.2	Assign storage area for raw materials, ship in sand, blast furnace slag. Likely south side of the facility, in the footprint of the prior training center.	
1.3	Set up mixing stations; hook up electrical power or diesel power.	
1.4	Truck in necessary water supply.	
1.5	Provide slip pipe access to nuclear area.	
1.6	Construct wash out pit. Lined excavation with water transfer. Likely near batch-mixing station.	
1.7	Level area for concrete pumper.	
1.8	Mix grout to required formula.	
1.9.a	Truck grout to pumping station (20 trips per day).	
1.9.b	Alternatively set up pumping lines from mixing station to various areas around the main building.	
1.10	Wash out cement truck sluice and pumper truck and slip pipes. (Daily)	8.3.001.24973
1.11	Sample and dewater the wash out pit. Emplace sediments into voids in condenser pit where feasible (or emplace during construction of the concrete cap).	8.3.001.24973
1.12	Demobilize batch plant after cap pour.	8.4.006.25027

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Activity No.	Project Activity	Corresponding WBS #
2	Grouting of Below Grade Structure	
2.1	<i>Room preparation.</i>	
2.1.1	Sealing of required holes from pipes, vents or other penetrations.	
2.1.2	Install reactor vault isolations at labyrinth to boiler room, if required.	
2.1.3	Drilling of holes in concrete for grout passage, air release and heat dissipation.	
2.1.4	Installation of 15 cm solid slip pipe for pumping of concrete.	8.3.007.00001
2.1.5	Demolition of walls to allow grout flow.	8.3.007.00002
2.1.6	Removal of 10 floor hatches from reactor hall or sealing blocks.	
2.1.7	Installation of lighting and cameras for monitoring of fill operations and assurance of safety.	
2.1.8	Prop doors open, and remove liquids from sumps.	
2.2	<i>Systems Preparation Large Vessels.</i>	
2.2.1	Drill holes, top and bottom of Helium storage tanks.	
2.2.2	Drill holes, top and bottom of Steam generator.	
2.2.3	Drill holes, top and bottom of Boiler.	
2.2.4	Drill holes, top and bottom of Dump Tank.	
2.2.5	Drill holes, top and bottom of Vault cooling vent runways.	8.2.005
2.2.6	Task removed.	
2.2.7	Drill access into reactor vault through fueling machine room.	
2.2.8	Seal rotating end shields.	
2.3	<i>Grout Fill Nuclear Area.</i>	
2.3.1	Isolate power to the entire facility. Disconnect 75 Kva source.	
2.3.2	Disconnect class III diesel.	
2.3.3	Remove diesel (from Class III Diesel Self-Contained Generator) for reuse.	
2.3.4	Install slip pipes for wells area sump, dump tank room, dump tank pipe trench, lower portion of vault cooling duct and fuel storage bay.	
2.3.5	Grout fill the used fuel storage bay.	8.3.001.24973
2.3.6	Grout fill lower areas to approximately 373-foot level.	
2.3.7	Install slip pipes for reactor vault fill.	
2.3.8	Grout fill reactor vault.	
2.3.9	Grout fill end access and tube withdrawal rooms.	
2.3.10	Grout fill boiler room to 401-foot level.	
2.3.11	Grout fill balance of nuclear area to 425-foot level.	
3	Removal of Above Grade Structure	
-	Removal of transite from the building exterior.	8.3.006.24987
3.1	Conventional heavy equipment knockdown of reactor hall.	8.3.006.24988

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Activity No.	Project Activity	Corresponding WBS #
3.2	Sizing of material such as cutting steel beams or crushing masonry for fitting into void areas.	8.3.006.24988
3.3	Set up lay down area for material sizing.	8.3.006.24988
3.4	Steel and rubble emplaced in condenser pit according to nesting plan. Fill to 380 level.	8.3.006.24988
3.5	Grout first level of demolition material in condenser pit.	8.3.001.24973
3.6	Steel and rubble emplaced in condenser pit. Fill to 400 level.	8.3.006.24988
3.7	Grout second level of demolition material in condenser pit.	8.3.001.24973
3.8	Steel and rubble in condenser pit. Fill to 425 level.	8.3.006.24988
3.9	Grout third level of demolition material in condenser pit.	8.3.001.24973
3.10	Demolition block walls and inside walls around control room and change rooms.	8.3.006.24988
3.11	Collapse ceilings of furnace room and adjacent rooms.	
3.12	Emplace block wall rubble in furnace room.	
3.13	Remove recyclables from guardhouse.	
3.14	Demolish guardhouse and emplace in furnace room and adjacent rooms.	
3.15	<i>No Longer Applicable (Ventilation Stack)</i>	<i>No Longer Applicable</i>
3.16		
3.17		
3.15	Grout furnace room and adjacent areas to ground level.	8.3.001.24973
3.16	Demolish above grade portion of pressure relief pit. Fill with grout.	8.3.006.24988 8.3.001.24973
4	Install Concrete Cap and Engineered Barrier	
4.1	<i>Concrete Cap.</i>	8.4.005.25030
4.1.1	Construct forms for concrete cap.	
4.1.2	Install rebar and anchor to top of concrete pour.	
4.1.3	Pour concrete, level and slope.	8.4.005.25031
4.2	<i>Engineered Barrier.</i>	
4.2.1	Ship in mound materials.	
4.2.2	Layer and shape mound.	
4.2.3	Install geotextile layer.	
4.2.4	Grade property for water shedding.	
4.2.5	Install remaining earth layers and seed.	
5	Final Site Restoration	
5.1	<i>Site Restoration.</i>	8.4.006.25027
5.1.1	No longer applicable.	
5.1.2	Install fencing around controlled area of mound.	
5.1.3	Install required monitoring wells (new or reconditioned current wells).	

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Activity No.	Project Activity	Corresponding WBS #
5.1.4	Remediate any areas impacted from decommissioning activities or by wash pits/settling ponds.	
5.1.5	Complete all closure surveys including areas previously occupied by training center and warehouses.	
5.1.6	Asphalt, parking areas and non-essential roadways rubblized and areas enhanced for natural environmental restoration.	
5.2	<i>Ventilation Stack Isolation</i>	8.4.003.24999 8.3.001.24973
5.2.1	Remove ancillary equipment.	
5.2.2	Seal below grade vent line connections.	
5.2.3	Cap at grade level.	
5.2.4	Install drainage and ventilation at base.	
5.3	<i>Demobilize Site.</i>	8.4.006.25027
5.3.1	Remove all temporary trailers and washroom facilities.	
5.3.2	Decontamination of heavy equipment.	
5.3.3	Remove power upgrades, return transformers to utility. Remove poles and lines back to Hwy 17.	
5.3.4	Installed controlled access gate at highway (if required).	
6	Long Term Care and Maintenance	
6.1	Groundwater sampling.	N/A ¹
6.2	Vegetation removal.	
6.3	Road maintenance.	
6.4	Fence maintenance.	
6.5	Inspection activities of geotextile cover	
6.6	Life management surveillance of concrete cap.	
6.7	Renaturalization	
6.8	Facility performance during the Institutional Controls phase	

Note:

1 – not part of decommissioning execution, thus, no corresponding WBS.

It is important to note that the facility ventilation system will be deactivated as part of the planned decommissioning activities. CNL may use local supplementary ventilation equipment if such a need is identified during the preparation of work control and radiation protection plans (which are prepared before decommissioning tasks are undertaken).

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7.3 Sources of Hazard

Sources of hazards can relate to the planned activities, to the site itself, and to the site's surroundings. Based on the hazard identification methodology and available information, relevant sources of hazards include:

- Presence of hazardous chemical compounds (see Section 5.2);
- Presence of radioactivity and radioactive compounds/components (see Section 5.1);
- Underground structures (e.g. potential for work in confined spaces, or in areas with reduced ventilation compared to open above-ground structures) (e.g. see Appendix B, Table B.3);
- Overhead aboveground structures (e.g. building roof/ceilings to be demolished; working at heights) (e.g. see Appendix B: Table B.1, Table B.4, Table B.5);
- Forested surroundings, and close proximity of the forest to the NPD structure itself (e.g. see Appendix B, Table B.1);
- Presence of electrical power supply (e.g. electrical grid power, and back-up generator power) (see Appendix B, Table B.1);
- Presence of heavy equipment (e.g. see Appendix B, Table B.1, Table B.2, Table B.4, Table B.5);
- Close proximity to the Ottawa River (e.g. see Appendix B, Table B.1);
- Presence of hydroelectric dams situated upstream (e.g. see Appendix B, Table B.1);
- Located within a region with moderate seismic risk (e.g. see Appendix B, Table B.1);
- Single point of site entry (e.g. site entry can more easily become blocked) (e.g. see Appendix B, Table B.1);
- Planned use of conventional 'hot-work' equipment (e.g. torch-cutters) (e.g. see Appendix B, Table B.1, Table B.3, Table B.4, Table B.5);
- Planned use of conventional power tools and equipment (e.g. see Appendix B, Table B.1, Table B.2, Table B.4, Table B.5);
- Presence of construction materials and stockpiles (e.g. see Appendix B, Table B.2);
- Potential for gas generation (e.g. see Appendix B, Table B.3); and,
- Planned use of compressed air tools and techniques.

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7.4 Existing and Planned Safeguards

It is important to note that *many* safeguards (preventative and mitigative) will be in place to improve the overall safety of the decommissioning activities. These safeguards have been accounted for in hazard identification, and, when estimating frequency and severity ratings for the hazards (see Section 7.6 for information on ratings). In other words, hazard identification and scenario development is based on *mitigated* risks.

Each activity carried out as part of the decommissioning process will begin with the preparation of work control documents. Work control documents are reviewed by CNL health physics to prepare radiological work control documents where required. Job Safety Analyses (JSAs) are reviewed by CNL Occupational Safety and Health representatives to ensure industrial hazards have been identified and mitigation measures have been properly developed. Together, this ensures that all activities are planned and that associated job-specific hazards are identified and managed before execution of the work begins. Work planning will strive to control hazards in decommissioning work according to the following sequence:

- Eliminate (e.g. eliminate hazards or exposures);
- Engineering controls (e.g. put in place engineered controls or barriers);
- Administrative controls (e.g. develop and follow administrative controls, such as time limits);
- Personal Protective Equipment (PPE) (e.g. identify appropriate PPE, and ensure it is being used properly); and
- Work plans, procedure and/or permits, Plan-of-Day, Pre-Job Brief, and Post-Job Reviews will be used to guide tasks.

As a result, when work is planned according to this list of safety priorities, hazards are preferentially eliminated or otherwise managed before PPE is relied upon.

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The following list presents key safeguards that will be in place for the decommissioning work:

- **Conventional Decommissioning Safeguards:**
 - *General:*
 - Staff and contractors will receive site orientation to ensure they are aware of decommissioning activities, hazards, and emergency procedures.
 - Signs will be posted to indicate where decommissioning work is taking place and to alert people to detours where applicable.
 - Work control documents will be developed to guide safe execution of the decommissioning activities.
 - Hazards to personnel will be identified through work control documents and eliminated or controlled using engineered controls, administrative controls, and PPE.
 - Regular updates will be given to site personnel on changes in the proposed decommissioning work plans.
 - CNL health and safety programs are in place to prevent and mitigate injury to personnel.
 - Routine maintenance checks on equipment.
 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.
 - Emergency response is available through local municipal Fire Department.
 - Stop work procedures will be followed for power outages.
 - Class III emergency power is available during Class IV (electrical grid) power failure, for existing safety related systems, while the system is still in operation.
 - Class II Uninterruptable-Power-Supply (UPS) emergency power is available for critical safety systems, in the event of a Class III power outage, while the system is still in operation.
 - Overall site 'good housekeeping' will be upheld.
 - Contractors' Health & Safety Management Programs.
 - Contractors' health and safety plans will be reviewed by supply chain management and meet CNL requirements.
 - *Working at Heights:*
 - Hazards to personnel will be identified through work control documents and eliminated or controlled using engineered controls, administrative controls, and PPE.
 - Procedures for safely performing work at heights are available and will be followed.
 - Contractors' Health and Safety Management Programs.
 - Vetting of contractors' training records.
 - CNL health and safety programs are in place.

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- *Electrical:*
 - Hazards to personnel will be identified through work control documents and eliminated or controlled using engineered controls, administrative controls, and PPE.
 - Grounding and Ground Fault Interrupters will be implemented, CSA approved, built to CSA Electrical Code.
 - CNL health and safety programs are in place to prevent and mitigate personnel injuries (e.g. Electrical Safety).
 - Electrical activities will be performed in an organized manner under work control documents.
 - Contractors' Health and Safety Management Programs.
 - Vetting of contractors' training/qualifications.
- *Confined Spaces:*
 - CNL health and safety programs are in place, including provisions for relevant confined space work.
 - Hazards to personnel will be identified through work control documents and eliminated or controlled using engineered controls, administrative controls, and PPE.
 - Contractors' Health and Safety Management Programs.
 - Vetting of contractors' training/qualifications.
- *Structural:*
 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil/engineering requirements.
 - Appropriate methods will be used during the demolition process to provide support and ensure that unintended structural failure does not occur.
 - If inclement weather occurs during the performance of project work, activities would be stopped (if deemed necessary) in order to minimize weather-related risks.
 - A demolition plan is prepared in accordance with PEO standards and approved by a Professional Engineer qualified in this discipline.
 - An exclusion zone will be established for decommissioning activities.
- **Site Routing & Transportation Safeguards:**
 - Staff and contractor orientation will be conducted to ensure they are aware of emergency procedures and routes.
 - Emergency routes will be in place and will be marked.
 - Speed limits will be posted.
 - Emergency response is available through local municipal Fire Department.
 - Transportation/shipping restrictions will be put in place during poor weather conditions.
 - A road maintenance program is in place for the NPD site.

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- A Site Plan will be developed, and notification sent to responders.
- An approved Staging and Transportation Plan will be developed and followed.
- Spill kits will be available.
- Vetting of contractors' qualifications/driving records.
- Flagmen will be used for turning corners, where needed.
- **Fueling Safeguards:**
 - A spill response/management plan will be in place.
 - Spill kits will be required for on-site vehicles with large fuel tanks.
 - Routine maintenance checks will be performed on equipment.
 - Secondary containment structures will be used to prevent spills from storage tanks or during refueling activities, where applicable.
- **Weather & Natural-Events Safeguards:**
 - Stop-work orders will be issued if detrimental weather conditions (where necessary), extreme weather, or natural events (e.g. forest fires, earthquakes) occur.
 - Fire index updates are available to on-site personnel, and will be assessed to as part of job planning.
 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program, which includes provisions for responding to fires, flood, earthquake, tornado, etc.
 - Firebreaks are in place and are maintained around the facility.
 - Environment Canada tornado warnings are issued, and would be received by CNL site staff.
 - The integrity of the superstructure will be maintained until demolition begins.
- **Decommissioning Material Spills Safeguards:**
 - Response will be provided through contractors regarding accidental spills of decommissioning material (e.g. aggregates).
 - Site supervision will be available to direct the movement of materials and batch mixing operations.
- **Equipment Wash-Down Safeguards:**
 - The Washout Pit will be used to collect wash water from the washing of cement vehicles and sluices.
 - Inspections will be performed on the wash-down pit liner, to avoid damage-related leakage.
 - Monitoring of pit water and sediments will be performed.
 - Wash-down water (once settled) will be reused for grout mixing, to the extent practicable.
 - Approved work control documents will be developed to guide cement vehicle and sluice washing operations.

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- Regarding pneumatic cleaning of slip pipes, if this process is applied, the slip pipes will be designed and constructed to accommodate safe pneumatic cleaning. A procedure for safely carrying out pneumatic cleaning of the slip pipes would also be prepared and followed.
- **Site Access/Security Safeguards:**
 - Site access and security protocols are in place.
 - An access control fence is installed around the licensed portion of the site, to deter intrusion.
- **Grouting Safeguards:**
 - Structural assessment will have been conducted prior to grouting, and incorporated into the decommissioning plan.
 - Approved work control documents (e.g. fill plan) will be developed to guide grouting operations.
 - Demolition activities and grouting activities will be planned in conjunction, to manage water infiltration into the facility and to account for structural factors while grouting.
 - Rooms will be inspected before grouting (pre-grouting room walk-downs).
 - Grout pouring will be monitored with disposable cameras to ensure safety of staff and to monitor progress.
 - Pathways will be created as part of room preparation to allow for dissipation of heat and off gassing during concrete curing.
 - Ventilation will be used when grouting of the reactor vault (to avoid accumulation of hydrogen gas).
 - Engineered seals will be installed.
- **Radiation Safeguards:**
 - As mentioned above, work control documents will be prepared for all activities. Where there is the potential for workers to encounter radiological hazards, the preparation of work control documents includes a radiological assessment completed by CNL health physics personnel. Work control documents are then developed to include radiological aspects as appropriate.
 - Hazards to personnel will be identified through work control documents and eliminated or controlled using engineered controls, administrative controls, and PPE.
 - Continuous air monitors, dosimeters, and bioassay will be used as appropriate to detect the spread and uptake of contamination before it exceeds limits.
 - In addition to routine compliance surveys, the development of radiological work control documents will include the requirement for operational radiation and contamination surveys during work to ensure that the magnitude of the workplace hazard is maintained within the bounds of the radiological assessment and ensure protection is optimized at all times.

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- **Fire/Hot-Work Safeguards:**

- Work control documents for safe hot-work will be available and followed.
- Use of a fire watch.
- Following a Fire Hazard Analysis report (Dunfield & Glennie, 2012), pre-decommissioning preparatory actions by NPD staff have involved removal of combustible material. A fire screening is completed to determine mitigation measures required for any increased fire risk from the current baseline (i.e. from that described in Dunfield and Glennie (2012) Fire Hazard Analysis).
- Fire inspections are performed, and the fire alarm system is maintained in an operating state.
- Combustibles will be stored separately in sea-containers outside of the Reactor Building.
- Small, manageable fires (e.g. from cutting materials) can be put out with hand-held fire extinguishers or other appropriate means consistent with procedures.
- Emergency response for larger fires is available through local municipal services.

- **Hazardous Material Safeguards:**

- *Asbestos:*
 - Signage will be installed to indicate asbestos laydown/interim-storage areas.
 - Procedures will be in place for handling and storage of abated asbestos (bagged).
 - Work control documents will be developed for all activities, including those involving handling of abated (bagged) asbestos and transite.
 - Appropriate personal protection equipment will be used, based on the nature of the activities (e.g. gloves, respirators, etc.).
 - Specialist asbestos removal contractor(s) will be used.
- *PCBs:*
 - Work control documents will be developed for all activities, including those involving handling PCB-containing light ballasts.
 - Sources of PCBs are known and will be clearly identified prior to executing decommissioning activities.
 - Appropriate personal protection equipment will be used, based on the nature of the activities (e.g. gloves, respirators, etc.).
- *Lead:*
 - Work control documents will be developed for all activities, including those involving lead-containing materials.
 - Sources of lead are known and will be clearly identified prior to executing decommissioning activities.
 - Appropriate personal protection equipment will be used, based on the nature of the activities (e.g. gloves, respirators, etc.).

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- *Mercury:*
 - Work control documents will be developed for all activities.
 - Sources of mercury are known and will be clearly identified prior to executing decommissioning activities.
 - Appropriate personal protection equipment will be used, based on the nature of the activities (e.g. gloves, respirators, etc.).

7.5 Consequence Types

A review of the identified hazards, and their postulated consequences, identified the following broad types of consequences:

- Personal conventional injury (e.g. falls, slips, strains, burns, or crushing, pinching or cutting injuries, etc.);
- Exposure to electricity (e.g. shock, electrocution);
- Impeded emergency response capability (resulting in greater severity, e.g. increased exposure or response time);
- Contamination of the site or surrounding environment (resulting in exposure to radiation/radioactive material and hazardous chemicals);
- Damage to structures or equipment (resulting in release and eventual exposure to radiation/radioactive material and hazardous chemicals);
- Fire (resulting in exposure to radiation/radioactive material and hazardous chemicals);
- Flooding (resulting in exposure to radiation/radioactive material);
- Explosion (resulting in personal injury);
- Release of hazardous chemicals (resulting in exposure to hazardous chemicals); and,
- Release of radioactive material (resulting in exposure to radiation/radioactive material).

The DecomSA assesses the potential impacts from consequences such as these on workers and members of the public, for bounding scenarios.

For releases of hazardous chemicals or radioactivity, the nature of the release is specific to the scenario. Some scenarios involve releases that ultimately remain inside of the building envelope, and as such, have exposure potential for workers; others involve releases that originate within the building or site, but have the ability to mobilize contaminants, therefore presenting an exposure potential for both workers and members of the public.

Conventional hazard scenarios would result in injuries or electric shocks, or in extreme cases, electrocution and fatality. The preliminary frequency and severity ranks assigned to these scenarios in the hazard identification tables (see Appendix B) generally include two different severity ratings, the higher of which is used to represent severe and catastrophic effects for major

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injuries resulting in fatalities. Conventional accidents are addressed in Section 8.3.3. The many safeguards in place (i.e. both mitigation and prevention measures) render the risk from conventional accident events as low as reasonably practicable. Additional actions will be recommended, as needed, during the preparation of future work control documents for specific activities.

7.6 Metrics – Frequency, Consequence, and Risk

Once identified, hazard scenarios are assigned preliminary estimated/potential frequency and severity ratings. Though these are estimates, they are based on professional judgement and are informed by available documentation (namely, estimates from Athauda-Arachchige (2015) for similar events during the SwS phase) and information gained during the hazard identification workshop. The assigned ratings help to identify scenarios with frequencies or severities that are very high or very low.

It is important to note that preventative and mitigative measures are accounted when assigning frequency and consequence ratings. The resulting risk rankings (see Section 7.6.3) therefore represent *mitigated* risk.

7.6.1 Frequency Ratings

For consistency, the frequency ratings from the Athauda-Arachchige (2015) *Safety Analysis* are used in this assessment. The SAR's frequency ratings are developed based on guidance in (CNL 1995). Table 7-4 presents these frequency ratings and their corresponding frequency ranges.

Table 7-4 Frequency Ratings (Athauda-Arachchige 2015)

Frequency Ratings	Frequency Range (Events/year)	Description of Event Occurrence
F3	$>3 \times 10^{-1}$	Frequent ; Events that are expected to occur several times during the lifetime of the facility. (e.g. frequency of approx. 1 every 3 years)
F2	3×10^{-1} to 3×10^{-2}	Occasional ; Events may occur a few times during the lifetime of the facility. (e.g. frequency of approx. 1 every 3 years to 1 every 30 years)
F1	$<3 \times 10^{-2}$ to 10^{-4}	Rare ; Events have slight chance of occurring during the lifetime of the facility. (e.g. frequency of approx. 1 every 30 years to 1 every 10,000 years)
F0	$<10^{-4}$ to 10^{-6}	Extremely Rare ; Events are not expected to occur during the lifetime of the facility. (e.g. frequency of approx. 1 every 10,000 to 1 every 1,000,000 years)

Note: Lifetime of the facility includes decommissioning but excludes post-closure.

It is important to note that several hazards are not unique to any particular activity, but are instead general hazards that can occur during numerous activities. These general hazards are grouped together, rather than being assigned to any particular work package (to reduce duplication).

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However, the selection of frequency ratings for these hazards does take into account the fact that they have the potential to occur in several different activities (i.e. they inherently have a higher potential frequency).

7.6.2 Severity Ratings

Severity ratings from the Athauda-Arachchige (2015) Safety Analysis are also used in this assessment, for consistency. Table 7-5 presents these severity ratings and their corresponding effects descriptions.

It is important to note that electrical hazards and hazards causing physical injury are represented using two different hazardous events to distinguish between high-severity events and low-severity events; for example, to distinguish between electrical shock (low-severity) versus electrocution (high severity).

Table 7-5 Severity Ratings (Athauda-Arachchige 2015)

Severity Ratings	Assoc. Hazard Types	Facility Worker (i.e. NEWs)	Off-Site Members of the Public
S0 No Discernable Effect	<i>External Hazards</i>	Superficial physical injuries not requiring medical attention	Not Applicable
	<i>Radiological Consequence</i>	Effective dose up to 0.1 mSv	None*
	<i>Chemical Exposure</i>	Short-term chemical exposure up to 10% of occupational limit	None*
S1 Minor Effect	<i>External Hazards</i>	Minor injuries requiring basic medical attention	Not Applicable
	<i>Radiological Consequence</i>	Effective dose up to 1 mSv	Effective dose up to 0.1 mSv
	<i>Chemical Exposure</i>	Short term chemical exposure up to occupational limit	None*
S2 Moderate Effect	<i>External Hazards</i>	Physical injuries resulting in several days of lost time	Not Applicable
	<i>Radiological Consequence</i>	Effective dose in the range of 1 – 50 mSv	Effective dose in the range of 0.1 – 0.5 mSv
	<i>Chemical Exposure</i>	Chemical exposure leading to acute effects requiring medical attention and lost time	Releases leading to minor restrictions on the public
S3 Severe Effect	<i>External Hazards</i>	Physical injuries resulting in several months of lost time or permanent disability	Not Applicable
	<i>Radiological Consequence</i>	Effective dose in the range of 50 – 1 000 mSv	Effective dose in the range of 0.5 – 5 mSv
	<i>Chemical Exposure</i>	Chemical exposure leading to lasting or permanent disability or reduced life expectancy	Releases leading to interferences with normal activities of the public (e.g. ban of food or water)
S4 Catastrophic Effect	<i>External Hazards</i>	Physical injuries resulting in one or more fatalities	Not Applicable
	<i>Radiological Consequence</i>	Effective dose greater than 1 000 mSv	Effective dose in the range of 5 – 100 mSv
	<i>Chemical Exposure</i>	Chemical exposure leading to one or more fatalities	Chemical exposure leading to acute effects requiring medical attention and evacuation

Notes:

*None – No exposure is associated with the particular receptor, for the particular severity rating.

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7.6.3 Risk Matrix

The frequency ratings from Table 7-4 and the severity ratings from Table 7-5 are combined using the risk matrix in Table 7-6 below to produce a risk rating for each hazard.

Table 7-6 Risk Matrix (Athauda-Arachchige 2015)

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	R0	R0	R0	R1	R2
F2	R0	R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

Notes:

R0 - The risk is negligible; no further action is necessary.

R1 - The risk is tolerable, further protective measures are not essential but should be considered.

R2 - The risk for internal events is unacceptable, additional engineered solutions must be put in place to reduce the risk. For external events that cause damage and injury, but not due to failure of the process, the risk is tolerable.

R3 - The risk is unacceptable, the proposed process is inherently unsafe, major modifications to the proposed design are required.

So, based on the risk rankings and descriptions in Table 7-6 above, any hazard events that receive preliminary R2 ranks will warrant further assessment (though other scenarios with lesser risk ranks may also warrant further assessment – see Section 7.9). Any such cases are noted in the hazard event tables in Appendix B. Those that are noted as warranting further assessment, are assessed further in Section 8.0 and Section 9.0. Following the assessments in Section 8.0 and Section 9.0, any scenarios that are still identified as having a *residual* risk rank that is greater-than or equal-to R2 are considered to be unacceptable in their current state/configurations (excluding external events – see Table 7-6 footnotes). For any such scenarios, future follow-up action will be required (i.e. additional preventative and/or mitigative measures will need to be established) in order to reduce the residual risk levels below R2.

7.7 Initiating Events

Initiating events are those events that cause hazard scenarios to occur. They originate from component/equipment failures, system malfunctions, human error, or external events. The frequency associated with an initiating event, later combined with any relevant conditional probabilities, provide an estimate of the frequency with which any particular hazard scenario can occur in a given period.

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Table 7-7 presents preliminary information on initiating events considered as part of the Hazard Identification (HI) process. These are grouped as follows:

- Operational initiating events;
- Human Error initiating events; and,
- Natural, external, or environmental initiating events.

Table 7-7 Initiating Events Considered in the HI Process

Initiating Event	Frequency Rating	Notes
Operational Initiating Events		
Power Failure (grid; Class IV failure)	F3	Estimated based on the frequency ranges defined in Table 7-4. Conservative, as this F3 value corresponds to the highest, most-frequent, category.
Power Failure (grid and backup power; Class III failure)	F2	Estimated based on the frequency ranges shown in Table 7-4 and the preventative and mitigative measures available.
Equipment failure (Crane, truck, loaders, engineered plugs / materials, etc.)	F2 <i>(for any particular equipment usage)</i>	
Vehicle accident (major)	F2	
Vehicle accident (minor)	F3	Estimated based on the frequency ranges defined in Table 7-4. Conservative, as this F3 value corresponds to the highest, most-frequent, category.
Human Error Initiating Events		
Human error (<i>per task performed</i>)	F1	Assuming an error rate of 10^{-3} per task performed; based on Kirwan (1994) 10^{-4} frequency associated with the human performance limit for a single operator activity, per task, increased to 10^{-3} to account for several handlings per task.
Human error (<i>overall, based on tasks performed multiple times</i>) <ul style="list-style-type: none"> • Handling • Accidental zone entry 	F2	Based on the error rate of 10^{-3} per activity (as above), increased by one or more orders of magnitude to account for the fact that several activities are performed multiple times, which compounds the frequency of errors.
Human error (<i>overall, based on tasks performed multiple times</i>) <ul style="list-style-type: none"> • Equipment operation 	F3	
Natural/External/Environmental Initiating Events		
Earthquake	F2	Preliminary estimates based on knowledge of the site, feedback from site staff, information from facility documentation, and, consideration of the findings and frequency estimates of the 2015 SAR (Athauda-Arachchige, 2015). For bounding scenarios (see Section 7.9.4), more detailed frequency assessment is provided in Section 9.6).
Forest Fire	F1	
Lightning	F2	
Flood (external; from dam break)	F0	
Tornado (EF-2 scale)	F2	
Flood (external; from precipitation)	F1	
Extreme Weather (ice, snow, hail)	F1	

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7.8 Hazard Scenarios

Using the methodology outlined in Section 7.1, and the information presented in Sections 7.2 to 7.7, a hazard identification exercise was performed which resulted in the development of several hazard scenarios. Overall, hazard scenarios can be divided into the following broad types (note though, some scenarios can be classified under many different categories):

- Fire scenarios (incl. external forest fire);
- Flood scenarios;
- Tornado scenarios;
- Seismic scenarios;
- Direct radiation exposure scenarios;
- Direct chemical exposure scenarios;
- Extreme weather scenarios;
- Spill/release scenarios;
- Transportation accident scenarios;
- Equipment failure scenarios;
- Structural failure scenarios;
- Explosion/gas generation scenarios;
- Electricity (shock/electrocution) scenarios;
- Personal injury scenarios;
- Restricted emergency response scenarios.

The complete list of resulting hazard scenarios is available in Appendix B.

7.9 Bounding Scenarios

Guidance provided by the International Atomic Energy Agency (IAEA 2009) states that the bounding or enveloping scenarios are those credible scenarios that present the greatest possible challenge to the relevant acceptance criteria and are limiting for the performance parameters of safety related equipment. Therefore, the identification of bounding scenarios requires the definition of credibility and the acceptance criteria or performance parameters for project components or activities.

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7.9.1 Screening Based on Potential Frequency

The Canadian Nuclear Safety Commission (CNSC 2010), across documents, has relied on the event frequency of 10^{-6} per year as the threshold for credibility. The Canadian Standards Association (CSA 2007, 2008) has also used event frequency of 10^{-6} per year as the threshold for credibility. In this study, a frequency criterion of $<10^{-6}$ (i.e. less-than 10^{-6}) per year is used as the credibility threshold, consistent with the lowest frequency-category cut-off from the prior Athauda-Arachchige (2015) Safety Analysis.

Scenarios with estimated frequencies that are greater than or equal to 10^{-6} per year are considered to be credible, and as such, warrant further assessment from a frequency perspective. Scenarios with estimated frequencies that are less than 10^{-6} per year are non-credible due to their extremely low frequencies. Section 7.7 outlines several initiating event frequency estimates that are considered among the hazard events. For example, scenarios initiated by aircraft crash were not considered because the frequency of such an initiating event was determined to be less than 10^{-6} per year (Athauda-Arachchige, 2015).

7.9.2 Screening Based on Potential Consequence Severity

From the perspective of consequence assessment, the performance criteria for any accident scenario are based on the exposure and health effects associated with the accident. Therefore, scenarios with no or negligible effects are not considered to be bounding. To ensure consistency with the severity rankings used in the Athauda-Arachchige (2015) *Safety Analysis*, the severity cut-off criteria (see Table 7-5) encompass three different types of effects as follows:

- Non-Radiological (Physical) Effects [Severity Rating 'S0' – No Discernable Effects]:
 - Public Receptors: None.
 - Worker Receptors: Superficial physical injuries not requiring medical attention.
- Non-Radiological (Chemical) Effects [Severity Rating 'S0' – No Discernable Effects]:
 - Public Receptors: None.
 - Worker Receptors: Short-term chemical exposure up to 10% of occupational limit.
- Radiological Effects [Severity Rating 'S0' – No Discernable Effects]:
 - Public Receptors: None.
 - Worker Receptors: Effective dose up to 0.1 mSv.

Therefore, scenarios with estimated consequences that meet or are less than the criterion above are considered negligible, and as such, they are excluded from further assessment.

Scenarios assigned preliminary consequences ranks that are greater than the criteria above are considered non-trivial, and as such, are considered for selection of bounding scenarios.

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7.9.3 Method for Selecting Bounding Scenarios

The selection of bounding scenarios involves the following steps:

1. Scenarios are reviewed to distinguish those that meet the credibility (i.e., frequency) criterion (from Section 7.9.1), and those that do not.
2. The *potential* consequences ('potential' because analyses have not yet been performed) of the remaining credible scenarios are reviewed - using industry experience (such as OPG 2009; NWMO 2011; Cameco 2012), professional judgement, and accounting for the identified preventive and mitigative measures that would be applied for each scenario - and compared to the severity screening criterion (from Section 7.9.2).
3. The remaining credible scenarios are grouped together into categories based on the type of consequence, e.g., radiological exposure, chemical exposure, etc.
4. Bounding scenarios are selected as those scenarios that cause the most severe consequence within each category. For example, for the category of radiological exposure from operations, bounding scenarios are associated with activities such as demolition of walls, cutting holes, cutting vessels and pipes in various facility locations.

NOTE: As discussed, the severity ratings presented for the hazard scenarios (see Appendix B) are based on a preliminary assessment. Further quantitative assessment is conducted in Section 9.0 for the selected bounding scenarios.

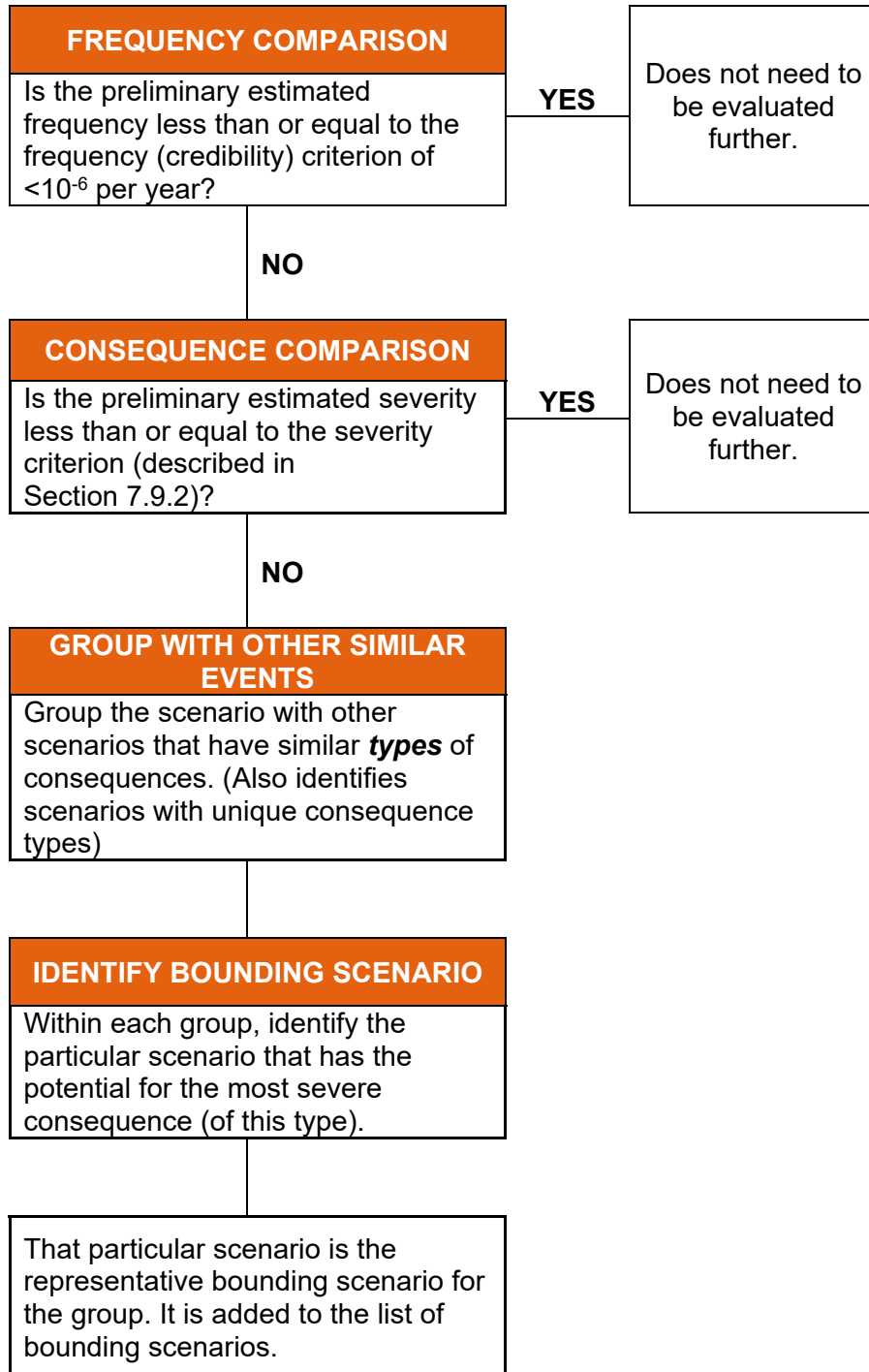
What results from this methodology is a list of bounding scenarios that warrant further evaluation because they are representative of the activities being assessed, encompass other similar scenario variants, have a credible potential to occur, and, are associated with non-negligible potential consequences.

Throughout the screening process, historical records (e.g. Seto 2014), experience from similar projects (such as OPG 2009; NWMO 2011; Cameco 2012), operational documents (e.g. Dunfield 2012; Reynard 2015), and facility or process drawings (e.g. McVeigh 2016a) are examples of inputs used to inform screening decisions.

This bounding scenario selection methodology is presented schematically in Figure 7-1.

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Figure 7-1 Bounding Scenario Identification Methodology



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7.9.4 Resulting Bounding Scenarios

Table 7-8 presents the resulting bounding accident scenarios identified for this assessment. For normal operations, Section 8.3 outlines the activities that undergo evaluation, including hydrogen gas generation from grouting activities.

Conventional accident events identified during the HI process (see Appendix B) are collectively addressed in Section 8.3.3.

Table 7-8 Resulting Bounding Scenarios

Number	Bounding Scenario	Consequence	Notes
1	Forest fire	Release of radioactivity due to fire spreading to the building and subsequently mobilizing and releasing radionuclides.	As per Appendix B – further assessment is warranted.
2	Forest fire	Release of chemicals due to fire spreading to the building and subsequently mobilizing and releasing chemicals.	
3	Tornado	Release of radioactivity due to damage to the building and subsequently mobilizing and releasing radionuclides.	These will be assessed further in the Accidents Assessment (Section 9.0).
4	Tornado	Release of chemicals due to damage to the building and subsequently mobilizing and releasing chemicals.	
5	Heavy precipitation flood	Release of radioactivity due to water ingress and subsequent mobilization of radionuclides.	As per Appendix B – further assessment is warranted. Assessed further in the Accidents Assessment (Section 9.0), <i>based on Athauda-Arachchige (2015) assessment.</i>
6	Accidental exposure to radioactivity .	Radiological dose during demolition of walls, cutting holes, cutting vessels and pipes. <i>Note: though radiological doses are anticipated as part of normal operations, this accident scenario represents exposure beyond the levels anticipated as part of normal planned demolition activities. See Section 8.0 for assessment of normal operations.</i>	Assessed further in Accidents Assessment (Section 9.0).

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Number	Bounding Scenario	Consequence	Notes
7	Accidental exposure to chemicals .	Exposure to chemicals during demolition of walls, cutting holes, cutting vessels and pipes. <i>Note: limited to exposure beyond the levels anticipated as part of normal planned demolition activities. See Section 8.0 for assessment of normal operations.</i>	For completeness, assessed further in Accidents Assessment (Section 9.0).
8	Underground fire (including equipment fire).	Airborne release of radionuclides and subsequent exposure.	Assessed further in Accidents Assessment (Section 9.0).
9	Underground fire (including equipment fire)	Airborne release of fire by-products (smoke and chemicals), as well as chemicals involved in the fire and subsequent exposure.	
10	Collapse of stack.	Release of radioactivity and exposure.	

7.9.4.1 Seismic Events

For seismic events, it is important to note that the HI tables in Appendix B identify earthquake events as having potential structural effects, and, potential physical effects similar to other conventional accidents (e.g. direct injuries). Exposure effects are not noted for seismic events because releases of chemicals and radionuclides are not attributed directly to the seismic events themselves – rather, such releases could occur from fires (or other events) that are initiated by a seismic event. This is also mentioned in the facility SAR. The exposure effects from fires (regardless of their initiating events) would be bounded among Bounding Scenarios #1, #2, #9 and #10 in the table above. Exposure effects from releases attributed to structural collapse are encompassed by the very conservative assumptions used to address demolition of the superstructure as part of normal operations (see Section 8.0). Conventional accident effects (regardless of their initiating events) are collectively addressed in Section 8.3.3.

7.9.4.2 Accidents During Institutional Control Period

Note that during the institutional controls phase (i.e. after completion of the decommissioning phase of the project) there is still the potential for external events (e.g. forest fires, floods, etc.) to occur. However, consequences of such events would be bounded by their consequences during decommissioning execution, though existing safeguards would be different in the institutional control phase. Were an external event such as forest fire, tornado, or earthquake to occur during

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the institutional control phase, follow-up actions would be performed to inspect the site and determine if the closed facility remains intact.

During the Institutional Controls phase, monitoring of the area around the mound will be carried out periodically, including groundwater sampling, topographical inspections, surface drainage inspections, removal of deep-rooting vegetation, and visual inspections of the stack.

7.9.4.3 Common-Cause Events

The term 'common-cause events' refers to events that have the ability to produce several accidents at the same time (as opposed to a single event producing a single accident). In risk and safety assessments, the consequences of all accident scenarios produced by a common-cause event should be evaluated and superimposed. Common-cause events can be internal (e.g. power outage) or external (e.g., earthquake).

The hazard identification process undertaken in this DecomSA has considered common-cause events, such as seismic activities or forest fires. In addition, the consequences of several bounding accident scenarios are based on conservative inventories (for example, the forest fire bounding scenario is based on release of the entire inventory of the above-grade structure).

7.9.4.4 Human Factors

It is important to note that the level of detail at which human factors can be incorporated into the DecomSA is primarily based on the level of detail available for the decommissioning tasks. Since the DecomSA is based on overall descriptions of the main decommissioning works, human factors are incorporated into the assessment at a commensurately high-level at this time. As the project evolves and more detailed procedures and work control documents are developed, human factors can be incorporated at a more detailed level.

At present, human factors are included in this DecomSA by using human error initiating events and their associated statistics. The initiating events outlined in Section 7.7 identify human error, along with a high-level value of 10^{-4} per task based on Kirwan (1994). This per-task value was then increased by one or more orders of magnitude to account for repeated tasks which compound the frequency of errors. What results are high-level human error frequencies that correspond to frequency ranks F3 (i.e. the highest frequency rating; >0.3) and F2 (i.e. between 0.3 and 0.03).

These resulting F2 and F3 human error initiating event frequency ranks are considered when assigning preliminary frequency ranks to hazard events (where applicable), along with other information such as feedback from site staff. It is acknowledged that many of the identified hazard events, especially vehicle accidents, small fires, and physical injuries, can potentially be caused (ultimately) by human error (among other causes). Within this assessment, bounding scenarios 6 and 7 (accidental radiological/non-radiological exposure) and bounding scenarios 8 and 9 (indoor

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fire) specifically include human error as their ultimate initiating event, while other scenarios that are driven by human error would be bounded by these. For these identified bounding scenarios, more detailed human error calculations were completed based on Kirwan (1994) and Gertman *et al.* (2005), using the SPAR-H framework recommended by the US Nuclear Regulatory Commission (US NRC) (see Section 9.6).

7.9.4.5 Safeguard Failures

The preliminary frequency ranks assigned to hazard events are based on several sources of information, including workshop feedback from site staff, and incorporate the fact that there are many potential initiating events (depending on the details of the task(s) involved) and many safeguards in place. Therefore, the hazard events and resulting bounding scenarios do account for safeguards.

It is also acknowledged that safeguard failures have the potential to cause accidents. There are many ways in which safeguards can fail, producing many different potential accident variants. However, following a bounding approach, the likelihood assessment (presented later, in Section 9.6) examines the likelihood of bounding scenarios using statistics that encompass all accident causes, including safeguard failures as well as other causes. Therefore, the statistics used inherently account for failure of safeguards.

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8.0 NORMAL OPERATIONS ASSESSMENT

8.1 Introduction

The EIS report is organized into several environmental components, which are used here for the normal operations assessment. Those environmental components that have potential interactions are assessed here in the DecomSA for the various activities. These environmental components include:

- **Atmospheric Environment:** This component analyses the effects of various activities regarding the atmospheric environment, which focuses on the air quality and noise levels.
- **Surface Water Environment:** This component analyses the effects of various activities regarding the surface water environment, which focuses on site drainage and water quality, flows and levels, and shoreline processes.
- **Geological and Hydrogeological Environment:** This component analyses the effects of various activities regarding the geological and hydrogeological environment, focusing on the soil quality, groundwater quality, and groundwater flow.
- **Radiation and Radioactivity Environment:** This component analyses the effects of various activities regarding radiation and radioactivity in the environment, which focuses on the external gamma radiation, radioactivity in the atmospheric, surface water and aquatic, geological and hydrogeological environments.
- **Public Health:** This component analyses the effects of various activities regarding the health of the general public.
- **Worker Health:** This component analyses the effects of various activities regarding the health and safety of the workers on site.
- **Non-Human Biota:** This component analyses the effects of various activities regarding the health of non-human biota, by reference to the *Ecological Risk Assessment* TSD (Garisto *et al.*, 2020a) (as per Section 1.2). The conclusions of the EcoRA TSD are reproduced in this DecomSA - at a high level - for completeness.

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8.2 Hazards Identified for Normal Operations

Normal operating conditions include planned decommissioning operations as well as maintenance/supporting activities.

8.2.1 Airborne Hazards during Decommissioning:

Airborne hazards associated with normal decommissioning operations are from emissions, including: vehicle/equipment exhaust emissions and dust (including batch mixing plant), demolition dust/particulate, releases of facility air as it is displaced by grout filling, and, releases of hydrogen gas (produced by grout interactions). These are assessed among Sections 8.4 to 8.8.

8.2.2 Waterborne Hazards during Decommissioning:

The potential liquids identified for normal decommissioning operations are:

1. Wash water; and,
2. Rainwater.

Wash Water:

Wash water will be produced from washing cement vehicles, sluices, and slip pipes installed within the facility.

- **Cement Vehicles and Sluices:** Wash water from cleaning cement vehicles and sluices will not have contacted radionuclides from the facility. The washout pit is used to collect wash water from these cleaning tasks. This wash water will be re-used in the grout mixing plant, as much as possible. Any wash water that cannot be used in the batch plant (for example, the final wash, which will be conducted after all grout mixing is complete) will be collected and regarded as a non-routine liquid and will be reviewed against criteria in CNL's Environmental Protection process (Matasich 2016), which outlines appropriate collection and disposition routes depending on the results of analyses. ***The key aspect is that no un-assessed liquid effluent releases will occur as part of the decommissioning work.***
- **Slip Pipes:** Slip pipes are sections of pipe installed within the facility to convey grout. Water used to flush the slip pipes will drain into rooms within the facility, where it would fall onto the most recently poured grout lift.

CNL will collect any accumulated wash water using appropriate protective equipment and following CNL's routine procedures for collecting liquids potentially containing radionuclides. Once collected, the liquid will be reviewed against criteria in CNL's

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Environmental Protection process (Matasich 2016), which outlines appropriate collection and disposition routes depending on the results of analyses. ***The key aspect is that no un-assessed liquid effluent releases will occur as part of the decommissioning work.***

It is important to understand that liquid collections are performed routinely at NPD. For example, NPD is collecting and dispositioning its sump water following these methodologies. Worker exposure will be avoided through a combination of work controls, standard procedures, and protective equipment. Therefore, exposure to contaminated wash water does not require assessment as part of Normal Operations.

Rainwater:

Rainwater could potentially collect inside the partially-grouted facility during the period in which the superstructure is removed but the final grout elevations are not yet poured. CNL has planned the decommissioning tasks in such a manner as to reduce this time, namely by keeping the superstructure and roof in place for much of the grouting process. Decommissioning of the superstructure and roof will not begin until the nuclear area has been grouted (thus there will be no potential exposure to its associated radioactive inventory). Since grouting of the nuclear and non-nuclear areas proceeds in parallel, most of the non-nuclear areas will also be grouted by this point in time, excluding the Condenser Pit into which the building rubble will be placed. Also, at that point in time all penetrations would have also been sealed or grouted. CNL's *NPD Building Characterization Report* (McVeigh 2018) indicates that radionuclide levels in the structural materials of the condenser pit (indeed for all Class 2 & 3 survey units, not only the Condenser Pit) are less than unconditional clearance levels. Thus, radionuclide levels in any rainwater that might accumulate in the condenser pit are expected to be low. Rainwater may also accumulate at the base of the ventilation stack.

Like wash water, accumulated rainwater would be regarded as a non-routine liquid. It would be collected and reviewed against criteria in CNL's Environmental Protection process (Matasich 2016), which outlines appropriate disposition routes depending on the results of analyses. ***Again, the key aspect is that no un-assessed liquid effluent releases will occur as part of the decommissioning work.***

Worker exposure to rainwater is not planned under Normal Operations since collection activities would follow CNL work control and radiation protection plans to avoid exposure. Unintentional exposure to contaminated rainwater is assessed as a potential accident scenario (see Section 9.0) rather than as part of Normal Operations.

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8.2.3 Exposure-Related Hazards

The radiological exposure hazards associated with normal operating conditions are:

- I. Potential exposure of members of the public to:
 - Airborne radionuclides.
- II. Potential exposure of workers to:
 - Direct radiation;
 - Airborne radionuclides.

The non-radiological exposure hazards associated with normal operating conditions are:

- I. Potential exposure of members of the public to:
 - Airborne releases of hazardous materials.
- II. Potential exposure of workers to:
 - Airborne releases of hazardous materials.

These are assessed among Sections 8.4 to 8.8.

8.2.4 Conventional Injury Hazards

Decommissioning and demolition activities involve the interaction of personnel with a variety of conventional injury hazards such as moving and stationary heavy equipment/machinery, electricity and temporary power lines, working with heat sources or hot equipment, working at heights, potentially working in confined spaces, working with compressed air tools and techniques, working with potentially unstable structures, potentially working with hazardous substances, etc. Therefore, conventional injury hazards will exist throughout the decommissioning project – further discussion is provided in Section 8.3.3.

8.3 Analysis Methodology

8.3.1 Methodology

Overall, normal operations are assessed by evaluating the effects of each group of activities upon the various environmental components. There are 5 major groups of activities, corresponding to the headings within the interaction matrix presented in the EIS:

- Batch Mixing Plant (aspects of WBS 8.1.003, 8.3.001 and 8.4.006);
- Grouting of Below Grade Structures (aspects of WBS 8.3.007, 8.2.005, and 8.3.001);
- Removal of Above Grade Structures (aspects of WBS 8.3.006, 8.3.001);
- Install Concrete Cap (aspects of WBS 8.4.005); and,
- Final Site Restoration (aspects of WBS 8.4.006, 8.4.003.24999 and 8.3.001).

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Each of these groups of activities contains a number of individual activities, as shown in Table 7-3. Sub-tasks in Table 7-3 that represent similar activities that occur more than once (or under different headings) have been grouped together for assessment. For each of these activity groups it has been identified if there is any potential interaction with the identified environmental components. The results of this have been summarized in Table 8-1. Any activities that do not have an *interaction* identified for a specific environmental compartment have been marked as having no effects. Any activity that has been identified as having potential interaction with an environmental component has been marked with a check, signifying that an analysis will be done in the corresponding section below to determine the effect of the interaction. Note that it is possible for an interaction to still result in no effect.

It is important to note that, as outlined in Section 1.2, the effects discussed throughout this section are representative of the exposure effects, and do not include non-exposure effects such as noise or habitat impact. These non-exposure effects will be assessed separately as part of the EIS.

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Table 8-1 Potential Interactions of Normal Activities on Environmental Compartments.

Activities	Activity Number	Atmospheric Environment	Surface Water Environment	Geological and Hydrogeological Environment	Radiation and Radioactivity Environment	Effects on Public Health	Effects on Worker Health	Effects on Non-Human Biota
Batch Mixing Plant								
Designate Location, Create Access, and Erect Temporary Fencing	1.1, 1.7	✓	✓	None	None	None	✓	None
Stockpile Grout Ingredients	1.2, 1.3, 1.4	✓	✓	None	None	None	✓	None
Mix Grout to Required Formula	1.8, 1.9	✓	None	None	None	None	✓	None
Provide Slip Pipe Access to Nuclear Area	1.5	✓	None	None	✓	None	✓	None
Wash Out Pits (Preparation and Operation)	1.6, 1.10, 1.11	✓	✓	None	None	None	✓	None
Grouting of Below Grade Structures								
Prepare Rooms and Large Vessels	2.1, 2.2, 5.2.2, 5.2.4	None	None	None	✓	None	✓	None
Grout Fill Nuclear Area	2.3, 5.2.3	✓	None	None	✓	✓	✓	✓
Removal and Grouting of Above Grade Structures								
Demolition of Above Grade Structures	3.1, 3.10, 3.11, 3.13, 3.14, 3.16, 5.2.1	✓	✓	✓	✓	✓	✓	✓
Sizing of Material	3.2	✓	✓	✓	✓	✓	✓	✓
Emplace Demolition Material, and Grout	3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.12, 3.15, 3.16	✓	None	None	✓	✓	✓	✓
Install Concrete Cap and Engineered Barriers								
Concrete Cap	4.1	✓	✓	None	None	None	✓	None
Engineered Barriers	4.2	✓	✓	None	None	None	✓	None
Final Site Restoration								
Site Restoration	5.1	✓	None	None	None	None	None	None
Demobilize Site	5.3, 1.12	✓	✓	None	None	None	✓	None

Notes:
None – No potential interactions identified
✓ – Assessed

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8.3.2 Assumptions on Operational Practices

Many of the activities that will take place as part of the decommissioning of the NPD facility will result in emissions that are typical of construction projects, such as vehicle and equipment exhaust emission, dust emissions, and water runoff.

Typical construction (and decommissioning) activities have the potential for short-term effects on air quality in the immediate vicinity of the site; primarily through exhaust emissions from equipment, and fugitive dust from disturbance of dry fine-grained soils (e.g. from dirt roads/routes or stockpiles). These are common emissions at construction and decommissioning sites. Greenhouses gas emissions from the project are assessed in the Greenhouse Gas Emission TSD (Garisto, *et al.*, 2020b). Other gas and dust emissions from the project (i.e. NO₂, SO₂, TSP, PM₁₀, and PM_{2.5}) are assessed in DecomSA Appendix F.

During decommissioning execution, industry best practices will be used to manage environmental effects of minor works. An example of such practices is CNLs spill response or management of land and habitat procedures. The Cheminfo (2005) "*Best Practices for the Reduction of Air Emissions from Construction and Demolition Activities*" report, prepared in conjunction with the Construction and Demolition Multi-Stakeholder Working Group for Environment Canada, identifies several practices, and those that are relevant to the decommissioning activities at NPD will be followed:

- plans to minimize dust generation through planning, site layout, proper use of materials, tools and equipment, and dust suppression techniques (e.g. water misting);
- compacting disturbed soil;
- activity scheduling;
- storage piles (stockpiles) management;
- minimization of drop heights;
- barriers to prevent dispersion of materials;
- work practices for loading debris;
- avoidance of prolonged storage of debris;
- maintaining equipment and vehicles in good working condition, to minimize combustion emissions to the extent practicable.

The application of industry best practices should minimize combustion emissions and limit fugitive dust emissions to the work area. As a result of the low concentrations of the atmospheric pollutants generated during decommissioning execution, no adverse effects on terrestrial vegetation due to these emissions are anticipated.

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Some NPD decommissioning activities may result in water runoff (e.g. from precipitation) and wash water, and as such, a discussion on industry practices for managing waterborne emissions is applicable. For perspective on industry practices related to waterborne emissions, mitigation measures potentially applicable to the NPD decommissioning project from the Ontario Ministry of the Environment (MOE) "*Guidelines for Evaluating Construction Activities Impacting on Water Resources*" (MOE, 1984) are described below. The *Stormwater Management Planning and Design Manual* may also be applicable (MOE, 2003).

- retention of existing vegetation where feasible;
- restriction of the use of heavy equipment to within the approved work areas to minimize soil disturbance and vegetation destruction;
- diversion of runoff away from exposed areas;
- maintenance of low runoff velocities (control run off);
- retention of sediment on site;
- re-vegetation of disturbed areas by seeding and/or planting (following completion) as soon as seasonal conditions permit; and,
- proper design and management of washout pits (settling ponds) and material storage site(s).

Demolition will be performed following a demolition plan prepared in accordance with demolition plan guidelines outlined by the Professional Engineers of Ontario and stamped by an engineer. Demolition plans include for example:

- a review of construction/design documents;
- a site inspection;
- necessary permits;
- descriptions of the structural characteristics and condition of the building;
- descriptions of utilities;
- descriptions of any inspections or testing that needs to be carried out;
- descriptions of any environmental hazards that could arise, and the measures needed to address the hazards and ensure safe work;
- descriptions of the methods chosen to perform the demolition;
- descriptions of the measures necessary to ensure that the integrity of other buildings/structures or utilities is not negatively affected by the demolition.

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8.3.3 Conventional Accidents & Safeguards

It is acknowledged that overall, conventional accidents represent the main source of risk for decommissioning activities.

Conventional Accident Statistics for Construction Projects

Since statistics of conventional accidents during reactor decommissioning are scarce, generic fatality statistics from the construction industry are used for comparison.

Major construction projects involve the interaction of personnel with hazards such as moving and stationary heavy equipment/machinery, electricity and temporary power lines, working at heights, working in confined spaces, working with pneumatic tools and techniques, working with potentially unstable structures, etc. In contrast to specific industrial facilities where each activity/position is routine, with little variability, well characterized, and the occupational settings are well defined, construction projects can involve several ad-hoc tasks performed by workers as part of the execution of a larger overall activity. Such projects may also use equipment that are generally rotated from one site to another (e.g. cranes). In these situations, conventional occupational accidents are governed by the limits of human performance as well as the reliability of the equipment (related to its maintenance).

According to the Ontario Ministry of Labour (MOL) 2017-2018 report entitled *Occupational Health & Safety in Ontario* (MOL 2019), data from 2011 to 2017 indicate 26% to 36% of traumatic fatalities and 26% to 37% of occupational disease fatalities occurred in the construction sector while this sector accounted for 8.0% of total employment under provincial jurisdiction. These statistics indicate that higher fatality rates occur in the construction industry compared with other industrial sectors. The MOL (2019) report also noted that for the last 10 years, construction and transportation sectors has been the top two sectors in terms of the fatality rates.

As indicated by the MOL (2019) data, the fatality rate in the construction sector has not changed significantly over this time period. This consistency over time suggests that the rates of these accidents in these sectors are being controlled by human performance in typical industry-practices, and as such, rates have reached as-low-as- human performance limits allow, under the existing health and safety regulatory framework. Given the awareness of the roles of human factors in these accidents, provisions including training, procedures, and safeguards have been put in place by CNL to achieve as-low-as-reasonably-practicable accident rates.

It should also be noted that the work-place accident statistics mentioned above are aggregated data collected from a large number of industrial sectors, some of which may not have robust occupational health and safety programs.

Fundamental Safety Principles

The Fundamental Safety Principles outlined in the Safety Analysis Report (Athauda-Arachchige, 2015) are expected to be followed for decommissioning activities. Information on these principles

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is presented below, based on Athauda-Arachchige (2015) but with revisions to apply to conventional safety of the planned decommissioning activities.

A safety culture governs the actions of all individuals and organizations engaged in activities related to radioactive waste management. The principles relating to safety culture include operating organization responsibility, quality and management system, human factors, and safety analysis and verification.

- Operating Organization Responsibility

The primary responsibility for assuring safety rests with CNL as the licensee. This responsibility includes, but is not limited to, the provision of trained, qualified staff and the provision of competent engineering and technical support staff.

The organization, responsibilities and processes are in place to: satisfy the CNL's policies on Health and Safety, and Environment; to ensure conformance with the Radiation Protection (RP) Program; to manage radiological hazards; and, to establish a safe working environment that ensures the protection of environment and personnel.

- Quality Assurance

A Management System meeting the requirements of the Canadian Standards Association Standard N286 is applied to the decommissioning phases of the project. All CNL employees must comply with the requirements of CNL's Quality Policy and those of the Management Manual.

- Feedback of Experience

CNL maintains an Operational Experience Database containing information obtained internally at CNL. In addition to this, CNL also has access to external operating experience. CNL has examined both of these sources of data to identify the lessons learned (LLD) from previous operating experience that may be relevant for planning decommissioning activities.

- Defence-in-depth Strategy

The "defence-in-depth principle" is fundamental to nuclear safety; in the context of this document, it has been applied to the safe storage of radiological materials.

This concept is centred on the use of independent and redundant levels of protection to compensate for potential human and equipment failures to ensure that no single level is exclusively relied upon for ultimate safety of a facility. Defence-in-depth ensures the safety of on-site personnel and the public during routine activities, anticipated operational occurrences and accident scenarios at the facility (see Athauda-Arachchige 2015 for specific references). Each level of protection has a specific purpose (e.g. prevention, mitigation and accommodation) and corresponds to the level of risk posed by the postulated event.

The application of defence-in-depth concept to abnormal events ensures that no single human or equipment failure (or external occurrence) will result in an unacceptable radiological risk. The

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approach to effectively control a hazard has been based on the following hierarchy of hazard control principles:

- Elimination of the hazard;
- Substitution and minimization of the hazard;
- Isolation of the hazard;
- Control of the hazard;
- Use of administrative controls (policies, procedures and documents); and,
- Use of Personal Protective Equipment and Clothing (PPE).

Of these six hazard control principles, the most effective is to eliminate a given hazard, and wherever possible, this has been the preferred method of hazard control.

Where a hazard cannot be eliminated, the remaining principles are implemented to various degrees to control the hazard. The substitution and minimization of a hazard is provided by the inherent design characteristics of the structures and components themselves, as well as by the reliability of the equipment used during storage with surveillance activities.

Hazard mitigation, as related to mechanical failures, is achieved by a combination of scheduled equipment inspections, scheduled preventive maintenance and corrective maintenance.

Isolation as related to radioactive materials, requires appropriate containment (i.e. multiple physical barriers), such that attendant doses of these radioactive and hazardous materials are well below the regulatory limits.

Administrative hazard controls consist of managerial efforts to reduce hazards through planning, training, human factors engineering studies, written policies and procedures, safe work practices and radiological monitoring. This level of hazard control primarily addresses the human element.

When the aforementioned hazard controls are not technically, operationally or financially feasible, PPE must be considered as a supplement. Personal protective equipment and clothing includes a variety of items worn by an individual (e.g. goggles, coats, gloves, respirators, etc.) to isolate that person from the hazards at hand.

Relevance to Project Decommissioning Activities

The activities identified for the NPD decommissioning project share similarities to those of conventional construction and demolition projects. The hazard identification process presented in Section 7.0 identified 29 potential hazard events involving conventional accidents, 13 of which have the *potential* for severe consequences (e.g. fatalities). Five (5) of these 13 represent the potentially severe consequences of natural phenomena (i.e. from forest fires, tornados, flooding, and earthquakes) [see Table B.1, Items 13, 17, 21, 25, and 28]. The remaining 16 conventional accident scenarios represent the potential consequences of: general conventional construction

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accidents; transportation accidents; electrocution; heavy equipment failure and load drop; working underground and in confined spaces in IDLH conditions (e.g. low oxygen); and structural collapse [Table B.1 Items 1, 6, 12, 16, 20, 24, 27, 29, and 31; Table B.2 Items 2 and 5; Table B.3 Items 6 and 7; Table B.4 Items 9 and 14; and, Table B.5 Item 4].

In contrast to typical construction projects (and typical safeguards) the project's planned decommissioning project activities will be performed with an *additional* degree of training, procedures, and safeguards in place, since this project involves decommissioning of a historic nuclear reactor and radiation protection principles are involved. Staff and contractors will receive orientation to ensure they are aware of decommissioning activities, hazards, and emergency procedures. Additionally, hazards to personnel will be identified through work control documents and eliminated or controlled using engineered controls, administrative controls, and PPE. This includes provisions for common construction hazards such as working at heights, working with electricity, confined spaces, etc.

To further emphasize the role of safety, a non-exhaustive list outlining many examples of safeguards that will be applied to the project was presented in Section 7.4 covering conventional accident safeguards, routing/transportation safeguards, fueling safeguards, weather and natural event safeguards, security safeguards, grouting safeguards, and many other topics.

Therefore, given the fundamental safety principles that govern project planning and execution, and the many safeguards involved, conventional accidents are considered to be managed to as low as reasonably practicable.

8.4 Batch Mixing Plant

8.4.1 Designate Location, Create Access, and Erect Temporary Fencing

This section analyses the effects from designating the footprint of the batch mixing plant and pumper station, creating access, and erecting temporary fencing (i.e. activities 1.1 and 1.7, see Table 7-3).

The batch plant will be constructed south east of the main building, in former parking area. This location makes use of existing site features and thus will not require the construction of a new road.

8.4.1.1 Atmospheric Environment

Dust produced from this activity would be minimal, as long as Standard Construction Practices (See Section 8.3.2) are followed; including measures to reduce dust. Furthermore, the composition of the dust from this activity represents background levels of chemicals and radionuclides. Creating access and erecting temporary fencing is therefore not expected to affect the atmospheric environment.

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8.4.1.2 Surface Water Environment

The creation of access to the batch mixing plant is not expected to require additional paving, therefore effects on the surface water environment will be negligible.

8.4.1.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on the soil quality, groundwater quality or groundwater flows. Digging to install fence posts is limited to shallow holes in a small area and is therefore not expected to affect ground water flows or soil quality.

8.4.1.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to involve any radioactive material, and as such are not expected to have any impact on the radiation and radioactivity environment. These activities will be carried out in a low radiological risk area.

8.4.1.5 Effects on Public Health

The activities associated with this task are not expected to have any effect on public health because they are not affecting any environmental components to which the public is exposed. In particular, the atmospheric environment only undergoes negligible effects, in a localized area that does not extend to public residents.

8.4.1.6 Effects on Worker Health

The activities associated with this task are routine construction activities. No exposure effects on workers' health are expected, as long as Standard Construction Practices are followed (Section 8.3.2). Conventional worker safety is addressed in Section 8.3.3. Therefore, the environmental impact of this task is negligible and is not expected to have an impact on worker health.

8.4.1.7 Effects on Non-Human Biota

The activities associated with this task are expected to have negligible effects on non-human biota because the only affected environment is atmospheric, and the dust releases to the atmospheric environment are expected to be minor, and localized, thereby limiting the potential for non-human biota to be exposed.

8.4.2 Stockpile Grout Ingredients

This section analyses the effects of several activities related to stockpiling of grout ingredients (i.e. activities 1.2, 1.3, and 1.4, see Table 7-3), including:

- Designating the storage area for raw grout materials (e.g. sand, blast furnace slag);

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- Truck in grout materials (e.g. sand, blast furnace slag) and truck in water supply;
- Creating access to the Stockpile; and,
- Set up mixing station for operation.

8.4.2.1 Atmospheric Environment

A bounding scenario was developed in order to assess the impact of decommissioning activities on the atmospheric Environment. Appendix F presents the effects assessment of this bounding scenario. This bounding scenario involves several activities occurring simultaneously, including:

- Batch mixing plant (raw material delivery, material handling, batch mixing, diesel generator, transport to placement site);
- Grouting of below grade structure (transport of concrete from batch plant to placement site); and,
- Removal of above grade structure (demolition activities including concrete cutting, material handling, heavy equipment activity, crushing and screening).

This activity includes trucking on unpaved roads to the storage location for the concrete batch plant (i.e. to bring raw materials to the stockpiles, from offsite), which results in emissions of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effects from these trucking activities are also bounded by the emission estimate in Appendix F. Appendix F shows that the effect of these trucking emissions on the atmospheric environment is considered not to be measurable and therefore does not require further consideration.

8.4.2.2 Surface Water Environment

The activities associated with this task could marginally change the surface water drainage properties of the site. However, these changes would be localized to the stockpiled material and would therefore not affect the surface water environment as a whole. Furthermore, stockpiles will be managed using standard construction practices to reduce runoff emissions (see also Section 8.3.2), as are typically used for construction projects. If future studies (e.g. those performed in support of work control documents) identified the need for additional or more specific control measures, CNL will investigate their implementation.

These practices would prevent possible surface water contamination from water run-off from the stockpiles. Specifically, there would be no resulting impact on the Ottawa River.

8.4.2.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on soil quality, groundwater quality or groundwater flows because no interactions between the activity and the geological and hydrogeological environment have been identified.

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8.4.2.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to have an effect on the radiation and radioactivity environment.

8.4.2.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they are not affecting any environmental components to which public receptors are exposed. In particular, the atmospheric environment and the surface water environment only experience localized, negligible effects which will not reach public residents.

8.4.2.6 Effects on Worker Health

The activities associated with this task are routine construction activities. No exposure effects on worker health are expected, as long as Standard Construction Practices are followed (see Section 8.3.2).

Conventional worker safety is addressed Section 8.3.3. The environmental impact of this task is negligible and is not expected to have an impact on worker health.

8.4.2.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because the effects to the environment that the non-human biota could be exposed through is negligible. Specifically, the dust released is not measurable (see Appendix F) and therefore the corresponding effects are negligible.

8.4.3 Mix Grout to Required Formula

This activity includes operating the concrete batch plant to mix the ingredients to the desired grout/concrete formula and transporting grout to pumper station (i.e. activities 1.8 and 1.9, see Table 7-3) by truck or piping. This includes:

- Operating the diesel generator to power the mixing plant;
- Transporting the grout ingredients from the stockpiles to the mixing plant; and,
- Transporting grout to pumper station (by truck or piping).

8.4.3.1 Atmospheric Environment

This activity would include operating the concrete batch plant, the diesel generator, the transport of raw materials from the stockpiles to the mixing plant, and the transport of mixed grout from the batch plant to the pumper station, which results in emissions of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}.

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The atmospheric effect from these trucking activities is also bounded by the emission estimate in Appendix F. Appendix F shows that the effect of these trucking emissions on the atmospheric environment is considered not to be measurable and therefore does not require further consideration.

8.4.3.2 Surface Water Environment

The activities associated with this task are not expected to have an effect on the surface water environment, flow characteristics or water quality, as there are no anticipated interactions between this activity and the surface water environment.

8.4.3.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on soil quality, groundwater quality or groundwater flows, as there are no anticipated interactions between this activity and the geological and hydrogeological environment.

8.4.3.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to involve any radioactive material, and as such are not expected to have any impact on the radiation and radioactivity environment as this activity does not involve any radioactive material.

8.4.3.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they do not affect any environmental components to which public receptors are exposed. In particular, the atmospheric environment only experiences negligible effects, and the surface water quality is not being affected.

8.4.3.6 Effects on Worker Health

The activities associated with this task are routine construction activities. No exposure effects on worker health are expected, as long as Standard Construction Practices are followed (see Section 8.3.2).

Conventional worker safety is addressed in Section 8.3.3. The environmental impact of this task is negligible and is not expected to have an impact on worker health.

8.4.3.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because the atmospheric environment is the only pathway to non-human biota where an interaction has been identified, and the dust release is not measurable (see Appendix F) and

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therefore the corresponding effects are negligible. The Standard Construction Practices outlined in Section 8.3.2 are to be followed.

8.4.4 Provide Slip Pipe Access to Nuclear Area

This section analyses the effects of providing slip-pipe access to the nuclear area for grouting (i.e. activity 1.5, see Table 7-3). This includes cutting/drilling holes in the building to allow grout to be poured.

8.4.4.1 Atmospheric Environment

This activity includes the use of gas-powered concrete saws and drills, which results in emissions of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effects from these activities are bounded by the emission estimate in Appendix F. Appendix F shows that the effect of these emissions on the atmospheric environment is considered not to be measurable and therefore does not require further consideration.

8.4.4.2 Surface Water Environment

The activities associated with this task are not expected to have an effect on the surface water environment, flow characteristics or water quality, as there are no anticipated interactions between this activity and the surface water environment.

8.4.4.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on soil quality, groundwater quality or groundwater flows, as there are no anticipated interactions between this activity and the geological and hydrogeological environment.

8.4.4.4 Radiation and Radioactivity Environment

The activities associated with this task have the potential to result in a change to the localized radiation and radioactivity environment. Specifically, the external radiation fields within certain locations of the facility could be affected by drilling/cutting. Therefore, a bounding scenario is assessed (below) where workers are drilling from the Fueling Machine (FM) room into the reactor vault (modelling details for this scenario are provided in Appendix D). Figure 8-1 shows the locations of the drilling holes, along with floor material compositions.

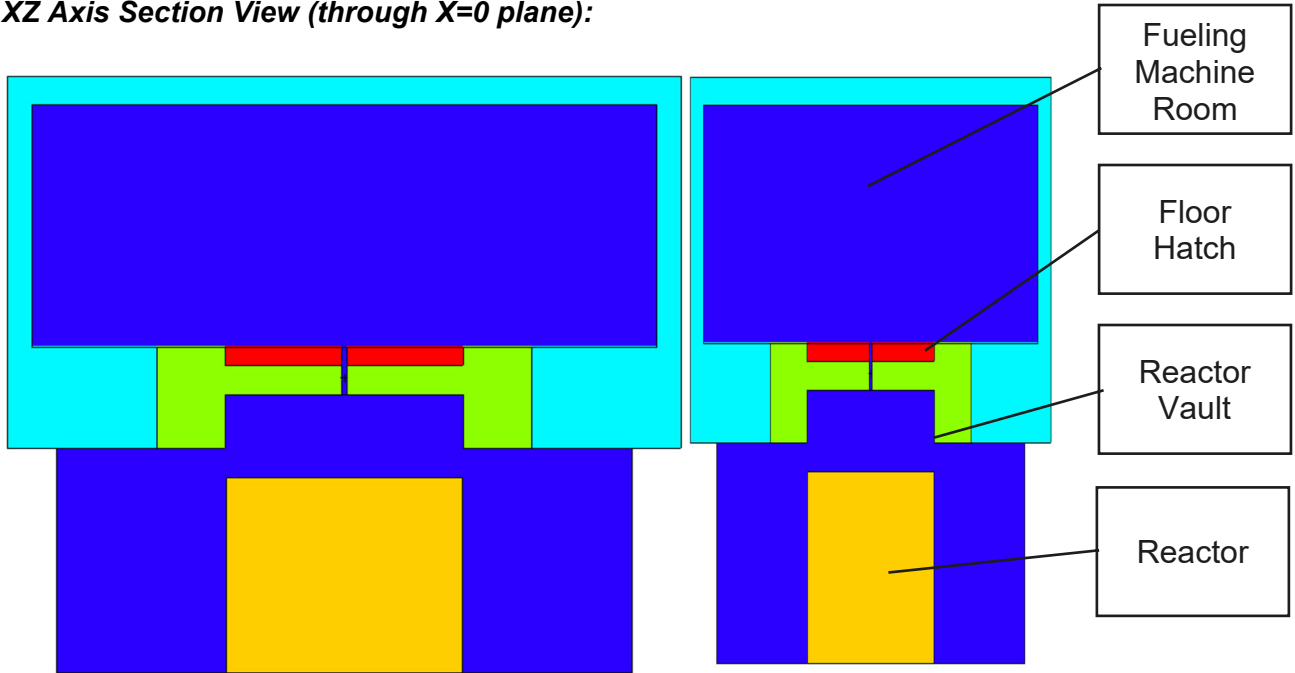
Other drilling activities would be bounded by this scenario because this scenario involves the highest drilling source term. This analysis will correspond to the estimated worker dose due to drilling, which is provided in Section 8.4.4.6.

The DDP will identify the expected total number holes drilled, and the resulting dose(s) to workers. Further details will be available in detailed work plans, once developed.

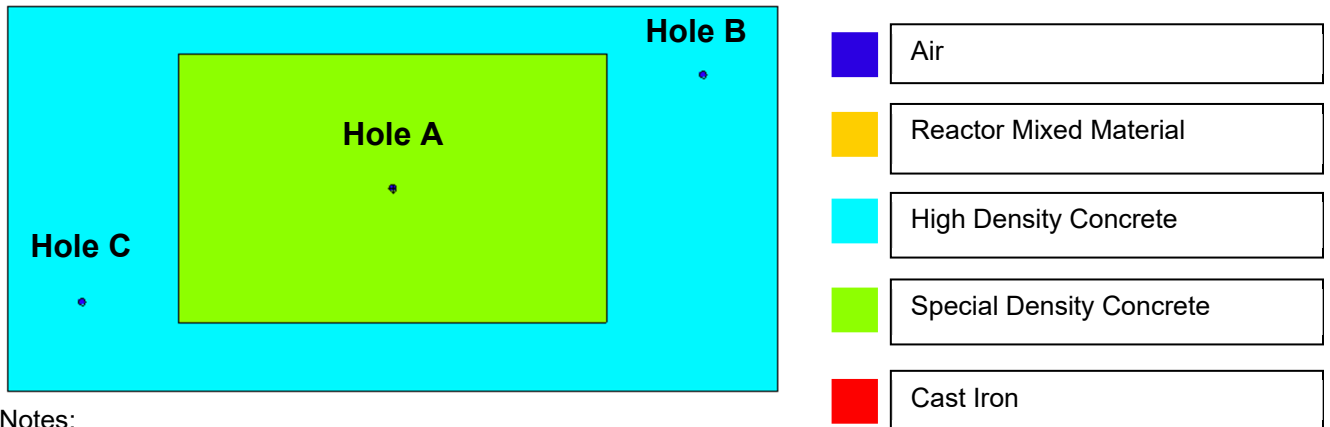
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Figure 8-1 MCNP Model Showing Drilling Locations

XZ Axis Section View (through X=0 plane):



YZ Axis Section View (through Y=0 plane):



Notes:
Not to scale.
See Appendix D, Table D-1 for dimensions.

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Dose Rate Results

Table 8-2 shows the *per-hour* dose rate estimates for the drilling activity (gamma dose rate from the drilled holes, and, ambient room gamma). The simulation was run for 1×10^{10} histories (simulated particles), in order to achieve an acceptable error level. It is important to note that the error associated with these dose rates is the statistical error from MCNP's generation of random numbers in Monte Carlo calculations, and is not the error associated with the model or its assumptions.

Table 8-2 Estimated Per-Hour Gamma Dose Rates for Drilling
(Drilling from the FM room, into the reactor vault)

Location	Dose Rate (mSv/hr)	Error (%)
Hole A	1.19E-2	1.13%
Hole B	9.36E-06	6.48%
Hole C	9.86E-06	5.81%
Ambient Dose Rate in FM Room	2.1 E-02	From (Primeau 2016)

Notes:

Dose rates modelled at 87.5 cm height above the floor level.

From Table 8-2, it can be seen that the ambient room dose rate is dominant, particularly for holes drilled to the side of the fueling machine room (holes B & C, as well as the measured value).

8.4.4.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they are not affecting any environmental components to which public receptors are exposed. In particular, the atmospheric environment only undergoes negligible effects, in a localized area that does not extend to public residents.

8.4.4.6 Effects on Worker Health

The activities associated with this task have the potential to result in exposure to nearby workers performing drilling activities (e.g. to install holes for slip pipe access). The following is a total dose estimate based on the external per-hour dose rates presented in Section 8.4.4.4 and anticipated drilling durations. *Since these activities are conducted as part of normal operations, it is assumed that dust and inhalation safeguards will be in place such that inhalation of dust is mitigated.*

Drilling of Vent Holes into the Reactor Vault

For this dose estimate, drilling is anticipated to take 2 days to complete (i.e. two 8-hour days for a total of 16 hours). Table 8-3 shows the total dose (i.e. gamma dose from the drilled hole *and* ambient room gamma dose) a worker is estimated to receive over this 16-hour drilling period, along with estimates for other drilling times for perspective. Please note that these estimates are

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conservative because they represent the dose received by a worker that is standing over the hole, actively drilling, for the entire drilling period.

Table 8-3 Total Gamma Doses from Drilling into the Reactor Vault (By Drilling Time)

Location	Total Dose (mSv)	Dose Limit (mSv) (Max Per Year)	Dose Limit (mSv) (Per 5-Year Period)
4 Hours			
Hole A	0.132	50	100
Hole B ¹	0.084	50	100
Hole C ¹	0.084	50	100
8 Hours			
Hole A	0.263	50	100
Hole B ¹	0.168	50	100
Hole C ¹	0.168	50	100
16 Hours²			
Hole A	0.527	50	100
Hole B ¹	0.336	50	100
Hole C ¹	0.336	50	100

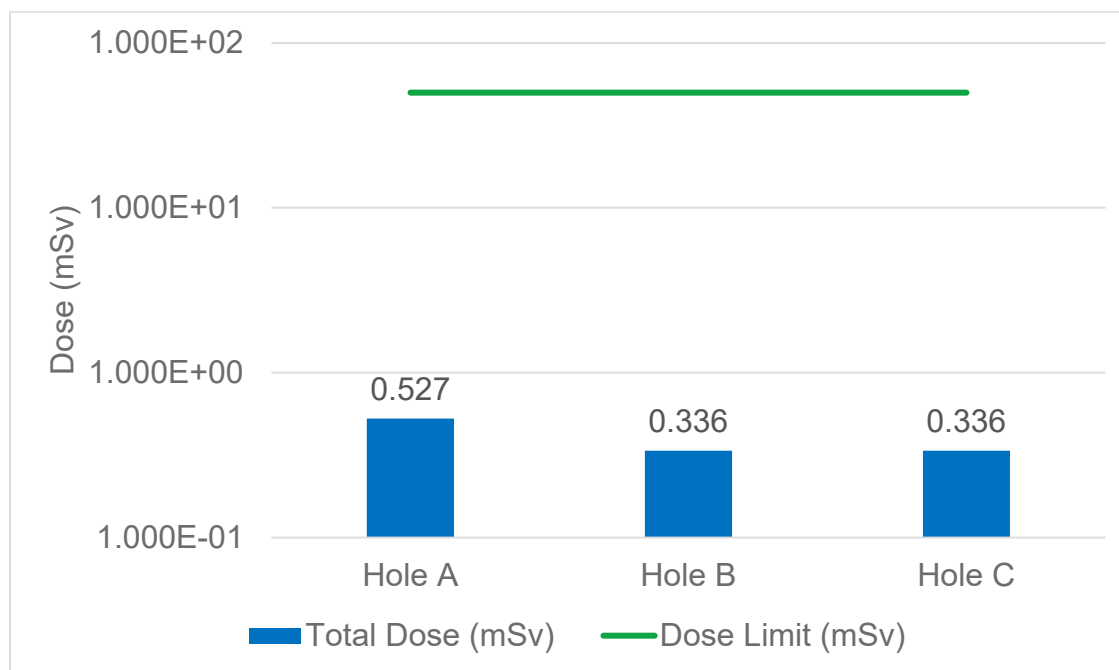
Note:

¹ – the ambient dose rate dominates this total dose.

² – assuming two 8-hour work days.

As shown in Table 8-3, the dose received by a worker drilling for 16 hours is below the regulatory limits (as discussed in Section 4.1.5). This is shown graphically in Figure 8-2. As such, the estimated dose received from drilling is not anticipated to result in any adverse health effects.

Figure 8-2 Estimated Dose Relative to Dose Criteria



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8.4.4.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because they are not affecting any environmental components to which biota are exposed. In particular, the atmospheric environment only undergoes negligible effects, and is contained within the facility. Furthermore, the radiation and radioactivity environment effects are localized to within the facility, and as such should not affect non-human biota.

8.4.5 Wash Out Pits (Preparation and Operation)

This section will analyse the effects of several activities, involving the construction and operation of the wash out pit (i.e. activities 1.6, 1.10, and 1.11, see Table 7-3). The activities associated with this task include:

- Construct wash out pit. Lined excavation with water transfer. Likely near batch-mixing station;
- Wash out cement truck sluice and pumper truck and slip pipes (daily); and,
- Sample and dewater the wash out pit. Emplace sediments into voids in condenser pit where feasible (or emplace during construction of the concrete cap).

8.4.5.1 Atmospheric Environment

This activity includes the use of excavators and backhoes for the construction of the washout pit, which results in emission of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effect from these activities are bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not require further consideration.

8.4.5.2 Surface Water Environment

The activities associated with this task are not expected to have an effect on the surface water environment. The wash out pits will be lined with a watertight material that will prevent contaminated water from leaching out of the pits. Wash water is expected to be re-used for the preparation of grout, in order to limit water releases. As discussed in Section 8.2, any wash water that cannot be reused in grout mixing, or any accumulated rainwater, will be collected, regarded as a non-routine liquid, and reviewed against criteria in CNL's Environmental Protection process (Matasich 2016) which outlines appropriate collection and disposition routes depending on the results of analyses. More specific mitigation measures can be implemented if later work and radiation surveys identify a problem.

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8.4.5.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on the soil quality, groundwater quality or groundwater flows, as there are no anticipated interactions between this activity and the geological and hydrogeological water environment. Spills are addressed through the hazard identification process (see Section 4.0 for more information).

8.4.5.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to involve any radioactive material, and as such are not expected to have any impact on the radiation and radioactivity environment.

8.4.5.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they are not affecting any environmental components to which public receptors are exposed. In particular, the atmospheric and surface water environments only undergoes negligible effects.

8.4.5.6 Effects on Worker Health

The activities associated with this task are routine construction activities. No exposure effects on worker health are expected, as long as Standard Construction Practices are followed (Section 8.3.2).

Conventional worker safety is addressed in Section 8.3.3. The environmental impact of this task is negligible and is expected to not have an impact on worker health.

8.4.5.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because the effects to the environment that the non-human biota could be exposed through is negligible. Specifically, the dust released is not measurable (see Appendix F) and therefore the corresponding effects are negligible. Furthermore, the surface water environment is not expected to be negatively affected by the water releases, as they will be monitored and ensured safe before release.

8.5 Grouting of Below Grade Structures

8.5.1 Prepare Rooms and Large Vessels

This section will analyze the effects of several activities involving preparing rooms and large vessels on the NPD site, for grouting (i.e. activities 2.1 and 2.2, see Table 7-3). This includes:

- sealing of any external penetrations (e.g. pipes);

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- cutting/drilling holes in large vessels for grout to flow through and fill the vessels; and,
- Drilling access holes in concrete for grout and heat dissipation.

Detailed descriptions of the grouting activities (e.g. what is being grouted, in what order, how grouting is executed, etc.) are available in the DDP.

8.5.1.1 Atmospheric Environment

The activities associated with this task are not expected to have an effect on the atmospheric environment outside of the facility. The activities will be carried out within the facility and therefore any releases will be contained within the facility. Any release of contamination will therefore be minimal and localized. Due to this, the effect on the atmospheric environment outside of the facility is negligible.

8.5.1.2 Surface Water Environment

The activities associated with this task are not expected to have an effect on the surface water environment, flow characteristics or water quality, as there are no anticipated interactions between this activity and the surface water environment.

8.5.1.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on the soil quality, groundwater quality or groundwater flows, as there are no anticipated interactions between this activity and the geological and hydrogeological environment.

8.5.1.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to have an effect on the *overall* radiation and radioactivity environment because the *overall* radiation levels in the environment remain unchanged from drilling holes in-place.

8.5.1.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because the emissions are limited to within the facility and therefore do not extend to public residents.

8.5.1.6 Effects on Worker Health

The activities associated with this task are related to routine construction activities. No exposure effects on worker health are expected, as long as Standard Construction Practices (Section 8.3.2) and worker safety safeguards are followed (addressed in Section 8.3.3). For radiation dose, the

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dose associated with drilling into the concrete of the reactor vault is assessed in Section 8.4.4, and it bounds drilling related to room and vessel preparation.

8.5.1.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because any emissions are limited to within the facility and therefore do not extend to locations where non-human biota will be exposed.

8.5.2 Grout Fill Nuclear Area

This section will analyze the effects of grouting the below grade structures, therefore the pouring of grout to fill the rooms in the nuclear area of the facility (i.e. activity 2.3, see Table 7-3).

Included in this activity is the release of hydrogen gases generated by chemical reactions between aluminum components and alkaline grout (Hongqiang, 2017).

8.5.2.1 Atmospheric Environment

Equipment Exhaust, Dust, and Related Releases

This activity includes transporting the grout from the batch plant to the reactor, which results in emission of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5} from the trucks. The atmospheric effect from transportation is bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not need further consideration. If piping is used to transport grout rather than trucking, this would result in less exhaust emissions, and therefore the estimates in Appendix F would be conservative overestimates.

Release of Displaced Air

In addition to this, during the grouting procedure, the air that is currently in the facility will be displaced by the grout, thereby forcing the air, and any contaminants suspended in it, into the atmosphere. There are currently low levels of asbestos and lead suspended in the air throughout the facility. The following assumptions are used in order to assess the release of contaminated air from the facility to the surrounding atmosphere during the grouting operation:

- The releases are not captured by the HEPA filtration system (since the ventilation system will be taken out of service by this time) and therefore the full amount of contamination is released to the environment.
- The amount of air being displaced is equal to the volume of grout being poured (approximately 19,000 m³). This is a conservative assumption because some of the grout

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included in this volume will be used to fill the condenser and turbine pits, which are not enclosed areas, and thus would not have tritiated air present.

- The rate that the grout is being poured, and therefore the rate that the air is being released, is based on the number of days spent grouting:
 - 139 total days are spent grouting.
 - It was assumed that 8 hours per day were spent pouring grout. This allowed for the total inventory to be divided by the total pour time providing a release rate.
- The air being released is assumed to have lead and asbestos concentrations equal to the highest contaminated room. This is a conservative assumption it overestimates the average lead and asbestos concentrations in the facility.
 - The highest measured concentration of lead is 0.01 mg/m³. All measurements that were taken throughout the facility were below the MDL values of 0.01 mg/m³, and as such the MDL value is being used as the air concentration. This will overestimate the actual amount present (AECL 2012).
 - The highest measured concentration of asbestos is 0.009 fibers/cm³, or 2.7E-04 mg/m³. This value corresponds to the highest measured airborne concentration of asbestos found through the facility, measured in room 607 (AECL 2015).

Air concentrations were estimated at worker receptor locations by applying the two-zone transfer model outlined in Section 6.1. The resulting air concentrations are presented in Table 8-4.

Table 8-4 Air Displacement – Airborne Asbestos and Lead Concentration at Worker Receptor Locations

Receptor Location	Estimated Exposure Concentration (Air) [in g/m ³]	
	Worker (near field)	Worker (far field)
Lead	2.37E-12	2.37E-12
Asbestos	6.41E-14	6.41E-14

These estimated air concentrations are assessed in Section 8.5.2.6 for potential effects on Worker Health.

Air concentrations were estimated at public receptor locations by applying the long-distance dispersion and method outlined in Section 6.2. Using the ADFs outlined in Section 6.2.2, two sets of calculations were performed. The first was performed using the conservative CALPUFF ADFs, and the second using CNL ADFs from the DRL (i.e. those from Chouhan 2016a). Table 8-5 below shows the resulting airborne concentrations of asbestos and lead at the receptor locations.

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Table 8-5 Air Displacement – Airborne Asbestos and Lead Concentration at Public Receptor Locations

Public Receptor Locations	Estimated Exposure Concentration (Air) [in g/m ³]			
	Lead		Asbestos	
	Using CALPUFF ADFs	Using CNL ADFs (Chouhan, 2016a)	Using CALPUFF ADFs	Using CNL ADFs (Chouhan, 2016a)
<i>Res. 1</i>	2.28E-13	N/A	6.15E-15	N/A
<i>Res. 2</i>	2.52E-13	N/A	6.79E-15	N/A
<i>Res. 3</i>	2.33E-13	N/A	6.28E-15	N/A
<i>Rec. (Res. 4)</i>	2.99E-13	N/A	8.07E-15	N/A
<i>Guardhouse</i>	2.09E-11	N/A	5.64E-13	N/A
<i>Rapides Des Joachims</i>	1.76E-13	1.43E-14	4.74E-15	3.86E-16
<i>Pt. Stewart Residential</i>	1.38E-13	1.14E-14	3.72E-15	3.09E-16
<i>Cottage</i>	1.99E-13	1.20E-14	5.38E-15	3.24E-16
<i>Rolphon Residential</i>	7.59E-14	5.27E-15	2.05E-15	1.42E-16
<i>Mackey Beef Farm</i>	4.32E-15	1.12E-15	1.17E-16	3.01E-17
<i>Bass Lake Beef Farm</i>	4.65E-15	1.03E-15	1.26E-16	2.79E-17

These estimated lead and asbestos air concentrations are assessed in Section 8.4.5.5 and 8.5.2.7 for potential effects on Public Health and Non-Human Biota, respectively.

Air Deposition to Soil

Lead in airborne releases can deposit onto soil, which may result in soil contamination. Asbestos in airborne releases, and its subsequent potential to deposit onto soil, has not been calculated because the primary hazard associated with asbestos is due to inhalation. Soil lead concentrations during grouting operations were assessed based on assumptions below:

- Soil concentrations at worker and public receptor locations were estimated by applying the air-to-soil transferring model outlined in Section 6.3.
- The duration of air-to-soil deposition is assumed to be 139 days, which is equal to the estimated duration of grouting operations.

The resulting soil concentrations are listed in Table 8-6 for worker receptor locations, and in Table 8-7 for public receptor locations.

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Table 8-6 Air-to-Soil Deposition – Soil Concentrations at Worker Receptor Locations

Receptor Location	Estimated Exposure Concentration (Soil) [in µg/g]	
	Worker (near field)	Worker (far field)
Lead	6.73E-06	6.73E-06
Asbestos	N/A	N/A

Table 8-7 Air-to-Soil Deposition – Soil Concentrations at Public Receptor Locations

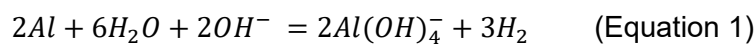
Public Receptor Locations	Estimated Exposure Concentration (Soil) [in µg/g]
	Lead
	Using CALPUFF ADFs
Res. 1	6.46E-07
Res. 2	7.13E-07
Res. 3	6.60E-07
Rec. (Res. 4)	8.48E-07
Guardhouse	5.92E-05
Rapides Des Joachims	4.98E-07
Pt. Stewart Residential	3.90E-07
Cottage	5.65E-07
Rolphon Residential	2.15E-07
Mackey Beef Farm	1.22E-08
Bass Lake Beef Farm	1.32E-08

These estimated lead soil concentrations are assessed in Section 8.5.2.5 and 8.5.2.7 for potential effects on Public Health and Non-Human Biota, respectively.

Release of Hydrogen Gas

Hongqiang (2017) examines the generation of hydrogen gases from chemical reactions between the alkaline grout and aluminum components inside the facility. The following is a brief excerpt. For references and additional details, the reader is referred to the original Hongqiang (2017) study.

Grout slurries typically have pH values higher than 12. In this alkaline environment, aluminum will be corroded to generate hydrogen according to Equation 1:



The US Department of Energy (DOE) Pacific Northwest National Laboratory (PNNL) has studied aluminum-grout reactions, and has derived a hydrogen generation rate of $1.04 \times 10^{-6} \text{ m}^3/(\text{m}^2 \cdot \text{s})$

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for a unit area of aluminum surfaces in a simulated solution. This generation rate is assumed to estimate the hydrogen produced by aluminum-grout reactions involving the dump tank and the reactor calandria.

Calandria

While filling the reactor vault with grout it is possible that some grout will enter the space between the pressure tubes and the calandria tubes. So, it is assumed that all 132 calandria tubes become completely filled – this is conservative because it will lead to a greater hydrogen release. With a total aluminum surface area of 306 m², the corresponding hydrogen production rate will be 3.18 x 10⁻⁴ m³/s. Assuming a grout set (pouring and solidifying) time of 30 hours, a total of 34.4 m³ of hydrogen will be produced.

The hydrogen concentration in the reactor vault depends on how the vault will be filled. If the reactor vault is filled continuously then once the calandria is immersed the available empty space will be 14.85 m³. This assumes a sealed vault environment which in reality does not exist. Then the hydrogen concentration in the remaining space will reach 100%. This scenario is based on the very conservative assumptions that all calandria surfaces maintain a constant hydrogen production rate during a 30-hour pouring process. In reality, the solidified grout is much less reactive compared with the fresh grout slurry. The corrosion products on calandria surfaces will also slow down the hydrogen production rate. Nevertheless, measures are needed to ensure hydrogen safety (discussed later, in Section 8.5.2.6).

Dump Tank

The dump tank is located in the lower level of the boiler room of NPD. Its material is ASTM B209-57T-GR40A-0 whose main constituent is aluminum.

Both the dump tank and the boiler room are to be filled with grout. Therefore, both the internal surfaces and external wall of the dump tank will contribute to hydrogen generation. The hydrogen concentration in the boiler room depends on how the room is to be filled. Two options are considered:

- Option 1: Fill the dump tank with grout first and allow to set before filling the boiler room;
- Option 2: Fill the boiler room from the bottom and fill the dump tank at the same time.

For option 1 the inner surface of the dump tank is grouted and releases hydrogen, then after solidifying, the boiler room (and therefore the external surface of the dump tank) is grouted and releases hydrogen. Based on an inner surface area of 207.9 m², the resulting hydrogen release rate is 2.16 x 10⁻⁴ m³/s, which produces 23.33 m³ of hydrogen over the 30-hour grout setting period. Using an open receiving volume of 2,687 m³, this produces a hydrogen concentration of 0.87% (by volume). Next, based on an outer surface area of 91.9 m², the resulting hydrogen release rate is 9.55 x 10⁻⁵ m³/s, which produces 10.3 m³ of hydrogen over the 30-hour grout setting

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period. Using an open receiving volume of 2,687 m³, this produces a hydrogen concentration of 0.38% (by volume).

For option 2, hydrogen production will occur on both the inner surfaces and exterior surfaces of the dump tank at the same time. Based on a combined inner and outer surface area of 323 m², the resulting hydrogen release rate is 3.35×10^{-4} m³/s, which produces 36.28 m³ of hydrogen over the 30-hour grout setting period. Using an open receiving volume of 2,687 m³, this produces a hydrogen concentration of 1.4 % (by volume).

Measures to ensure hydrogen safety are discussed later, in Section 8.5.2.6.

8.5.2.2 Surface Water Environment

The activities associated with this task are not expected to have an effect on the surface water environment, flow characteristics or water quality, as there are no anticipated interactions between this activity and the surface water environment.

8.5.2.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have any effect on the soil quality, groundwater quality or groundwater flows, as there are no anticipated interactions between this activity and the geological and hydrogeological environment.

8.5.2.4 Radiation and Radioactivity Environment

During the grouting procedure, the air that is currently in the facility will be displaced due the pouring of grout. The air within the facility contains low levels of tritium (Primeau 2016). The grouting operations could lead to the release of a portion of this contaminated air. In addition to the assumptions described in Section 8.5.2.1, the following assumptions were also used:

- The air being released is assumed to have a tritium concentration equal to the highest contaminated room, R-103 (the dump tank room) (1.04E+06 Bq/m³ from Table 5-13). This is a conservative assumption that overestimates the average tritium concentration in the facility.
 - The amount of air being displaced is equal to the volume of grout being poured (i.e. approximately 19,000 m³) (see Section 8.5.2.1) (resulting in a release rate of 4.94E+03 Bq/s).
 - The contamination is assumed to be limited to tritium in the air, for which measurement data are available from continuous passive air samplers.
 - For dose calculations, tritium is treated as HTO to be conservative, wherever HTO DCs are available.

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Air concentrations were estimated at worker receptor locations by applying the two-zone transfer model outlined in Section 6.1. The resulting air concentrations are presented in Table 8-8.

Table 8-8 Air Displacement – Airborne Tritium Exposure Concentration at Worker Locations

Receptor Location	Estimated Exposure Concentration (Air) [in Bq/m ³]
<i>Worker (near field)</i>	2.46E-01
<i>Worker (far field)</i>	2.46E-01

These estimated tritium concentrations are assessed in Section 8.5.2.6 for potential effects on Worker Health.

Using the ADFs outlined in Section 6.2.2, two sets of calculations were performed. The first was performed using the conservative CALPUFF ADFs, and the second using the CNL ADFs from the DRL (i.e. those from Chouhan 2016a). Table 8-9 below shows the resulting airborne concentrations of tritium at receptor locations.

Table 8-9 Exposure Concentrations at Receptor Locations (Air) [in Bq/m³]

Source Term Release Rate (QR) [Bq/s]	4.94E+03	
Public Receptor Locations	Exposure Concentrations (Bq/m ³)	
	Using CALPUFF ADFs	Using CNL ADFs (Chouhan, 2016a)
<i>Res. 1</i>	2.36E-02	N/A
<i>Res. 2</i>	2.61E-02	N/A
<i>Res. 3</i>	2.41E-02	N/A
<i>Rec. (Res. 4)</i>	3.10E-02	N/A
<i>Guardhouse</i>	2.16E+00	N/A
<i>Rapides Des Joachims</i>	1.82E-02	1.48E-03
<i>Pt. Stewart Residential</i>	1.43E-02	1.19E-03
<i>Cottage</i>	2.07E-02	1.24E-03
<i>Rolphton Residential</i>	7.87E-03	5.46E-04
<i>Mackey Beef Farm</i>	4.47E-04	1.16E-04
<i>Bass Lake Beef Farm</i>	4.82E-04	1.07E-04

These estimated tritium concentrations are assessed in Section 8.5.2.5 and 8.5.2.7 for potential effects on Public Health and Non-Human Biota, respectively.

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8.5.2.5 Effects on Public Health

Airborne Releases - Radiological

As outlined in Section 8.5.2.4, concentrations of tritium at various receptor locations, resulting from contaminated air being displaced during grouting operations, have been calculated. From these concentrations, the dose rate to the receptors is calculated by pro-rating the DRL (Chouhan and Scheier 2011). This was performed according to the ratio below:

$$\dot{D}_{calculated} = \dot{D}_{DRL} * \frac{\dot{Q}_{calculated}}{\dot{Q}_{DRL}}$$

Where:

$\dot{D}_{calculated}$ = the dose rate calculated for the air displacement

\dot{D}_{DRL} = the dose rate used by the DRL $\left(1 \frac{mSv}{A}\right)$

$\dot{Q}_{calculated}$ = the calculated release rate for the air displacement = $1.27 E + 10 \frac{Bq}{month}$

\dot{Q}_{DRL} = the allowed release rate, corresponding to the DRL = $3.77 E + 15 \frac{Bq}{month}$

In using this ratio method, it is important to note that the DRL values are based on continuous releases of their respective radionuclides, whereas grout filling (and therefore air displacement) is not continuous (it ceases once rooms are sufficiently full). This difference is not accounted for when using this ratio method, and therefore, mathematically, the ratio method produces values as if the release rate (Bq/s) is continuous.

In the DRL, the Rapides des Joachims residents were identified as the critical group and therefore, the calculated dose rate is representative of them. Because the Point Stewart, Cottage, Rolphton Residential, and Mackey and Bass Lake Beef Farms are not the critical group, the dose rates at those locations would therefore be less than the dose rate for Rapides des Joachims. It is safe to assume that the dose rate for these particular non-critical locations are lower than that of Rapides des Joachims, since their air concentrations are also lower than those at Rapides des Joachims.

Outside of the DRL, an additional five receptor locations were identified: three residential, one recreational, and the guardhouse location (as noted in Section 4.6). For these locations not included in the DRL, dose rates were scaled relative to ADFs.

The resulting dose rates for the receptor locations are presented in Table 8-10, using ADFs from Chouhan (2016a).

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Table 8-10 Expected Dose Rates (mSv/yr) at the Receptor Locations

Location	Dose Rate (mSv/yr)	Source
<i>Rapides Des Joachims</i>	3.38E-06	Scaled From DRL
<i>Pt. Stewart Residential</i>	<3.38E-06	Non-Critical Receptors
<i>Cottage</i>	<3.38E-06	Non-Critical Receptors
<i>Rolphon Residential</i>	<3.38E-06	Non-Critical Receptors
<i>Mackey Beef Farm</i>	<3.38E-06	Non-Critical Receptors
<i>Bass Lake Beef Farm</i>	<3.38E-06	Non-Critical Receptors
<i>Residential (R1)</i>	4.39E-06	Scaled Relative to ADF ¹
<i>Residential (R2)</i>	4.84E-06	Scaled Relative to ADF ¹
<i>Residential (R3)</i>	4.48E-06	Scaled Relative to ADF ¹
<i>Recreational (R4)</i>	5.76E-06	Scaled Relative to ADF ¹
<i>Guardhouse</i>	4.02E-04	Scaled Relative to ADF ¹

Note: The CALPUFF ADFs were used to scale the dose rate at Rapides des Joachims by:

$$\dot{D} = \dot{D}_{RdJ} * \frac{ADF}{ADF_{RdJ}}$$

As shown in Table 8-10, these estimated proportional dose rates are less than the public dose limit, and therefore, no undue effects on public health are expected.

Airborne Releases - Non-Radiological

Atmospheric releases need to be assessed for potential effects on public health. This is accomplished by comparing calculated air concentrations at receptor locations (derived in Section 8.5.2.1) against corresponding benchmark values (outlined in Section 4.1.6.1). Only the results calculated using the CALPUFF ADFs are compared to the benchmark values because they are more conservative, and because they are available for all receptor locations.

The result of the comparison is a screening index, which is a ratio of an estimated air concentration to its corresponding benchmark value. Screening indices for non-radiological airborne releases are shown in Table 8-11.

Table 8-11 Air Displacement - Inhalation Screening Index (Public Receptors)

Public Receptor Location	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>	
	Lead	Asbestos
<i>Res. 1</i>	2.28E-06	5.13E-09
<i>Res. 2</i>	2.52E-06	5.66E-09
<i>Res. 3</i>	2.33E-06	5.23E-09
<i>Rec. (Res. 4)</i>	2.99E-06	6.73E-09
<i>Guardhouse</i>	2.09E-04	4.70E-07
<i>Rapides Des Joachims</i>	1.76E-06	3.95E-09
<i>Pt. Stewart Res.</i>	1.38E-06	3.10E-09
<i>Cottage</i>	1.99E-06	4.49E-09
<i>Rolphon Res.</i>	7.59E-07	1.71E-09
<i>Mackey Beef Farm</i>	4.32E-08	9.72E-11
<i>Bass Lake Beef Farm</i>	4.65E-08	1.05E-10

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As can be seen in Table 8-11, all of the screening indices are much less than 1, and therefore, no undue effects on public health are anticipated.

Air Deposition to Soil

Atmospheric releases of lead, and their deposition to soil, are also assessed for potential effects on public health. This is accomplished by comparing the estimated soil concentrations at receptor locations (derived in Section 8.5.2.1, using the method outlined in Section 6.3) against corresponding soil benchmark values (outlined in Section 4.1.6).

Only lead soil concentrations calculated using the CALPUFF ADFs are compared to the benchmark value, because they are more conservative, and because they are available for all receptor locations. Asbestos soil concentrations were not assessed because the primary hazard associated with asbestos is through inhalation (potential effects associated with airborne asbestos were assessed earlier in this section).

The result of the comparison is a screening index, which is a ratio of an estimated soil concentration to its corresponding benchmark value. Screening indices for lead soil concentrations are shown in Table 8-12.

Table 8-12 Air Displacement - Screening Index for Lead (Public)

Public Receptor Location	Soil Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>
	Lead
<i>Res. 1</i>	5.38E-09
<i>Res. 2</i>	5.94E-09
<i>Res. 3</i>	5.50E-09
<i>Rec. (Res. 4)</i>	7.07E-09
<i>Guardhouse</i>	4.94E-07
<i>Rapides Des Joachims</i>	4.15E-09
<i>Pt. Stewart Res.</i>	3.25E-09
<i>Cottage</i>	4.71E-09
<i>Rolphon Res.</i>	1.79E-09
<i>Mackey Beef Farm</i>	1.02E-10
<i>Bass Lake Beef Farm</i>	1.10E-10

As can be seen in Table 8-12, all of the screening indices are well below 1, and therefore, no undue effects on public health are expected.

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8.5.2.6 Effects on Worker Health

Airborne Releases - Radiological

As explained in Section 8.5.2.4, the concentrations of tritium for the near and far-field worker receptors, as a result of contaminated air being displaced during grouting, has been calculated. The two-zone box model (for details see Section 6.1) was used to estimate air concentrations using the assumptions outlined in Section 8.5.2.1. The method for calculating inhalation and air immersion doses is presented in Section 9.4. Table 8-13 shows the exposure concentrations and resulting doses for worker receptors in the near-field and far-field zones.

Table 8-13 Exposure Concentrations, Inhalation Dose, Air Immersion Dose, and Total Dose for Workers

Receptor Location	Exposure Concentrations (Air) [in Bq/m ³]	Inhalation Dose [in mSv]	Air Immersion Dose [in mSv]	Total Dose (Inhalation + Immersion) [in mSv]
Worker Near Field	2.46E-01	1.35E-05	0	1.35E-05
Worker Far Field	2.46E-01	1.35E-05	0	1.35E-05

As shown in Table 8-13, all dose estimates are less than the worker dose criterion, and much less than the worker dose limit. Therefore, no undue effects on worker health are expected.

Airborne Releases – Non-Radiological

As outlined in Section 8.5.2.1, airborne concentrations of asbestos and lead for near and far-field worker receptors, as a result of contaminated air being displaced during grouting, have been calculated. The two-zone box model (for details see Section 6.1) was used to estimate air concentrations using the assumptions outlined in Section 8.5.2.1.

Similar to the public, worker exposure concentrations are compared against corresponding benchmark values (8-hr limits in this case) and a screening index is developed. The benchmark values that are compared against are explained in Section 4.1.6, and Table 8-14 shows the results.

Table 8-14 Air Displacement - Inhalation Screening Index (Workers)

Worker Receptors	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>	
	Lead	Asbestos
Worker (Near Field)	4.75E-08	2.14E-08
Worker (Far Field)	4.75E-08	2.14E-08

As can be seen in Table 8-14, all of the screening indices are much less than 1, and therefore, no undue effects on worker health are expected.

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Air to Soil Deposition

Atmospheric releases of lead, and their deposition to soil, are also assessed for potential effects on worker health. This is accomplished by comparing estimated soil concentrations at receptor locations (derived in Section 8.5.2.1, using the method outlined in Section 6.3) against corresponding soil benchmark values (outlined in Section 4.1.6). Asbestos soil concentrations were not assessed because the primary hazard associated with asbestos is through inhalation (potential effects associated with airborne asbestos were assessed earlier in this section).

The result of the comparison is a screening index, which is a ratio of an estimated soil concentration to its corresponding benchmark value. Screening indices for lead soil concentrations are shown in Table 8-15.

Table 8-15 Air Displacement – Soil Screening Index for Lead (Worker)

Contaminant	Soil Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>
	<i>Lead</i>
<i>Worker (Near Field)</i>	5.61E-08
<i>Worker (Far Field)</i>	5.61E-08

As can be seen in Table 8-15, all of the screening indices are much less than 1, and therefore, no undue effects on worker health are expected.

Releases of Hydrogen Gas

Hongqiang (2017) notes that the flammability level of hydrogen gas (in air) is 4% to 74%, with an explosion limit of 18% to 59%, and a stoichiometric mixture of 29% (by volume, all).

For the dump tank, by comparison, either pour option would result in hydrogen levels that are less than the flammability and explosion criteria.

For the calandria, the hydrogen concentration in the reactor vault depends on how the vault will be filled. The most conservative estimate (i.e. if the reactor vault is filled continuously) indicates that once the calandria is immersed the available empty space will be 14.85 m³, and, if a sealed environment is also assumed (which in reality is not the case), this produces a hydrogen concentration reaching 100%. Again though, this is based on very conservative assumptions since it:

- Assumes a sealed vault environment (which does not exist); and,
- Assumes that all calandria surfaces maintain a constant hydrogen production rate during a 30-hour pouring process; and,

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- Neglects corrosion products on calandria surfaces which will also slow down the hydrogen production rate.

Nevertheless, measures are needed to ensure hydrogen safety. The primary measure that will be used to maintain the hydrogen levels at a safe concentration will be to control the environment in the vault with active ventilation that can sufficiently sweep out the produced hydrogen. Given the maximum hydrogen generation rate of 3.18×10^{-4} m³/s, an air flow rate of 3.18×10^{-1} m³/s (674 cfm) would ensure the hydrogen concentration does not rise above 1%. Ventilation can be sized accordingly. A standard 2000 cfm ventilator should be adequate. Additional measures to reduce hydrogen generation include pouring grout in batches to allow a set up time between pours or lowering grout temperature (< 20°C) which also reduces the hydrogen production rate.

Based on the findings of Hongqiang (2017), and assuming that the measures to address hydrogen safety are implemented, adverse effects on workers are not anticipated.

8.5.2.7 Effects on Non-Human Biota

The assessment of effects on non-human biota for this activity is provided in the *Ecological Risk Assessment* TSD (Garisto *et al.*, 2020a). The *Ecological Risk Assessment* TSD (Garisto *et al.*, 2020a) shows that there is no adverse effect on non-human biota from exposure to radioactive or chemical contaminants (i.e. hydrogen and lead) associated with grouting of below-grade structures.

8.6 Demolition and Grouting of Above Grade Structures

8.6.1 Demolition of Above Grade Structures

This section will analyze the effects of several demolition activities of the above ground structures (i.e. activities 3.1, 3.10, 3.11, 3.13, 3.14, and 3.16, see Table 7-3), which includes:

- Removal of transite from the building exterior.
- Conventional heavy equipment knockdown of reactor hall.
- Demolition of block walls and inside walls around control room and change rooms.
- Collapse ceilings of furnace room and adjacent rooms.
- Demolish guardhouse and emplace in rooms.

Note that these generic groupings encompass many repeating activities such as demolishing various facility components. Detailed descriptions of the demolition activities (e.g. what is being demolished, how, and in what order) are available in the DDP.

Demolition material will be emplaced within the facility (turbine hall, and control wing basement as required – see Table 7-2 and Table 7-3) for grouting.

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8.6.1.1 Atmospheric Environment

This activity includes operating heavy equipment to demolish above grade structures, which results in the emission of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effect from these activities is bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not need further consideration.

Airborne Releases of Lead (from Demolition Involving Lead Paint):

During the demolition of the above grade structures there is the possibility of lead (from lead-based paint) being released into the atmosphere, and potentially affecting the environment and the public. The following assumptions have been made for the analysis of this case:

- The total inventory of lead paint in the above-grade structure was assumed to be released as particulate (see Section 5.2).
- Given that much of the paint will remain adhered to the demolition debris, and will not be released as airborne particulate, an airborne release fraction of 0.01 has been applied.
- Of the particulate created, only a portion will be of a respirable size. Therefore, it has been assumed that 10% of the airborne particulate will be respirable (i.e. a factor of 0.1).
- Given that water spray misting will be used as a dust control measure, it is assumed that only a small portion (i.e. 10%) of the released respirable particles would not be captured.
- The rate that the buildings are being demolished, and therefore the rate that the lead is being released, is estimated based on the number of days spent demolishing the above grade buildings:
 - 30 total days are spent actively demolishing the above grade structures (excluding the stack);
 - It was assumed that 8 hours per day were spent demolishing buildings. This allowed for the total inventory to be divided by the total demolition time (s) producing a resulting release rate in g/s.

The release occurs at approximately 1 m (corresponding to the height of release for the CALPUFF calculations (Appendix C)). The human and public receptors are the same as those discussed in Section 8.5.2.4.

Additionally, the ADFs used are the same as those discussed in Section 8.5.2.4.

The resulting air concentrations at receptor locations are presented in Table 8-16. These concentrations are assessed in Section 8.6.1.5 and 8.6.1.6 for worker and public receptors, respectively.

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Table 8-16 Demolition – Airborne Lead Concentrations at Receptor Locations

Receptor Location	Estimated Lead Concentration (Air) [in g/m ³]
<i>Worker (near field)</i>	1.94E-09
<i>Worker (far field)</i>	1.94E-09
<i>Res. 1</i>	1.86E-10
<i>Res. 2</i>	2.05E-10
<i>Res. 3</i>	1.90E-10
<i>Rec. (Res. 4)</i>	2.44E-10
<i>Guardhouse</i>	1.71E-08
<i>Rapides Des Joachims</i>	1.43E-10
<i>Pt. Stewart Residential</i>	1.12E-10
<i>Cottage</i>	1.63E-10
<i>Rolphon Residential</i>	6.20E-11
<i>Mackey Beef Farm</i>	3.53E-12
<i>Bass Lake Beef Farm</i>	3.80E-12

Air Deposition to Soil

Lead in airborne releases can deposit onto soil, which may result in soil contamination. Soil lead concentrations during demolition operations were assessed based on assumptions below:

- Soil concentrations at worker and public receptor locations were estimated by applying the air-to-soil transferring model outlined in Section 6.3.
- The duration of air-to-soil deposition is assumed to be 30 days, which is equal to the estimated duration of demolition operations.

The resulting soil concentrations are listed in Table 8-17 for worker receptor locations, and in Table 8-18 for public receptor locations.

Table 8-17 Air-to-Soil Deposition – Soil Concentrations at Worker Receptor Locations

Receptor Location	Estimated Lead Concentration (Soil) [in µg/g]
<i>Worker (near field)</i>	1.19E-03
<i>Worker (far field)</i>	1.19E-03

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Table 8-18 Air-to-Soil Deposition – Soil Concentrations at Public Receptor Locations

Receptor Location	Estimated Lead Concentration (Soil) [in µg/g]
<i>Res. 1</i>	1.14E-04
<i>Res. 2</i>	1.26E-04
<i>Res. 3</i>	1.16E-04
<i>Rec. (Res. 4)</i>	1.50E-04
<i>Guardhouse</i>	1.04E-02
<i>Rapides Des Joachims</i>	8.78E-05
<i>Pt. Stewart Residential</i>	6.88E-05
<i>Cottage</i>	9.97E-05
<i>Rolphon Residential</i>	3.80E-05
<i>Mackey Beef Farm</i>	2.16E-06
<i>Bass Lake Beef Farm</i>	2.33E-06

These estimated lead soil concentrations are assessed in Section 8.6.1.5 and 8.6.1.6 for potential effects on Public Health and Worker Health, respectively.

8.6.1.2 Surface Water Environment

The activities associated with this task are not expected to have an effect on the surface water environment, flow characteristics or water quality. Standard forms of dust mitigation (e.g. water spray misting) will be utilized to trap dust and other potential contaminants produced from demolition of the above-grade structures, thus preventing dust from directly entering and affecting surface water quality.

However, during demolition activities associated with the NPD above grade structure there is a possibility that tritium may be present in the water run-off arising from the water spray used for dust suppression. To prevent a release to the external environment an absorbent layer of material, e.g. sand or other suitable material, will be placed around the perimeter of the demolition area to collect any water that may be released. As required the absorbent material will be collected and disposed of inside the below grade structure. On completion of the demolition activities the area around the remaining above ground structure will be monitored for contamination. Any contamination that is found will be removed and placed within the below grade structure.

8.6.1.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on the groundwater quality or groundwater flows, however there is the potential for contaminated particulate matter to affect the soil quality. Standard forms of dust mitigation (e.g. misting) will be utilized to trap dust and other potential contaminants produced from the demolition of the structures, thus limiting the amount of contaminated dust that is allowed to settle onto the soil. This mitigation combined with the fact that the above grade buildings have a lower risk of contamination (see zoning plan; McVeigh 2016a) will ensure that effects on soil quality are negligible.

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8.6.1.4 Radiation and Radioactivity Environment

During the demolition of the above grade structures there is the possibility of surface contamination being released into the atmosphere, and potentially affecting the environment and the public. The following assumptions have been made for the analysis of this case:

- The release occurs at approximately 1 m (corresponding to the height of release for the CALPUFF calculations (Appendix C).
- The source term being released has been conservatively assumed to be equal to the above-grade structure inventory, as provided in Section 5.1.1.5.
- The rate that the buildings are being demolished, and therefore the rate that the contaminants are being released, is estimated based on the number of days spent demolishing the above grade buildings:
 - 30 total days are spent actively demolishing the above grade structures (excluding the stack);
 - It was assumed that 8 hours per day were spent demolishing buildings. This allowed for the total inventory (in Bq) to be divided by the total demolition time (s) producing a resulting release rate in Bq/s.

The human and public receptors are the same as those discussed in Section 8.5.2.4.

Additionally, the ADFs used are the same as those discussed in Section 8.5.2.4.

Table 8-19 below shows the air concentrations of the isotopes at each of the receptor location.

Table 8-19 Release Rates and Exposure Concentrations at All Receptor Locations Using CALPUFF ADFs

	Radionuclides	
	H-3	C-14
Source Term Release Rate (QR) [Bq/s]	9.55E+04	3.15E+02
Locations	Exposure Concentrations at Receptor Locations (Air) [in Bq/m³]	
<i>Worker (Near-Field)</i>	4.77E+00	1.57E-02
<i>Worker Far-Field</i>	4.77E+00	1.57E-02
<i>Res. 1</i>	4.58E-01	1.51E-03
<i>Res. 2</i>	5.06E-01	1.67E-03
<i>Res. 3</i>	4.68E-01	1.54E-03
<i>Rec. (Res. 4)</i>	6.02E-01	1.98E-03
<i>Guardhouse</i>	4.20E+01	1.39E-01
<i>Rapides Des Joachims</i>	3.53E-01	1.16E-03
<i>Pt. Stewart Residential</i>	2.77E-01	9.13E-04
<i>Cottage</i>	4.01E-01	1.32E-03
<i>Rolphon Residential</i>	1.53E-01	5.04E-04
<i>Mackey Beef Farm</i>	8.69E-03	2.86E-05
<i>Bass Lake Beef Farm</i>	9.36E-03	3.09E-05

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These estimated radionuclide levels are assessed in Sections 8.6.1.5, 8.6.1.6, and 8.6.1.7 with respect to potential effect on Public Health, Worker Health and Non-human Biota, respectively.

8.6.1.5 Effects on Public Health

Airborne Releases - Radiological

The release rates that were calculated for this scenario and the DRL release rates are shown in Table 8-20 below. It is clear that the release rates of these isotopes are much less than corresponding DRL values. A dose rate has also been calculated, in the same manner as discussed in Section 8.5.2.5, and it can be seen that the resulting dose rate estimates are well below 1 mSv/yr.

Table 8-20 Calculated and DRL Release Rates and Resulting Dose Rate

Radionuclide	Calculated Release Rate (Bq/s)	DRL Release Rate ^a (Bq/s)	Dose Rate ^b (mSv/yr)
H-3	9.55E+04	1.45E+09	6.56E-05
C-14	3.15E+02	1.03E+08	3.04E-06
			6.87E-05

Notes:

The dose rate has been calculated by scaling the dose rate from the DRL.

^a Ref: Chouhan & Scheier, 2011; Table 10-1. Converted to Bq/s using 60 seconds/minute, 60 minutes/hour, 24 hours/day, 30 day/month.

^b Dose rate to critical receptor in Rapides Des Joachims as per DRL (Chouhan and Scheier 2011).

In using this ratio method, it is important to note that the DRL values are based on continuous releases of their respective radionuclides, whereas demolition releases are not (ceasing once the above grade structure has been taken down). This difference is not accounted for when using this ratio method, and therefore, mathematically, the ratio method produces values as if the release rate (Bq/s) is continuous. This is a conservative assumption.

In addition to the base case presented above, a sensitivity case where the demolition is completed within 5 days has also been completed. The decrease in total demolition time does not affect the total amount of radiation being released, but results in a faster release of the same amount, thereby resulting in higher dose rates.

Table 8-21 Calculated and DRL Release Rates and Resulting Dose Rate for 5-day Demolition

Radionuclide	Calculated Release Rate (Bq/s)	DRL Release Rate (Bq/s)	Dose Rate ¹ (mSv/yr)
H-3	5.73E+05	1.45E+09	3.94E-04
C-14	1.89E+03	1.03E+08	1.30E-06
			3.95E-04

Notes:

The dose rate has been calculated by scaling the dose rate from the DRL.

^a Ref: Chouhan & Scheier, 2011; Table 10-1. Converted to Bq/s using 60 seconds/minute, 60 minutes/hour, 24 hours/day, 30 day/month.

^b Dose rate to critical receptor in Rapides Des Joachims as per DRL (Chouhan and Scheier 2011).

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As shown in Table 8-21, the releases associated with a 5-day demolition time are less than the existing site DRLs, and therefore no adverse effects are expected to public receptors.

Airborne Releases - Non-Radiological

In addition to radiological dose, the potential non-radiological effects of airborne lead released during demolition are also assessed. This is accomplished by comparing calculated air concentrations at receptor locations (derived in Section 8.6.1.1) against corresponding benchmark values (presented in Section 4.1.6.1).

The result of the comparison is a screening index, which is a ratio of an estimated air concentration to its corresponding benchmark value. Screening indices for lead air concentrations are shown in Table 8-22.

Table 8-22 Demolition – Inhalation Screening Index (Public Receptors)

Receptor Location	Inhalation Screening Index [unitless; comparison of estimated concentration to benchmark value]
<i>Res. 1</i>	1.86E-03
<i>Res. 2</i>	2.05E-03
<i>Res. 3</i>	1.90E-03
<i>Rec. (Res. 4)</i>	2.44E-03
<i>Guardhouse</i>	1.71E-01
<i>Rapides Des Joachims</i>	1.43E-03
<i>Pt. Stewart Residential</i>	1.12E-03
<i>Cottage</i>	1.63E-03
<i>Rolphon Residential</i>	6.20E-04
<i>Mackey Beef Farm</i>	3.53E-05
<i>Bass Lake Beef Farm</i>	3.80E-05

As can be seen in Table 8-22, all of the screening indices are less than 1, and therefore, no undue effects on public health are anticipated.

Air Deposition to Soil

Atmospheric releases of lead, and their deposition to soil, are also assessed for potential effects on public health. This is accomplished by comparing the estimated soil concentrations at receptor locations (derived in Section 8.6.1.1, using the method outlined in Section 6.3) against corresponding soil benchmark values (outlined in Section 4.1.6).

The result of the comparison is a screening index, which is a ratio of an estimated soil concentration to its corresponding benchmark value. Screening indices for lead soil concentrations are shown in Table 8-23.

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Table 8-23 Demolition – Soil Screening Index for Lead (Public)

Receptor Location	Soil Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>
<i>Res. 1</i>	9.49E-07
<i>Res. 2</i>	1.05E-06
<i>Res. 3</i>	9.69E-07
<i>Rec. (Res. 4)</i>	1.25E-06
<i>Guardhouse</i>	8.70E-05
<i>Rapides Des Joachims</i>	7.32E-07
<i>Pt. Stewart Residential</i>	5.74E-07
<i>Cottage</i>	8.31E-07
<i>Rolphon Residential</i>	3.16E-07
<i>Mackey Beef Farm</i>	1.80E-08
<i>Bass Lake Beef Farm</i>	1.94E-08

As can be seen in Table 8-23, all of the screening indices are well below 1, and therefore, no undue effects on public health are expected.

8.6.1.6 Effects on Worker Health

Airborne Releases - Radiological

Table 8-24 shows the estimated concentrations in the worker near-field and far-field locations, along with corresponding dose rates, based on the methods for calculating inhalation and air immersion doses presented in Section 9.4.

In addition to this base case, a sensitivity case where the demolition is completed within 5 days has also been done as discussed in Section 8.6.1.5. However, because the worker dose is not based upon the DRL, and is instead based on inhalation and immersion dose, the total dose received does not change. This is because the release rate is calculated by the total inventory divided by the time over which it is released, and the inhalation and immersion doses are multiplied by the time spent in the contaminated area. Given that these are the same time, they cancel out, and the total dose received does not change.

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Table 8-24 Exposure Concentrations, Inhalation, Air Immersion and Total Dose Estimates for Demolition Workers

Radionuclides	Exposure Concentrations at Receptor Locations (Air) [in Bq/m ³]		Inhalation Dose [in mSv]		Air Immersion Dose [in mSv]		Total Dose (Inhalation + Immersion) [in mSv]	
	Worker (Near-Field)	Worker Far-Field	Worker (Near-Field)	Worker (Far-Field)	Worker (Near-Field)	Worker (Far-Field)	Worker (Near-Field)	Worker (Far-Field)
H-3	4.77E+00	4.77E+00	5.64E-05	5.64E-05	0.00E+00	0.00E+00	5.64E-05	5.64E-05
C-14	1.57E-02	1.57E-02	2.63E-06	2.63E-06	3.54E-11	3.54E-11	2.63E-06	2.63E-06
TOTAL DOSE							5.90E-05	5.90E-05

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As shown in Table 8-24, all dose estimates are below the worker dose criteria, and therefore there are no anticipated effects.

Airborne Releases – Non-Radiological

As outlined in Section 8.6.1.1, airborne concentrations of lead for near and far-field worker receptors, as a result of contaminated air being displaced during grouting, have been calculated. The two-zone box model (for details see Section 6.1) was used to estimate air concentrations using the assumptions outlined in Section 8.6.1.1.

Similar to the public, worker exposure concentrations are compared against corresponding benchmark values (8-hr limits in this case) and a screening index is developed. The benchmark values that are compared against are explained in Section 4.1.6, and Table 8-25 shows the results.

Table 8-25 Demolition – Inhalation Screening Index (Workers)

Receptor Location	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>
Worker (Near Field)	3.88E-05
Worker (Far Field)	3.88E-05

As can be seen in Table 8-25, all of the screening indices are much less than 1, and therefore, no undue effects on worker health are expected.

Air-to-Soil Deposition

In addition to radiological dose, the potential effects of lead released during demolition was also assessed. This is accomplished by comparing the estimated soil concentrations at receptor locations (derived in Section 8.6.1.1, using the method outlined in Section 6.3) against corresponding soil benchmark values (outlined in Section 4.1.6).

The result of the comparison is a screening index, which is a ratio of an estimated soil concentration to its corresponding benchmark value. Screening indices for lead soil concentrations are shown in Table 8-26.

Table 8-26 Demolition – Soil Screening Index for Lead (Worker)

Receptor Location	Soil Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>
Worker (near field)	9.89E-06
Worker (far field)	9.89E-06

As can be seen in Table 8-26, all of the screening indices are much less than 1, and therefore, no undue effects on worker health are expected.

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8.6.1.7 Effects on Non-Human Biota

The assessment of effects on non-human biota for this activity is provided in the *Ecological Risk Assessment* TSD (Garisto *et al.*, 2020a). The *Ecological Risk Assessment* TSD (Garisto *et al.*, 2020a) shows that there is no adverse effect on non-human biota from exposure to radioactive or chemical contaminants (i.e. lead) from demolition of above-grade structures.

8.6.2 Sizing of Material

This section analyses the effects of material re-sizing (activity 3.2, see Table 7-3). This involves:

- cutting beams;
- crushing masonry and concrete; and
- otherwise reducing the size of waste material to allow for emplacement.

8.6.2.1 Atmospheric Environment

This activity includes operating a concrete saw, heavy equipment, and crushing material to resize it to be used as fill within the below ground structures, which results in emissions of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effect from these activities is bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not need further consideration.

The effects of torch-cutting and plasma-cutting in particular are evaluated as part of the *Greenhouse Gas Emissions TSD* (Garisto, *et al.*, 2020a). Garisto, *et al.* (2020b) assessed cutting emissions based on acetylene torch cutting since this produces conservatively high CO₂ emissions in comparison to plasma-cutting. Garisto, *et al.* (2020b) determined that the direct and life-cycle greenhouse gas emissions are negligible in comparison to other dominant emissions in Ontario, and as such, no further consideration is required. For more detailed information, the reader is referred to the original Garisto, *et al.* (2020b) study.

8.6.2.2 Surface Water Environment

The activities associated with this task are not expected to have an effect on the surface water environment, flow characteristics or water quality. Standard forms of dust mitigation (e.g. misting) will be utilized to trap dust and other potential contaminants produced from the cutting and crushing of the demolished materials, thus preventing them from affecting surface water quality.

For laydown areas, standard runoff controls will be in place, as are typically used for construction projects. If future studies (e.g. those performed in support of work control documents) identified the need for additional or more specific control measures, CNL will investigate their implementation at that time.

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8.6.2.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on the groundwater quality or groundwater flows, however there is the potential for contaminated particulate to affect soil quality. Releases from sizing tasks would be a small fraction of those from building demolition (which are assessed in Section 8.6.1). Standard forms of dust mitigation (e.g. misting) will be utilized to trap dust and other potential contaminants produced from the crushing of masonry and concrete, thus limiting the amount of contaminated dust that is allowed to settle onto the soil. Cutting will be done in a controlled manner to limit the amount of particulate that is released to the surrounding soil. These mitigation measures combined with the fact that the above grade buildings are less contaminated, will ensure that effects on soil quality are negligible.

8.6.2.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to have an effect on the radiation and radioactivity environment. The components that are being sized are primarily portions of the aboveground facility superstructure, and therefore have a lower risk of contamination (based on the zoning of these areas; McVeigh 2016a) in contrast to the belowground reactor vault, which will remain in place. As such, the effect on the radiation and radioactivity environment is negligible.

8.6.2.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they are not affecting any environmental components to which public receptors are exposed. In particular, the atmospheric environment only undergoes negligible effects.

8.6.2.6 Effects on Worker Health

The activities associated with this task are routine construction activities. As mentioned in Section 8.6.2.4, the effect on the radiation environment is expected to be negligible and as such, the workers are expected to receive negligible exposure.

Conventional worker safety is addressed in Section 8.3.3. The environmental impact of this task is negligible and is not expected to have an impact on worker health.

8.6.2.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because they are not affecting any environmental components to which non-human biota are exposed (namely, surface water). In particular, the atmospheric environment and the radiation and radioactivity environment undergo negligible effects.

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8.6.3 Emplace Demolition Material and Grout

This section analyses the effects of emplacing material and grouting (i.e. activities 3.4, 3.5, 3.6, 3.7, 3.8, 3.9, 3.12, 3.15, and 3.16, see Table 7-3). This includes:

- placing the sized material into the void spaces below-grade;
- pouring grout; and;
- repeating the above tasks until the area is filled.

Note that these generic groupings encompass many repeating activities such as emplacing materials to a given level and grouting to that level.

8.6.3.1 Atmospheric Environment

This activity includes transporting the grout to the facility, pouring it, transporting and placing sized fill materials, which results in emission of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effect from these activities is bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not need further consideration.

8.6.3.2 Surface Water Environment

The activities associated with this task are not expected to have an effect on the surface water environment, flow characteristics or water quality, as there are no anticipated interactions between this activity and the surface water environment.

8.6.3.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on the soil quality, groundwater quality or groundwater flows, as there are no anticipated interactions between this activity and the geological and hydrogeological environment.

8.6.3.4 Radiation and Radioactivity Environment

The effects on the radiation and radioactivity environment, from air displaced from the facility due from the pouring of grout is bounded by the assessment presented in Section 8.5.2.4. Please refer to this section for expected effects.

8.6.3.5 Effects on Public Health

The effects on public health is bounded by the displacement of contaminated air by grouting operations as assessed in Section 8.5.2.5 There are no significant effects predicted.

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8.6.3.6 Effects on Worker Health

The effects on worker health due to grouting is presented in Section 8.5.2.6, where emplacing material and the pouring of grout activities is bounded by that scenario. Please refer to Section 8.5.2.6 for details regarding worker health effects.

8.6.3.7 Effects on Non-Human Biota

The effects on non-human biota from this activity is bounded by the scenario presented in Section 8.5.2.4. Therefore, please see Section 8.5.2.7 for details.

8.7 Install Concrete Cap and Engineered Barriers

8.7.1 Concrete Cap

This section analyses the effects of activities associated with the concrete cap (i.e. activity 4.1, see Table 7-3, and sub-activities 4.1.1, 4.1.2, and 4.1.3), which include:

- Construct forms for concrete cap.
- Install rebar and anchor to top of concrete pour.
- Pour high strength concrete, level and slope.

8.7.1.1 Atmospheric Environment

This activity includes operating the concrete batch plant and transporting the concrete to the mound, which results in emission of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effect from these activities is bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not need further consideration.

8.7.1.2 Surface Water Environment

These effects to the surface water flow and site drainage will be localized to the area surrounding the concrete cap. There will be no effect on the Ottawa River. Additionally, there are no expected effects on the surface water quality.

8.7.1.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to affect groundwater flow; presently the facility roof diverts precipitation, and since the concrete cap and engineered barrier will be installed on a similar footprint, it will divert precipitation in a similar manner. Additionally, there are no expected effects on the groundwater or soil quality.

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8.7.1.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to involve any radioactive material, and as such are not expected to have any impact on the radiation and radioactivity environment.

8.7.1.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they are not affecting any environmental components to which public receptors are exposed. In particular, the atmospheric environmental component only undergoes negligible effects.

8.7.1.6 Effects on Worker Health

The activities associated with this task are routine construction activities. No exposure effects on worker health are expected, as long as Standard Construction Practices are followed (Section 8.3.2).

Conventional worker safety is addressed in Section 8.3.3. The environmental impact of this task is negligible and therefore, is not expected to have an impact on worker health.

8.7.1.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because the effects on the environmental components to which non-human biota are exposed are not measurable or are determined to be negligible.

8.7.2 Engineered Barriers

This section analyses the effects of activities associated with the engineered barriers (i.e. activity 4.2 - see Table 7-3 - and sub-activities 4.2.1, 4.2.2, 4.2.3, 4.2.4, 4.2.5). This includes heavy equipment used to:

- Ship in mound materials;
- Layer and shape mound;
- Install geotextile layer;
- Grade property for water shedding; and,
- Install remaining earth layers and seed.

8.7.2.1 Atmospheric Environment

This activity includes operating heavy equipment which would result in the emission of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effect from these activities is bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not need further consideration.

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8.7.2.2 Surface Water Environment

These effects to the surface water flow and site drainage will be localized to the area surrounding the concrete cap and barriers. There will be no effect on the Ottawa River. Additionally, there are no expected effects on the surface water quality.

8.7.2.3 Geological and Hydrogeological Environment

The activities associated with this task may affect the groundwater flow; however, these effects will be localized to the area surrounding the concrete cap and barriers. Additionally, there are no expected effects on the groundwater or soil quality.

8.7.2.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to involve any radioactive material, and as such are not expected to have any impact on the radiation and radioactivity environment.

Radiological surveys of the licensed area will be conducted after demolition, but before capping and closure, to demonstrate that the area is zoned as a low radiological risk.

8.7.2.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they are not affecting any environmental components to which public receptors are exposed. In particular, the atmospheric environment only undergoes negligible effects.

8.7.2.6 Effects on Worker Health

The activities associated with this task are routine construction activities. No exposure effects on worker health are expected, as long as Standard Construction Practices are followed (Section 8.3.2).

Conventional worker safety is addressed in Section 8.3.3. The environmental impact of this task is negligible and is expected to not have an impact on worker health.

8.7.2.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because the effects on the environmental components to which non-human biota are exposed are not measurable or are determined to be negligible.

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8.8 Final Site Restoration

8.8.1 Site Restoration

This section analyses the effects of the final site restoration (i.e. activity 5.1 - see Table 7-3 - and sub-activities 5.1.1 to 5.1.6). This includes:

- Install fencing around controlled area of mound.
- Install required monitoring wells (new or reconditioned current wells).
- Remediate any areas impacted from decommissioning activities or by wash pits/settling ponds.
- Complete all closure surveys.
- Asphalt, parking areas and non-essential roadways rubblized and area enhanced for natural environmental restoration.

8.8.1.1 Atmospheric Environment

This activity includes the use of machinery to drill fence post holes, drill monitoring wells, demolish and rubblize non-essential pavement areas, and transport remaining rubble offsite, all of which would result in emissions of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effect from these activities is bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not need further consideration.

8.8.1.2 Surface Water Environment

The activities associated with this task are not expected to have a negative effect on the surface water environment, flow characteristics or water quality, as there has been no interactions identified between these activities and the surface water environment.

8.8.1.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have a negative effect on soil quality, groundwater quality or groundwater flows, as there has been no interactions identified between these activities and the geological and hydrogeological environment.

8.8.1.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to involve any radioactive material, and as such are not expected to have any impact on the radiation and radioactivity environment.

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8.8.1.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they are not affecting any environmental components to which public receptors are exposed. In particular, the atmospheric environment only undergoes negligible effects.

8.8.1.6 Effects on Worker Health

The activities associated with this task are routine construction activities. No exposure effects on worker health are expected, as long as Standard Construction Practices are followed (Section 8.3.2).

Conventional worker safety is addressed in Section 8.3.3. The environmental impact of this task is negligible and is expected to not have an impact on worker health.

8.8.1.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have any effect on non-human biota because the effects on the atmospheric environment are not measurable and therefore will have no effect.

8.8.2 Demobilize Site

This section analyses the effects of demobilizing the site (i.e. activities 1.12 and 5.3 including sub-activities 5.3.1 to 5.3.4, see Table 7-3). This includes:

- Remove all temporary trailers and washroom facilities.
- Decontamination of heavy equipment.
- Remove power upgrades, return transformers to utility. Remove poles and lines back to Hwy 17.
- Installed controlled access gate at highway (if required).

8.8.2.1 Atmospheric Environment

This activity includes operating machinery (non-road vehicles) to install the access gate, and remove power lines and poles back to highway 17, which results in emission of NO_x, SO₂, TSP, PM₁₀, and PM_{2.5}. The atmospheric effect from these activities is bounded by the emission estimate in Appendix F. Appendix F shows the effect of these emissions on the atmospheric environment is considered not to be measurable and does not need further consideration.

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8.8.2.2 Surface Water Environment

The activities associated with this task will result in localized changes to the surface water flow and site drainage, specifically where pavement has been removed. These effects will be localized and will not cause adverse effects to the Ottawa River.

8.8.2.3 Geological and Hydrogeological Environment

The activities associated with this task are not expected to have an effect on the soil quality, groundwater quality or groundwater flows, as there have been no interactions identified between these activities and the geological and hydrogeological environment.

8.8.2.4 Radiation and Radioactivity Environment

The activities associated with this task are not expected to involve any radioactive material, and as such are not expected to have any impact on the radiation and radioactivity environment.

8.8.2.5 Effects on Public Health

The activities associated with this task are not expected to have an effect on public health because they are not affecting any environmental components to which public receptors are exposed. In particular, the atmospheric environment only undergoes negligible effects.

8.8.2.6 Effects on Worker Health

The activities associated with this task are routine construction activities. No exposure effects on worker's health are expected, as long as Standard Construction Practices are followed (Section 8.3.2).

Conventional worker safety is addressed in Section 8.3.3. The environmental impact of this task is negligible and is not expected to have an impact on worker health.

8.8.2.7 Effects on Non-Human Biota

The activities associated with this task are not expected to have an effect on non-human biota because the effects on the atmospheric environment are not measurable and therefore will have no negative effects.

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8.9 Normal Assessment Conclusions

The normal operations assessment reviewed of the planned decommissioning activities for potential interactions with key environmental components and receptors. Those activities (or groups of activities) that were identified as having potential interactions with one or more environmental components underwent more detailed assessment.

As discussed in Section 8.3.3, the fundamental Safety Principles outlined in the Safety Analysis Report (Athauda-Arachchige, 2015) are followed in order to ensure that safety is incorporated into all activities, from planning through to execution. However, in contrast to typical construction projects (and typical safeguards) decommissioning project activities are performed with an *additional* degree of training, procedures, and safeguards in place since radiation protection principles are involved. Staff and contractors will receive orientation to ensure they are aware of decommissioning activities, hazards, and emergency procedures. Additionally, hazards to personnel will be identified through work control documents and eliminated or controlled using engineered controls, administrative controls, and PPE. This includes provisions for common construction hazards such as working at heights, working with electricity, confined spaces, etc. Therefore, given the fundamental safety principles that govern project planning and execution, and the many safeguards involved, conventional accidents are considered to be managed to as low as reasonably practicable.

With respect to safety involving exposure to radiation or hazardous chemicals (part of the Worker Health and Public Health environmental components), a quantitative assessment was performed for activities that had potential interactions with environmental components. These include bounding activities involving drilling/cutting and sizing; pouring of grout (and resulting displacement of air, airborne tritium, and generated hydrogen gas); and building demolition. For these activities, dose estimates were below corresponding worker and public criteria (for hydrogen, the estimated concentration is below the flammability limit), and as such, no adverse effects are expected.

With respect to potential decommissioning effects on the surface water environment component and the geological/hydrogeological environment component, standard practices typical of construction projects – as discussed in Section 8.3.2 - will be implemented. Once implemented, these control measures will reduce surface water runoff/releases and dust releases, and as such, no adverse effects are expected.

Potential effects on the atmospheric environment component were also assessed for each group of activities, with the detailed analysis presented in Appendix E. Based on the results, no adverse effects are expected on environmental components or on Valued Components (VCs).

Therefore, overall, the activities assessed as part of normal decommissioning operations are not expected to have adverse effects on the identified environmental components.

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9.0 ACCIDENTS ASSESSMENT

9.1 Bounding Scenario Descriptions

This section provides descriptions of the identified bounding scenarios. Later, in Section 9.2.1, several factors are derived for each bounding scenario, based on these descriptions of the events of the bounding scenarios.

9.1.1 Bounding Scenario 1: Forest Fire and Release of Radioactivity

In this bounding scenario, it is postulated that a large forest fire occurs and engulfs the facility. The intense heat radiation ignites a fire at the facility. It is assumed that the fire is of sufficient size and strength to affect the entire above grade facility, such that all radioactive contaminants within the above grade structure walls become airborne.

9.1.2 Bounding Scenario 2: Forest Fire and Release of Chemical Contaminants

This bounding scenario follows the same forest fire event as described above for bounding scenario 1 (Section 9.1.1), but investigates the release of hazardous non-radiological chemicals associated with this event.

9.1.3 Bounding Scenario 3: Tornado and Release of Radioactivity

In this bounding scenario, it is postulated that a tornado (category EF-2; consistent with Athauda-Arachchige (2015)) strikes the facility. Aboveground structures are affected, but not material or structural components located in underground portions of facility. It is assumed that the reactor vault is not lifted or breached, due to its underground location, size, and robust concrete structure.

A category EF-2 tornado is used as the Design Basis Tornado (DBT) for CNL's CRL site, and due to the close proximity of the NPD Site to the CRL site, it is assumed that the CRL DBT is also applicable to NPD. The DBT for the CRL site has been selected as one having a return frequency of 1 in 100,000 years (CNL 2018b, Weaver 2018). Canadian data relating tornado return frequency with intensity is not available, therefore it is conservatively assumed that, Region 2 in NUREG-4461 (PNNL 2007) includes the CRL site for the 10-5-a-1 tornado strike event. The maximum tornado wind speed for 10-5-a-1 tornado strike event in Region 2 is given in PNNL (2007), Table 8.1, as 140 miles per hour (225 km per hour) which corresponds to the upper limit of an EF2 tornado (TTU 2006).

9.1.4 Bounding Scenario 4: Tornado and Release of Chemical Contaminants

This bounding scenario follows the same tornado event as described above for bounding scenario 3 (Section 9.1.3), but investigates the release of hazardous non-radiological chemicals associated with this event.

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9.1.5 Bounding Scenario 5: Major Flood and Release of Radioactivity

In this bounding scenario, it is postulated that a large flood occurs – resulting from a precipitation event - causing a large volume of water to enter the facility. It is assumed that the floodwater mobilizes radionuclides which are then released outside the facility.

It is important to note that the facility SAR assesses such a scenario, and its assessment is used as the basis in this DecomSA.

9.1.6 Bounding Scenario 6: Accidental Exposure to Radioactivity

In this bounding scenario, it is postulated that decommissioning personnel working underground receive a dose that is higher than anticipated. This could hypothetically occur as a result of two primary drivers:

- a) A worker spends additional time performing their task (e.g. drilling holes for slip pipe access or ventilation) within a radioactive environment, thereby increasing their exposure time and their resulting dose;
- b) A worker performs their task without additional time, but in an environment where levels of radioactivity greater than those anticipated and planned-for under normal operations.

In either event, it is further assumed that the exposure occurs without protective equipment.

Unexpectedly high source term (i.e. Item (b) above) was assessed in the 2017 DecomSA submission; however, since that time, CNL has conducted several additional studies – including several measurement campaigns – and has used these to re-derive the inventory. The newly derived inventory (described in Section 5.1) is intended to be bounding, and, has much a higher degree of confidence. Now, this particular scenario driver is assumed to be too unlikely to warrant further consideration, since it would involve high levels of radiation remaining undetected despite:

- completion of several on-site measurement campaigns;
- scoping surveys performed during the preparation of future work control documents; and,
- radiological control during drilling, such as the use of dosimeters to monitor exposure.

The remaining driver (i.e. Item (a) above - a worker spending additional time to perform a task), though unlikely (due to work planning and controls), is plausible, and therefore warrants consideration.

Thus, this bounding scenario assesses a worker spending additional time drilling in a radioactive environment. The analysis is based on a worker spending 32 hours on a drilling task in the FM room. This time is double the maximum amount of time expected for normal drilling, which is very conservative, and would be bounding.

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9.1.7 Bounding Scenario 7: Accidental Exposure to Chemicals

In this bounding scenario, it is postulated that decommissioning personnel working underground receive unanticipated exposure to hazardous chemicals. This could occur for example, during demolition or cutting activities, or through unplanned interaction with chemicals. It is further assumed that the exposure occurs without protective equipment.

9.1.8 Bounding Scenario 8: Underground (Indoor) Fire and Release of Radioactivity

In this bounding scenario, it is postulated that an underground (indoor) fire occurs at the facility. Such a fire could occur due to an electrical malfunction, human error during hot work, accidental ignition of a small fuel spill from hand-held equipment, or other similar types of initiating event variants. However, since there is little to no combustible material remaining in the facility, it is assumed that a spill of combustible material (e.g. small fuel spill) would be necessary for this scenario to be plausible. It is assumed that a portion of the total inventory of combustible materials would be involved in the fire. Volatile radionuclides, radioactivity contamination embedded in combustible materials, and loose surface contamination, become partially airborne.

9.1.9 Bounding Scenario 9: Underground (Indoor) Fire and Release of Chemicals

This bounding scenario follows the same underground (indoor) fire event as described above for bounding scenario 8 (Section 9.1.8), but investigates the release of hazardous non-radiological chemicals associated with this event.

9.1.10 Bounding Scenario 10: Stack Collapse and Release of Radioactivity

In this bounding scenario, it is postulated that the ventilation stack accidentally fails and falls due to demolition activities (e.g. by heavy equipment accident while demolishing the main structure) or a natural event. In addition to potential personal injuries and fatality, stack collapse would result in loose surface contamination within the stack becoming partially airborne, along with a portion of the fixed contamination (tritium) in the stack's construction material also becoming partially airborne.

Included in this accident scenario is the potential for a worker in the vicinity to be exposed to radioactive water contained within the base of the stack. This accident scenario also bounds exposures and doses that could result from liquid collection tasks, because:

- *Potential worker exposure is bounded by stack water:*
Worker exposure considered in this accident scenario involves a worker being splashed with stack water, whereas wash water is unlikely to be disturbed inside the facility (other than by controlled collection).
- *The radionuclide content of wash water is likely to be bounded by stack water:*
Wash water from grout line flushing would pool on top of the most recently poured grout lift. Only a small quantity of the water could contact any potentially contaminated

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surfaces (facility walls) at the edge of the wash water pool. When collection is needed, it would likely be performed on the next operational day, so the amount of time the liquid remains in place is likely up to a few days. Therefore, the water at the base of the stack which has been in contact with the contaminated walls for a long period of time, has a radionuclide content (mostly tritium) than the wash water in contact with fresh grout.

9.2 Source Terms

The assessment of the consequences of the identified scenarios requires the definition of the source terms for these scenarios. In this assessment, we generally follow the widely accepted methodology proposed by U.S. Department of Energy (DOE 1994) to estimate the source terms.

Definition of the source term involves a number of considerations, among them the quantity of material released, the physical and chemical form(s) of the released materials, the time dependence of the release and other factors that may affect the initial characteristics of the released material (e.g., meteorological conditions at the time of the release and building wake effects).

The airborne source term is typically estimated by the following five-component linear equation:

$$\text{Source Term} = \text{MAR} \times \text{DR} \times \text{ARF} \times \text{RF} \times \text{LPF} \quad (\text{Equation 1})$$

where:

MAR = Material-at-Risk is the amount of chemical or radiological material available to be affected by the postulated scenario. For facilities, processes, and activities, the MAR is a value representing some maximum quantity of chemical present or reasonably anticipated for the process or structure being analyzed.

DR = Damage Ratio is the fraction of the MAR actually impacted by the initiating event(s) (fire, extreme winds, accident-generated conditions for example). The DR is estimated based upon engineering analysis of the response of material and materials-of-construction for containment to the type and level of stress/force generated by the event. These estimates often include a degree of conservatism due to simplification of phenomena to obtain a useable model.

ARF = Airborne Release Fraction (or Airborne Release Rate for continuous release) is the coefficient used to estimate the amount of material released or suspended in air as an aerosol or gas and thus available for transport due to a physical stress from a specific accident. For discrete events, the ARF is a fraction of the material affected. For mechanisms that continuously act to cause releases, a release rate is required to estimate the potential airborne release from postulated accident conditions.

RF = Respirable Fraction is the fraction of airborne chemical particles that can be transported through air and inhaled into the human respiratory system and is commonly assumed to include particles 10 μm Aerodynamic Equivalent Diameter

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(AED) and less. (Other definitions of "respirable particles" have been presented by various groups at different times, but for present purposes, 10 µm and smaller particles were considered respirable). For gaseous chemicals, the RF is one.

LPF = Leakpath Factor is the fraction of the chemical transported through some confinement deposition or filtration mechanism. There can be many LPFs for some accident conditions (e.g., the fraction leaked from the enclosure to the operating area around the enclosure or room; the fraction leaked from the room to the building-atmosphere interface).

The initial source term and initial respirable source term are products of the first three factors and first four factors, respectively. A depleted source term after subsequent stages of deposition or filtration is a product of the initial source term multiplied by the leakpath factor.

The inventory of radionuclides and chemicals are identified and described in Section 5.0. These inventories are used to calculate the MAR value from the equation above. The MAR term, and the resulting Source Term value, are calculated specific to each bounding scenario based on the characteristics of the hazardous event and the amount of inventory potentially involved. Section 9.2.1 presents the MAR and Source Term derivations for each bounding scenario.

Combustion By-Products

During fire accident scenarios, combustion by-products (dioxins and furans) may be released from PCBs. The MAR quantity of these combustion by-products released as agents in smoke is calculated as the product of the mass of combustible material (from which the byproduct is generated) and an emission factor (EF), as follows:

$$MAR_{BP} = M \times EF$$

Where,

MAR_{BP} = source term of combustion by-product (g);
 M = mass of combustible material (i.e. PCBs MAR) from which the byproduct is generated (g);
 EF = emission factor (g/g, or similar).

This study focuses on the emission of dioxins and furans from PCBs, due to their potential toxicity. An EF of 0.835 µg per kg was obtained from the US EPA's online AP-42 emission factors compilation (US EPA 2016), based on mass burning of municipal refuse (uncontrolled), assumed to be representative of the combustible portion of material identified in the hazard scenarios. This value encompasses emission of total tetra-through-octa-chlorinated dibenzo-p-dioxin/chlorinated dibenzofurans, 2,3,7,8-tetrachlorodibenzo-p-dioxin, and dibenzofurans.

9.2.1 MAR & Source Term Factors for Bounding Scenarios

Table 9-1 to Table 9-9 present the source term parameters selected for each bounding scenario. A summary of all bounding scenarios is shown in Table 9-10.

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Table 9-1 Source Term Factors – Bounding Scenario 1 (Forest Fire; Radiological Release)

Factor (Equation 1)	Value Selected	Discussion
MAR	<i>Above Ground Surface Contamination</i>	<p>It is conservatively assumed that the total radionuclide inventory of the superstructure would be potentially available to a forest fire.</p> <p>The tritium inventory of asbestos stored within the sealand containers has been excluded; given the containers' construction, it is assumed to contain its contents and prevent releases.</p>
DR	1.0	It is conservatively assumed that a large forest fire could affect all (i.e. 100%) of the available MAR.
ARF	<p><u>Surface Contamination:</u></p> <ul style="list-style-type: none"> • Tritium: 1.0 • C-14: 1.0 • Others (non-combustible): 0.006 	<p><u>Surface Contamination:</u></p> <p><i>Tritium & C-14:</i> The ARF and RF for tritium and C-14 (volatile surface contamination) were conservatively assumed to be 1.0.</p>
RF	<p><u>Surface Contamination:</u></p> <ul style="list-style-type: none"> • Tritium: 1.0 • C-14: 1.0 • Others (non-combustible): 0.01 	<p><i>Others (non-combustible):</i> US DOE (1994) bounding (i.e. conservative) ARF and RF values for non-combustible material, resulting in suspension of non-reactive powders under thermal stress in a flow airstream.</p>
LPF	1	Conservatively assumed that there is no reduction in the release.

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Table 9-2 Source Term Factors – Bounding Scenario 2 (Forest Fire; Chemical Release)

Factor (Equation 1)	Value Selected		Discussion
MAR	Asbestos	<i>Transite and A/g structural</i>	The following MAR assumptions are made: <ul style="list-style-type: none"> • Asbestos: asbestos that is assumed to be available for release includes the transite cladding and any asbestos in the walls of the above grade structure. The asbestos inventory within the sealand containers has been excluded; given the containers' construction, it is assumed to contain its contents and prevent releases. • Lead: in the above-grade structure, only lead paint is available for a fire. • Mercury: there is no mercury available to a forest fire because the only remaining mercury is located underground, in the boiler room. • PCBs: There are no PCBs available to a forest fire because the only light ballasts that will be present at the onset of decommissioning will be located below ground.
	Lead	<i>A/g Paint</i>	
	Mercury	<i>None Available</i>	
	PCBs	<i>None Available</i>	
	Dioxins & Furans	<i>Based on PCBs</i>	
DR	1.0		It is conservatively assumed that a large forest fire could affect all (i.e. 100%) of the available MAR.
ARF	<ul style="list-style-type: none"> • <i>Asbestos: 0.006</i> • <i>Lead: 0.001</i> 		<i>Asbestos:</i> Based on US DOE (1994).
RF	<ul style="list-style-type: none"> • <i>Asbestos: 0.01</i> • <i>Lead: 1.0</i> 		<i>Lead:</i> Based on US DOE (1994) bounding ARF and RF values for thermal stress of metals, solid form, complete oxidation.
LPF	0.5		Chosen to represent the fraction of release contained within the remaining structure.

Notes:

A/g – Above-ground

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Table 9-3 Source Term Factors – Bounding Scenario 3 (Tornado; Radiological Release)

Factor (Equation 1)	Value Selected	Discussion
MAR	<i>Above Ground Surface Contamination</i>	It is conservatively assumed that the total radionuclide inventory of the superstructure would be potentially available to a tornado, plus the inventory of tritium within the asbestos waste stored in the sealand containers.
DR	<i>EF Scale 2: 0.01</i>	The DR depends on the strength of a tornado: <i>EF Scale 2 Tornadoes:</i> based on tornado EF-scaling, an EF-2 tornado is assumed to be 1/10 th as powerful as an EF-4 or EF-3 tornado, which is assumed to be 1/10 th as powerful as an EF-5 tornado. This produces a conservative DR of 0.01 for an EF-2, since Athauda-Arachchige (2015) notes that EF-2 and EF-1 tornadoes would not cause significant damage to the facility, though they <i>may</i> damage the ventilation system.
ARF	<ul style="list-style-type: none"> • <i>Tritium in A/G Structure: 0.5</i> • <i>Tritium in stored asbestos: 1.0</i> • <i>C-14 in A/G Structure: 1.0</i> • <i>Others: see discussion</i> 	<p>For tritium in above-grade structure material, the ARF was assumed to be 0.5 based on US DOE (1994) information on low-temperature release of evaporable water from aggregates (concrete or cement). The RF was assumed to be 1.0 (for all vapour or volatile compounds).</p> <p>For tritium in asbestos stored in the sea containers, an ARF and RF of 1 are used.</p> <p>For C-14, the ARF was conservatively assumed to be 1.0. The RF was assumed to be 1.0 (for all vapour or volatile compounds).</p> <p>For other radionuclides, the ARF and RF are calculated in a combined manner using the following equation from US DOE (1994) for fragmentation/fracture of solid aggregate (concrete, cement) from free-fall and impact (i.e. being lifted and thrown by the tornado):</p>
RF	<ul style="list-style-type: none"> • <i>Tritium in A/G Structure: 1.0</i> • <i>C-14 in A/G Structure: 1.0</i> • <i>Tritium in stored asbestos: 1.0</i> • <i>Others: see discussion</i> 	$ARF \times RF = A \times P \times g \times h$ <p>Where,</p> <ul style="list-style-type: none"> A = empirical correlation constant (2x10⁻¹¹ cm³ per g-cm³/s²); P = density (g/cm³); g = gravitational acceleration (980 cm/s² at sea level); h = fall height (cm). <p>Density (P) values used are 2.4 g/cm³ for building debris (i.e. concrete) (Dorf 1996). Fall height (h) is assumed to be 100 cm (1 m) for an EF-2 tornado. From this, a combined factor of 4.7E-6 is derived.</p>
LPF	<i>A/G Structure: 0.1 Stored Asbestos: 1.0</i>	To represent the portion that would be retained by (and forms part of) the remaining structure, given the intensity of the tornado considered. For asbestos stored in sealand containers, an LPF of 1 is used.

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Table 9-4 Source Term Factors – Bounding Scenario 4 (Tornado; Chemical Release)

Factor (Equation 1)	Value Selected		Discussion
MAR	Asbestos	<i>Transite; A/g structural; Sea Container</i>	<p>The following MAR assumptions are made:</p> <ul style="list-style-type: none"> • Asbestos: The available inventory is assumed to include all exterior transite, all of the estimated above-grade structural asbestos, and asbestos stored within the sea container (assumed to be low-density chrysotile pipe insulation type material), using the corresponding volumes outlined in Section 5.2.3. • Lead: In the above-grade structure only lead paint is available for a tornado. • Mercury: There is no mercury available to a tornado, as the only remaining mercury is in the boiler room. • PCBs: There is no PCBs available for a tornado, as the only light ballasts that will remain at the start of decommissioning are below ground.
	Lead	<i>A/g Paint</i>	
	Mercury	<i>None Available</i>	
	PCBs	<i>None Available</i>	
DR	<i>EF Scale 2: 0.01</i>		<p>The DR depends on the strength of a tornado:</p> <p><i>EF Scale 2 Tornadoes:</i> based on tornado EF-scaling, an EF-2 tornado is assumed to be 1/10th as powerful as an EF-4 or EF-3 tornado, which is assumed to be 1/10th as powerful as an EF-5 tornado. This produces a conservative DR of 0.01 for an EF-2, since Athauda-Arachchige (2015) notes that EF-2 and EF-1 tornadoes would not cause significant damage to the facility, though they <i>may</i> damage the ventilation system.</p>
ARF	<ul style="list-style-type: none"> • <i>Asbestos:</i> See Discussion • <i>Lead:</i> 1 • <i>Others:</i> Not Applicable 		<p><u>Asbestos:</u> For low-density asbestos insulation material stored within the sea container, an ARF of 1 and RF of 0.1 are used. For high-density asbestos material (transite and structural), the ARF and RF for asbestos is calculated using the equation described in Table 9-3, based on a density of approximately 2.4 g/cm³ for high-density chrysotile (NIOSH 2016c) which is consistent with a density of 2.4 g/cm³ for concrete (Dorf, 1996). Using the remaining parameters as outlined in Table 9-3, this produces a value of 4.7E-06 for 'ARF x RF' based on an EF-2 tornado class.</p> <p><u>Lead:</u> 1 – An ARF and RF of 1 are conservatively used.</p> <p><u>Others:</u> there is no MAR, and as such this is not applicable (see MAR discussion above).</p>
RF			
LPF	<i>0.1</i>		<p>To represent the portion that would be retained by (and forms part of) the remaining structure, given the intensity of the tornado considered.</p>

Note: A/g – Above-ground

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Table 9-5 Source Term Factors – Bounding Scenario 5 (Flood/Water Ingress; Radiological Release)

Factor (Equation 1)	Value Selected	Discussion
MAR		
DR		
ARF		<p>The effects of external flooding due to a precipitation event have been assessed in the facility SAR (Athauda-Arachchige 2015; Section 10.5.3.2). As such, no MAR, DR, ARF, RF, or LPF estimates are presented here – the reader is referred to the original facility SAR (Athauda-Arachchige, 2015) for details on parameters used to derive flood source terms.</p>
RF		<p>The consequence results identified in the facility SAR (Athauda-Arachchige 2015) are discussed in Section 9.5 of this report with the consequence results for all other bounding scenarios.</p>
LPF		

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Table 9-6 Source Term Factors – Bounding Scenarios 6 & 7 (Radiological Exposure; Chemical Exposure)

Factor (Equation 1)	Value Selected	Discussion
MAR	<i>See discussion</i>	<p>For this bounding scenario, the amount of material involved can be calculated directly, by determining the amount of concrete removed by drilling and multiplying by per-gram activity of the concrete.</p>
DR		<p>Holes drilled in the reactor vault wall are expected to be 6 inches (15.24 cm) in diameter, drilled using a concrete core drill. Therefore, the material of the core remains intact. So, the actual volume of material released is that of the ring that is drilled through the thickness of the wall. This is calculated as the volume of the cylinder from the outer diameter of the drill, minus the volume of the cylinder from the inner diameter of the drill. Assuming a core drill thickness of ¼ inch (0.635 cm), and a concrete wall/floor thickness of 269 cm (i.e. 106 inches, (Harris, 1958)), this produces a volume of 7,837 cm³ of powder released. Using the 3.692 g/cm³ density value - from measurements of a high-density concrete core obtained by Kraznai (1991) - this results in 28,936 g of concrete powder released.</p> <p>The remaining source term derivation, (i.e. the results, by applying the per-gram activities) is presented in Section 9.2.2.6, for each of the two variants of this Bounding Scenario (i.e. 32-hour drilling period, and, increased radioactivity).</p> <p><i>Non-Radiological:</i> It is important to note that, due to the form and location of non-radiological hazardous chemicals, there is no chemical inventory involved in this scenario:</p> <p>Mercury: is present only as a residual contaminant in the sump, which would not be involved in such a scenario.</p> <p>PCBs: As discussed in Section 5.2.4, some PCBs may be present in the form of remaining ceiling light ballasts, until grouting raises the floor to a sufficient height that these can be safely accessed and removed as part of decommissioning tasks. Regardless of quantity, removal of the light ballasts does not require drilling or cutting. Thus, PCBs would not be involved in this scenario.</p> <p>Asbestos: the concrete walls relevant to this scenario have not been identified as asbestos-containing.</p> <p>Lead: drilling/cutting will not be carried out on lead shielding walls or lead doors, and as such lead is also not relevant to this scenario.</p>
ARF	<u>Fixed Contamination:</u> • All: 0.01	<p><u>Fixed Contamination:</u> Based on US DOE (1994) bounding ARF and RF values for suspension of bulk powder by debris impact and air turbulence from falling.</p>
RF	<u>Fixed Contamination:</u> • All: 0.2	
LPF	1.0	It is conservatively assumed that there is no reduction in the release.

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Table 9-7 Source Term Factors – Bounding Scenario 8 (Indoor/Below-ground Fire; Radiological Release)

Factor (Equation 1)	Value Selected	Discussion
MAR	<i>Drum #7 inventory</i>	Given that this scenario is depicting a fire in a room (FM Room conservatively chosen), the inventory that is expected to be involved is the contents of Drum #7. This is due to the potentially flammable nature of the contents (polyethylene personal protective equipment).
DR	1	It is conservatively assumed that the entire contents of Drum #7 are affected by this indoor fire bounding scenario, and as such the entire inventory is damaged.
ARF	<i>Combustibles: 0.01</i>	<i>Combustibles:</i> US DOE (1994) bounding (i.e. conservative) ARF and RF values for uncontained burning of combustible cellulose such as paper, wood, or cardboard.
RF	<i>Combustibles: 1.0</i>	
LPF	1.0	It is conservatively assumed that there is no reduction in the release.

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Table 9-8 Source Term Factors – Bounding Scenario 9 (Indoor/Below-ground Fire; Chemical Release)

Factor (Equation 1)	Value Selected	Discussion
MAR	<ul style="list-style-type: none"> • <i>Asbestos: 30 m³ (in BR)</i> • <i>PCBs: None (in BR)</i> • <i>Mercury: 10 g (in BR)</i> • <i>Lead: 2.35E+07 g (in FM room)</i> 	<ul style="list-style-type: none"> • <i>Asbestos:</i> The MAR selected for asbestos is the amount in the boiler room, which represents the highest inventory of asbestos in any particular room. The FM room does not contain asbestos. • <i>PCBs:</i> As discussed in Section 5.2.4, PCBs may be present in the form of remaining ceiling light ballasts, until grouting raises the floor to a sufficient height that these can be safely accessed and removed as part of decommissioning activities. Prior to raising the floor, the ceiling light ballasts will be high enough that a small fire (e.g. from a hand-held gas-powered equipment fuel spill) would not reach a large enough size to impact them. Once the floor level has been raised, the light ballasts will be removed and this does not involve the use of gas-powered equipment, and so a fire event would not occur. Thus, PCBs would not be involved in this scenario. • <i>Mercury:</i> Mercury is present as residual contamination in the boiler room, and is not present at any other location. Therefore, the boiler room inventory will be used for the bonding calculation. • <i>Lead:</i> Lead is present in the form of lead paint throughout the facility, exposed lead (i.e. lead bricks) in the fueling machine room, and lead contained within concrete or encased in steel. Of these, exposed lead and lead paint could be available to a fire. Therefore, the MAR selected for lead is the total amount of exposed lead (i.e. lead bricks) in the FM room (Room 408) which represents the highest known quantity of exposed lead in any given room, and, the estimated quantity of lead paint in the below grade structure.
DR	<p><i>Lead: 0.01, 0.0001</i> <i>Asbestos: 0</i> <i>Others: 0.1</i></p>	<p><i>Lead:</i> For lead paint, a DR of 0.01 (i.e. 1%) is used to represent the very small portion of total below-grade lead paint that would be present in the fueling machine room, and of this, the small portion that could be impacted by a small fire. This is selected because for an indoor fire to occur within the fueling machine room, there would likely need to be a spill of combustible liquid as there is otherwise little-to-no combustible material within the room. For lead bricks, a DR of 0.0001 (i.e. 0.01%) is used to represent the <i>very</i> small fraction of lead that could be released. This is selected because a fire of small size and short duration (due to lack of combustible materials) would only heat a very thin outer exposed layer. A small fire would be very unlikely to produce the sustained heat required to heat the body of the large solid mass of lead bricks to a high enough temperature to produce a release.</p> <p><i>Asbestos:</i> Asbestos is used as a fire-retardant material, and as such is not expected to be affected by a fire of this size. As such, a DR of 0 has been applied.</p> <p><i>Others:</i> It is assumed that only a portion (10%) of the material at risk could be affected by this indoor fire bounding scenario given the expected size of the fire (for further details, see the bounding scenario description in Section 9.1.8). This DR of 0.1 also follows from the assumed DR of 1.0 for a large forest fire, from bounding scenarios 1 and 2, as this fire is significantly smaller (i.e. less than 1/10th the size) than a forest fire.</p>
ARF	<ul style="list-style-type: none"> • <i>Asbestos: 0.006</i> • <i>PCBs: 1.0</i> • <i>Mercury: 1.0</i> • <i>Lead: 0.001</i> 	<p><i>Asbestos:</i> Based on US DOE (1994).</p> <p><i>PCBs and Mercury:</i> ARF and RF conservatively assumed to be 1.0 (i.e. no loss from release fraction, and complete conversion to respirable fraction).</p>
RF	<ul style="list-style-type: none"> • <i>Asbestos: 0.01</i> • <i>PCBs: 1.0</i> • <i>Mercury: 1.0</i> • <i>Lead: 1.0</i> 	<p><i>Lead:</i> Based on US DOE (1994) bounding ARF and RF values for thermal stress of metals, solid form, complete oxidation.</p>
LPF	1.0	It is conservatively assumed that there is no reduction in the release.

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Table 9-9 Source Term Factors – Bounding Scenario 10 (Stack Collapse; Radiological Release)

Factor (Equation 1)	Value Selected	Discussion
MAR	<i>Radionuclides in Stack Concrete and Liquid</i>	Measured radionuclide activities in ventilation stack concrete were used (see Section 5.1.6). Maximum measured radionuclide concentrations (decayed to 2018) in stack liquid were used.
DR	1.0	It is assumed that the total inventory of radionuclides could be impacted by this scenario (i.e. a DR of 1.0 is selected).
ARF	0.8	The ARF was assumed to be 0.8. This is intended to be a very conservative estimate of the fraction of building material that could be made airborne (as dust) rather than as larger rubble pieces.
RF	1.0	
LPF	1.0	It is conservatively assumed that there is no reduction in the release.

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Table 9-10 MAR and Source Term Factor Summary

Scenario		MAR	DR	ARF	RF	LPF
Scenario #	Scenario Name					
1	Forest Fire – Radiological	A/g Surface Contamination	1	Tritium – 1 C-14 - 1 Other – 0.006	Tritium – 1 C-14 - 1 Other – 0.01	1
2	Forest Fire – Non-Radiological	Asbestos – A/g Transite & Structural Lead – A/g paint Mercury – none PCBs – none Dioxins & Furans – none	1	Asbestos – 0.006 Lead – 0.001 Mercury – 1 PCBs - 1	Asbestos – 0.01 Lead – 1 Mercury – 1 PCBs - 1	0.5
3	Tornado (EF-2) – Radiological	A/g Surface Contamination Tritium in Stored Asbestos (in sealand container)	EF Scale 4 & 3: 0.1 EF Scale 2 & 1: 0.01 to 0	<u>A/G Structure:</u> Tritium ARF – 0.5 (or 1) Tritium RF – 1.0 C-14 ARF – 1.0 C-14 RF – 1.0 <u>ARF x RF Tornado Calculation:</u> Others – EF 4 & 3 – 4.7E-05 EF 2 & 1 – 4.7E-06	A/G Structure: 0.1 Sea Container: 1.0	
4	Tornado (EF-2) – Non-Radiological	Asbestos - A/g Transite, Structural, & sea container Lead – A/g paint Mercury – none PCBs – none	EF Scale 4 & 3: 0.1 EF Scale 2 & 1: 0.01 to 0	Asbestos in sea container: ARF 1, RF 0.1 Others: ARF x RF: EF 4 & 3 – 4.7E-05 EF 2 & 1 – 4.7E-06	1 (sea container) 0.1 (structure)	
5	Flood – Radiological	<i>Not Applicable:</i> Effects of external flooding due to precipitation events have been assessed in the facility SAR (Athauda-Arachchige 2015; Section 10.5.3.2). No MAR, DR, ARF, RF, or LPF estimates are presented here. Consequence results are discussed in Section 9.5.				
6	Accidental Exposure – Radiological	Specific Amount Calculated (by mass) (see discussion in Table 9-6)		0.01	0.2	1
7	Accidental Exposure – Non-Radiological	No MAR	N/A	0.01	0.2	1
8	Indoor Fire – Rad.	Drum #7	1	0.01	1	1
9	Indoor Fire – Non-Radiological	Asbestos – BR quantity PCBs – None Mercury – BR quantity Lead –Exposed & U/g paint	Lead – 0.01, 0.0001 Asbestos - 0 Others – 0.1	Asbestos – 0.006 Lead – 0.001 Mercury – 1 PCBs - 1	Asbestos – 0.01 Lead – 1 Mercury – 1 PCBs - 1	1
10	Stack Collapse	Stack Concrete & Liquid	1	0.8	1	1

A/g: Above-ground; U/g: Under-ground; BR: Boiler Room; FM Room: Fueling Machine Room

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9.2.2 Source Term Results

9.2.2.1 Source Terms - Bounding Scenario 1 (Forest Fire; Rad.)

Table 9-11 presents the estimated source term values for Bounding Scenario 1, derived based on the inventory (see Section 5.1) and the source term parameters identified for this bounding scenario (see Table 9-1).

Table 9-11 Source Terms – Bounding Scenario 1

Radionuclides	Source Term (Q) [Bq]	
	Above-Grade Structure	TOTAL SUM [Bq]
H-3	8.25E+10	8.25E+10
C-14	2.72E+08	2.72E+08

9.2.2.2 Source Terms - Bounding Scenario 2 (Forest Fire; Non-Rad.)

Table 9-12 presents the estimated source term values for Bounding Scenario 2, derived based on the inventory (see Section 5.2) and the source term parameters identified for this bounding scenario (see Table 9-2).

Table 9-12 Source Terms – Bounding Scenario 2

Hazardous Chemicals	Source Term (Q) [g]
Asbestos	2.16E+03
Lead	1.68E+02
Mercury	0.00E+00
PCBs	0.00E+00
Dioxins & Furans	0.00E+00

9.2.2.3 Source Terms - Bounding Scenario 3 (Tornado; Rad.)

Table 9-13 presents the estimated source term values for Bounding Scenario 3 (for an EF-2 strength tornado), derived based on the inventory (see Section 5.1) and the source term parameters identified for this bounding scenario (see Table 9-3).

Table 9-13 Source Terms – Bounding Scenario 3

Radionuclides	Source Term (Q) [Bq]	
	Above Ground Structure, and Tritium in Asbestos Waste in Sealand Containers	TOTAL SUM [Bq]
H-3	1.88E+10	1.88E+10
C-14	2.72E+05	2.72E+05

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9.2.2.4 Source Terms - Bounding Scenario 4 (Tornado; Non-Rad.)

Table 9-14 presents the estimated source term values for Bounding Scenario 4 (for an EF-2 strength tornado), derived based on the inventory (see Section 5.2) and the source term parameters identified for this bounding scenario (see Table 9-4).

Table 9-14 Source Terms – Bounding Scenario 4

Hazardous Chemicals	Source Term (Q) [g]
<i>Asbestos</i>	2.64E+04
<i>Lead</i>	3.35E+02
<i>Mercury</i>	0.00E+00
<i>PCBs</i>	0.00E+00

9.2.2.5 Source Terms - Bounding Scenario 5 (Flood; Rad.)

The effects of external flooding due to a precipitation event have been assessed in the facility SAR (Athauda-Arachchige 2015; Section 10.5.3.2). As such, source terms have not been recalculated here – for details on source terms the reader is referred to the facility SAR (Athauda-Arachchige, 2015).

The consequence results identified in the facility SAR (Athauda-Arachchige 2015) are discussed in Section 9.5 of this report.

9.2.2.6 Source Terms - Bounding Scenario 6 (Accidental Exposure; Rad.)

For this bounding scenario the drilling period is increased to 32 hours (therefore doubling the exposure time of a worker receptor engaged in this activity).

Table 9-15 presents the estimated source term values for Bounding Scenario 6. Values are derived based on the modelled inventory of activation products in concrete (see Section 5.1.1, assuming concrete mass of 39.5 kg [NMNTI 2017]), and also based on the radionuclide measurement data obtained from concrete cores (see Section 5.1.2), multiplied by the estimated mass of cored concrete and other source term parameters identified for this bounding scenario in Table 9-6. It should be noted that the total list of radionuclides has been screened to remove short lived radionuclides (radionuclides with a half-life less than 1 year). A scoping calculation was conducted to ensure that the removal of these short-lived radionuclides would not affect the dose, and it indeed was found to have no significant effect. From this, the highest derived value for each radionuclide is used (denoted in the ‘Max.’ column of the table).

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Table 9-15 Source Terms – Bounding Scenario 6 (32-hr Drilling Period)

Radionuclides	Source Term (Q) [Bq]		
	Activ. Prd. (Concrete Only)	Concrete Core (see Section 5.1.2)	Max. [Bq]
<i>H-3</i>	2.07E+06	4.95E+04	2.07E+06
<i>C-14</i>	3.52E+04	1.71E+04	3.52E+04
<i>Ag-108m</i>	5.80E-03	Not Available	5.80E-03
<i>Ba-133</i>	2.30E+00	Not Available	2.30E+00
<i>Ca-41</i>	1.12E+04	1.16E+02	1.12E+04
<i>Cd-113m</i>	3.15E-05	Not Available	3.15E-05
<i>Cl-36</i>	2.55E+02	Not Available	2.55E+02
<i>Co-60</i>	4.66E+05	1.98E+03	4.66E+05
<i>Cs-135</i>	5.66E-05	Not Available	5.66E-05
<i>Cs-137</i>	1.57E+00	1.18E+02	1.18E+02
<i>Eu-152</i>	1.80E+05	6.35E+02	1.80E+05
<i>Eu-154</i>	2.02E+00	3.60E+01	3.60E+01
<i>La-137</i>	1.73E-05	Not Available	1.73E-05
<i>Nb-93m</i>	3.30E-03	Not Available	3.30E-03
<i>Nb-94</i>	2.37E-01	Not Available	2.37E-01
<i>Ni-59</i>	2.46E+00	Not Available	2.46E+00
<i>Ni-63</i>	1.00E+05	1.41E+02	1.00E+05
<i>Pu-238</i>	1.22E+03	Not Available	1.22E+03
<i>Pu-239</i>	3.02E+01	Not Available	3.02E+01
<i>Pu-240</i>	3.36E-05	Not Available	3.36E-05
<i>Sb-125</i>	2.27E-05	Not Available	2.27E-05
<i>Se-79</i>	3.02E-06	Not Available	3.02E-06
<i>Sm-151</i>	8.07E-01	Not Available	8.07E-01
<i>Sn-121m</i>	2.34E-04	Not Available	2.34E-04
<i>Sn-126</i>	4.86E-06	Not Available	4.86E-06
<i>Sr-90</i>	1.48E+00	Not Available	1.48E+00
<i>Tc-99</i>	5.77E-04	Not Available	5.77E-04
<i>Th-229</i>	3.30E-04	Not Available	3.30E-04
<i>Th-230</i>	4.62E-03	Not Available	4.62E-03
<i>Th-232</i>	4.60E-01	Not Available	4.60E-01
<i>U-233</i>	8.38E-02	Not Available	8.38E-02
<i>U-234</i>	6.37E-01	Not Available	6.37E-01
<i>U-235</i>	2.96E-02	Not Available	2.96E-02
<i>U-236</i>	1.49E-05	Not Available	1.49E-05
<i>U-238</i>	6.45E-01	Not Available	6.45E-01
<i>Zr-93</i>	4.10E-03	Not Available	4.10E-03

Note: "Not Available" – activity of given isotope not available in this form

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9.2.2.7 Source Terms - Bounding Scenario 7 (Accidental Exposure; Non-Rad.)

As discussed in Table 9-6, this bounding scenario has no material at risk, and as such does not require further source term derivation calculations.

9.2.2.8 Source Terms - Bounding Scenario 8 (Indoor Fire; Rad.)

Table 9-16 presents the estimated source term values for Bounding Scenario 8, derived based on the inventory (see Section 5.1) and the source term parameters identified for this bounding scenario (see Table 9-7).

Table 9-16 Source Terms – Bounding Scenario 8

Radionuclides	Source Term (Q) [Bq]	
	Drum #7	TOTAL SUM [Bq]
Cs-137	7.81E+04	7.81E+04
Co-60	1.23E+04	1.23E+04

9.2.2.9 Source Terms - Bounding Scenario 9 (Indoor Fire; Non-Rad.)

Table 9-17 presents the estimated source term values for Bounding Scenario 9, derived based on the inventory (see Section 5.2) and the source term parameters identified for this bounding scenario (see Table 9-8).

Table 9-17 Source Terms – Bounding Scenario 9

Hazardous Chemicals	Source Term (Q) [g]
Asbestos (Boiler Room)	0.00E+00
Lead (FM Room)	6.28E+00
Mercury (Boiler Room)	1.00E+01
PCBs (Boiler Room)	0.00E+00
Dioxins & Furans (Boiler Room)	0.00E+00

Note that the lead source term relies on different DRs for lead paint versus lead bricks - see Table 9-8.

9.2.2.10 Source Terms - Bounding Scenario 10 (Stack Collapse; Rad.)

Table 9-18 presents the estimated source term values for Bounding Scenario 10, derived based on the inventory (see Section 5.1) and the source term parameters identified for this bounding scenario (see Table 9-9). The ventilation stack water is the maximum value among three sampling locations.

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Table 9-18 Source Terms – Bounding Scenario 10 (Concrete)

Radionuclides	Source Term (Q) [Bq]	
	Ventilation Stack Concrete	TOTAL SUM [Bq]
H-3	5.20E+07	5.20E+07
C-14	3.20E+07	3.20E+07

Table 9-19 Source Terms – Bounding Scenario 10 (Water)

Radionuclides	Source Term (Q) [Bq/L]
	Ventilation Stack Water
H-3	7.03E+06
Co-60	1.18E+00
Cs-137	9.14E-01

9.3 Exposure Concentrations

The following tables present the estimated concentrations of radionuclides and chemicals at receptor locations (i.e. exposure concentrations) for each relevant bounding scenario, based on the corresponding source term (see Section 9.2.2) and dispersion/transport modelling methods (see Section 6.0) for each bounding scenario.

9.3.1 Bounding Scenario 1: Forest Fire and Release of Radioactivity

Table 9-20 presents the estimated exposure concentrations at receptor locations, for Bounding Scenario 1.

Table 9-20 Exposure Concentrations – Bounding Scenario 1 – Forest Fire

Radionuclides	Exposure Concentrations at Receptor Locations												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Residential	Cottage	Rolphon Residential	Mackey Beef Farm	Bass Lake Beef Farm
H-3 (Air) [in Bq/m ³]	1.15E+03	1.15E+03	8.02E+00	8.02E+00	9.17E+00	7.33E+00	1.19E+02	6.65E+00	5.96E+00	6.42E+00	8.94E+00	2.75E+00	4.81E+00
C-14 (Air) [in Bq/m ³]	3.78E+00	3.78E+00	2.64E-02	2.64E-02	3.02E-02	2.42E-02	3.93E-01	2.19E-02	1.96E-02	2.12E-02	2.95E-02	9.07E-03	1.59E-02
H-3 (Soil) [in Bq/kg]	Not Applicable	Not Applicable	5.76E+01	5.76E+01	6.58E+01	5.26E+01	8.56E+02	4.77E+01	4.28E+01	4.61E+01	6.42E+01	1.97E+01	3.45E+01
C-14 (Soil) [in Bq/kg]	Not Applicable	Not Applicable	1.90E-01	1.90E-01	2.18E-01	1.74E-01	2.83E+00	1.58E-01	1.41E-01	1.52E-01	2.12E-01	6.53E-02	1.14E-01

Notes:

Worker Receptor Locations: Calculated using short-distance dispersion method (see Section 6.1).

Public Receptor Locations: Calculated using long-distance dispersion method (see Section 6.2).

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

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9.3.2 Bounding Scenario 2: Forest Fire and Release of Chemical Contaminants

Table 9-21 presents the estimated exposure concentrations at receptor locations, for Bounding Scenario 2. As discussed in Section 9.2.1, asbestos and lead are identified as MAR.

Table 9-21 Exposure Concentrations – Bounding Scenario 2 – Forest Fire

Hazardous Chemicals	Exposure Concentrations at Receptor Locations												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Residential	Cottage	Rolphon Residential	Mackey Beef Farm	Bass Lake Beef Farm
Asbestos (Air) [in g/m³]	3.00E-05	3.00E-05	2.10E-07	2.10E-07	2.40E-07	1.92E-07	3.12E-06	1.74E-07	1.56E-07	1.68E-07	2.34E-07	7.20E-08	1.26E-07
Lead (Air) [in g/m³]	2.33E-06	2.33E-06	1.63E-08	1.63E-08	1.86E-08	1.49E-08	2.42E-07	1.35E-08	1.21E-08	1.30E-08	1.81E-08	5.58E-09	9.77E-09
Lead (Soil) [in µg/g]	Not Applicable	Not Applicable	1.17E-07	1.17E-07	1.34E-07	1.07E-07	1.74E-06	9.71E-08	8.71E-08	9.38E-08	1.31E-07	4.02E-08	7.03E-08

Notes:

Worker Receptor Locations: Calculated using short-distance dispersion method (see Section 6.1).

Public Receptor Locations: Calculated using long-distance dispersion method (see Section 6.2).

Soil Concentration: Calculated using soil deposition model (see Section 6.3)*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

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9.3.3 Bounding Scenario 3: Tornado and Release of Radioactivity

Table 9-22 presents the estimated exposure concentrations at receptor locations, for Bounding Scenario 3, for an EF-2 tornado.

Table 9-22 Exposure Concentrations – Bounding Scenario 3 – Tornado (EF-2)

Radionuclides	Exposure Concentrations at Receptor Locations												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Residential	Cottage	Rolphon Residential	Mackey Beef Farm	Bass Lake Beef Farm
H-3 (Air) [in Bq/m ³]	5.23E-07	5.23E-07	5.23E-07	5.23E-07	5.23E-07	5.23E-07	5.23E-07	2.35E+01	5.23E-07	5.23E-07	2.35E+01	7.84E-01	7.84E-01
C-14 (Air) [in Bq/m ³]	7.56E-12	7.56E-12	7.56E-12	7.56E-12	7.56E-12	7.56E-12	7.56E-12	3.40E-04	7.56E-12	7.56E-12	3.40E-04	1.13E-05	1.13E-05
H-3 (Soil) [in Bq/kg]	Not Applicable	Not Applicable	3.76E-06	3.76E-06	3.76E-06	3.76E-06	3.76E-06	1.69E+02	3.76E-06	3.76E-06	1.69E+02	5.64E+00	5.64E+00
C-14 (Soil) [in Bq/kg]	Not Applicable	Not Applicable	5.44E-11	5.44E-11	5.44E-11	5.44E-11	5.44E-11	2.45E-03	5.44E-11	5.44E-11	2.45E-03	8.16E-05	8.16E-05

Notes:

All Receptor Locations: Calculated using tornado-scenario dispersion method (see Section 6.2.3).

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

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9.3.4 Bounding Scenario 4: Tornado and Release of Chemical Contaminants

Table 9-23 presents the estimated exposure concentrations at receptor locations, for Bounding Scenario 4, for an EF-2 tornado. As discussed in Section 9.2.1, asbestos and lead are identified as MAR.

Table 9-23 Exposure Concentrations – Bounding Scenario 4 – Tornado (EF-2)

Hazardous Chemicals	Exposure Concentrations at Receptor Locations												
	<i>Worker* (Near-Field)</i>	<i>Worker* (Far-Field)</i>	<i>Res. 1</i>	<i>Res. 2</i>	<i>Res. 3</i>	<i>Rec. (Res. 4)</i>	<i>Guardhouse</i>	<i>Rapides Des Joachims</i>	<i>Pt. Stewart Residential</i>	<i>Cottage</i>	<i>Rolphton Residential</i>	<i>Mackey Beef Farm</i>	<i>Bass Lake Beef Farm</i>
Asbestos (Air) [in g/m³]	7.33E-13	7.33E-13	7.33E-13	7.33E-13	7.33E-13	7.33E-13	7.33E-13	3.30E-05	7.33E-13	7.33E-13	3.30E-05	1.10E-06	1.10E-06
Lead (Air) [in g/m³]	9.31E-15	9.31E-15	9.31E-15	9.31E-15	9.31E-15	9.31E-15	9.31E-15	4.19E-07	9.31E-15	9.31E-15	4.19E-07	1.40E-08	1.40E-08
Lead (Soil) [in µg/g]	Not Applicable	Not Applicable	6.70E-14	6.70E-14	6.70E-14	6.70E-14	6.70E-14	3.01E-06	6.70E-14	6.70E-14	3.01E-06	1.00E-07	1.00E-07

Notes:

All Receptor Locations: Calculated using tornado-scenario dispersion method (see Section 6.2.3).

Soil Concentration: Calculated using soil deposition model (see Section 6.3).

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

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9.3.5 Bounding Scenario 5: Major Flood and Release of Radioactivity

The effects of external flooding due to a precipitation event have been assessed in the facility SAR (Athauda-Arachchige 2015; Section 10.5.3.2). As such, source terms and their resulting environmental concentrations have not been recalculated here – for details on resulting environmental concentrations, the reader is referred to the facility SAR (Athauda-Arachchige, 2015).

The consequence results identified in the facility SAR (Athauda-Arachchige 2015) are discussed in Section 9.5 of this report.

9.3.6 Bounding Scenario 6: Accidental Exposure to Radioactivity

Table 9-24 presents the estimated exposure concentrations at receptor locations, for Bounding Scenario 6: extended (i.e. 32-hour) extended drilling time.

Table 9-24 Exposure Concentrations (in Air) – Bounding Scenario 6 – Drilling [Bq/m³]

Radionuclides	Exposure Concentrations at Receptor Locations (Air) [in Bq/m ³]	
	Worker (Near-Field)	Worker (Far-Field)
H-3	8.16E+02	8.00E+02
C-14	1.39E+01	1.36E+01
Ag-108m	2.29E-06	2.25E-06
Ba-133	9.09E-04	8.91E-04
Ca-41	4.41E+00	4.32E+00
Cd-113m	1.24E-08	1.22E-08
Cl-36	1.01E-01	9.87E-02
Co-60	1.84E+02	1.80E+02
Cs-135	2.24E-08	2.19E-08
Cs-137	4.65E-02	4.55E-02
Eu-152	7.12E+01	6.98E+01
Eu-154	1.42E-02	1.40E-02
La-137	6.83E-09	6.69E-09
Nb-93m	1.30E-06	1.28E-06
Nb-94	9.38E-05	9.19E-05
Ni-59	9.73E-04	9.53E-04
Ni-63	3.96E+01	3.87E+01
Pu-238	4.81E-01	4.71E-01
Pu-239	1.19E-02	1.17E-02
Pu-240	1.33E-08	1.30E-08
Sb-125	8.98E-09	8.79E-09
Se-79	1.19E-09	1.17E-09
Sm-151	3.19E-04	3.13E-04
Sn-121m	9.27E-08	9.08E-08

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Radionuclides	Exposure Concentrations at Receptor Locations (Air) [in Bq/m ³]	
	Worker (Near-Field)	Worker (Far-Field)
Sn-126	1.92E-09	1.88E-09
Sr-90	5.85E-04	5.73E-04
Tc-99	2.28E-07	2.24E-07
Th-229	1.30E-07	1.28E-07
Th-230	1.82E-06	1.79E-06
Th-232	1.82E-04	1.78E-04
U-233	3.31E-05	3.25E-05
U-234	2.52E-04	2.47E-04
U-235	1.17E-05	1.15E-05
U-236	5.91E-09	5.79E-09
U-238	2.55E-04	2.50E-04
Zr-93	1.62E-06	1.59E-06

Notes:

Worker Receptor Locations: Calculated using short-distance dispersion method (see Section 6.1).

9.3.7 Bounding Scenario 7: Accidental Exposure to Chemicals

As discussed in Table 9-6, this bounding scenario has no material at risk, and as such does not warrant further exposure concentration calculations.

9.3.8 Bounding Scenario 8: Underground (Indoor) Fire and Release of Radioactivity

Table 9-25 presents the estimated exposure concentrations at receptor locations, for Bounding Scenario 8.

Table 9-25 Exposure Concentrations – Bounding Scenario 8 – Indoor Fire – Fueling Machine Room

Radionuclides	Exposure Concentrations at Receptor Locations												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Residential	Cottage	Rolphon Residential	Mackey Beef Farm	Bass Lake Beef Farm
Cs-137(Air) [in Bq/m ³]	9.88E+02	9.68E+02	7.59E-06	7.59E-06	8.68E-06	6.94E-06	1.13E-04	6.29E-06	5.64E-06	6.07E-06	8.46E-06	2.60E-06	4.56E-06
Co-60(Air) [in Bq/m ³]	1.56E+02	1.52E+02	1.20E-06	1.20E-06	1.37E-06	1.09E-06	1.78E-05	9.91E-07	8.88E-07	9.57E-07	1.33E-06	4.10E-07	7.18E-07
Cs-137 (Soil) [in Bq/kg]	Not Applicable	Not Applicable	5.47E-05	5.47E-05	6.25E-05	5.00E-05	8.12E-04	4.53E-05	4.06E-05	4.37E-05	6.09E-05	1.87E-05	3.28E-05
Co-60 (Soil) [in Bq/kg]	Not Applicable	Not Applicable	8.61E-06	8.61E-06	9.84E-06	7.87E-06	1.28E-04	7.13E-06	6.39E-06	6.89E-06	9.59E-06	2.95E-06	5.16E-06

Notes:

Worker Receptor Locations: Calculated using short-distance dispersion method (see Section 6.1).

Public Receptor Locations: Calculated using long-distance dispersion method (see Section 6.2).

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

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9.3.9 Bounding Scenario 9: Underground (Indoor) Fire and Release of Chemicals

Table 9-26 and Table 9-27 present the estimated exposure concentrations at receptor locations, for Bounding Scenario 9 (a and b). As discussed in Section 9.2.1, PCBs (and therefore resulting dioxins and furans) are not identified as MAR, whereas asbestos is identified as MAR but with a DR of zero.

Table 9-26 Exposure Concentrations– Bounding Scenario 9a – Indoor Fire – Fueling Machine Room

Hazardous Chemicals	Exposure Concentrations at Receptor Locations												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Residential	Cottage	Rolphon Residential	Mackey Beef Farm	Bass Lake Beef Farm
Lead (in Air) [g/m³]	7.95E-02	7.79E-02	6.11E-10	6.11E-10	6.98E-10	5.59E-10	9.08E-09	5.06E-10	4.54E-10	4.89E-10	6.81E-10	2.09E-10	3.67E-10
Lead (in Soil) [µg/g]	Not Applicable	Not Applicable	4.40E-09	4.40E-09	5.03E-09	4.02E-09	6.53E-08	3.64E-09	3.27E-09	3.52E-09	4.90E-09	1.51E-09	2.64E-09

Notes:

Worker Receptor Locations: Calculated using short-distance dispersion method (see Section 6.1).

Public Receptor Locations: Calculated using long-distance dispersion method (see Section 6.2).

Soil Concentration: Calculated using soil deposition model (see Section 6.3).

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

Table 9-27 Exposure Concentrations (in Air) – Bounding Scenario 9b – Indoor Fire – Boiler Room [g/m³]

Hazardous Chemicals	Exposure Concentrations at Receptor Locations (Air) [in g/m ³]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Residential	Cottage	Rolphon Residential	Mackey Beef Farm	Bass Lake Beef Farm
Asbestos	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mercury	2.39E-03	2.38E-03	9.72E-11	9.72E-11	1.11E-10	8.89E-11	1.44E-09	8.06E-11	7.22E-11	7.78E-11	1.08E-10	3.33E-11	5.83E-11

Notes:

Worker Receptor Locations: Calculated using short-distance dispersion method (see Section 6.1).

Public Receptor Locations: Calculated using long-distance dispersion method (see Section 6.2).

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9.3.10 Bounding Scenario 10: Stack Collapse and Release of Radioactivity

Table 9-28 presents the estimated exposure concentrations at receptor locations, for Bounding Scenario 10.

Table 9-28 Exposure Concentrations – Bounding Scenario 10 – Stack Collapse

Radionuclides	Exposure Concentrations at Receptor Locations												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Residential	Cottage	Rolphon Residential	Mackey Beef Farm	Bass Lake Beef Farm
H-3 (Air) [in Bq/m ³]	4.33E+01	4.33E+01	3.03E+02	2.86E+02	2.51E+02	2.51E+02	1.30E+04	9.53E+01	7.97E+01	1.73E+02	7.28E+01	1.39E+02	4.85E+00
C-14 (Air) [in Bq/m ³]	2.67E+01	2.67E+01	1.87E+02	1.76E+02	1.55E+02	1.55E+02	8.00E+03	5.87E+01	4.91E+01	1.07E+02	4.48E+01	8.53E+01	2.99E+00
H-3 (Soil) [in Bq/kg]	Not Applicable	Not Applicable	3.63E+01	3.42E+01	3.01E+01	3.01E+01	1.56E+03	1.14E+01	9.54E+00	2.07E+01	8.71E+00	1.66E+01	5.81E-01
C-14 (Soil) [in Bq/kg]	Not Applicable	Not Applicable	2.24E+01	2.11E+01	1.86E+01	1.86E+01	9.60E+02	7.04E+00	5.89E+00	1.28E+01	5.37E+00	1.02E+01	3.58E-01

Notes:

Worker Receptor Locations: Calculated using short-distance dispersion method (see Section 6.1).

Public Receptor Locations: Calculated using long-distance dispersion method (see Section 6.2).

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

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9.4 Receptor Exposure Modelling - Accidents

The DecomSA examines the radiological and non-radiological dose consequences to workers and members of the public. The following subsections identify and describe the exposure pathways relevant to each of these receptor types, and present the models for calculating exposures.

9.4.1 Worker Receptors

9.4.1.1 Relevant Pathways

For accidents, relevant exposure pathways for worker receptors include inhalation, air immersion, and external radiation as shown in Table 9-29.

According to CSA N288.2 (CSA 2014b), the ingestion pathway is not considered essential for safety assessments, due to the short-term nature of events and assuming that countermeasures would be put in place after an accident to avoid exposure from ingestion of contaminated foodstuffs and water. CNL has a process for notifying members of the public of emergency countermeasures, if required.

Table 9-29 Worker Receptors – Exposure Pathways (based on CSA N288.2 (2014b))

Worker Pathways	Radionuclides	Non-Radiological Species
Inhalation	Included	Included
Air Immersion	Included	i.e. Dermal Uptake: Not Applicable
External radiation	Included (see Section 9.4.3)	Not Applicable
Water Immersion ('splash')*	Included	Not Applicable

*Applicable to Bounding Scenario 10 (stack collapse) only.

9.4.1.2 Inhalation

Radionuclides - Inhalation

Worker radionuclide inhalation doses are calculated using the following equation:

$$WD_{INH} = C_{AirW} \times INH_{AirW} \times T_{EXP_AirW} \times DC_{INHw}$$

Where,

WD_{INH}	Dose to Workers through Inhalation (mSv);
C_{AirW}	Air Concentration near Workers [varies for each bounding scenario] (Bq/m ³);
INH_{AirW}	Worker Inhalation Rate (m ³ /hr) [1.2 m ³ /hr (Lundie 2014)];
T_{EXP_AirW}	Time of Exposure (hr) [see Section 9.4.1.4];
DC_{INHw}	Inhalation Dose Coefficient (DC) for Workers [see Table 9-30].

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For C-14, select DCs are available for either particulate form or for vapour form. This assessment uses DCs for particulate form, as these impart a greater dose per-Becquerel, and therefore produce conservative dose estimates.

For tritium, DCs for HTO are used in dose calculations whenever available, as these impart a greater dose per-Becquerel and therefore produce conservative dose estimates. Where HTO DCs are not available, the most conservative available DC is used.

Dose coefficients for inhalation and air immersion - for workers - are shown in Table 9-30.

Table 9-30 Worker Receptors – Dose Coefficients

Radionuclides	Worker Receptors		
	Inhalation ^a (mSv/Bq)	Air Immersion ^b (mSv per Bq/m ³)	Water Immersion ^{c,d} (mSv per Bq/L)
H-3	4.1E-08 (Conservative DC)	0.0E+00	5.3E-10 (see discussion in Section 9.4.1.3)
C-14	5.8E-07	9.4E-12	
Cl-36	6.9E-06	6.0E-10	
Ar-39	Not Available		
Ca-41	1.9E-07	0.0E+00	
Fe-55	9.2E-07	0.0E+00	
Co-60	2.9E-05	4.3E-07	9.9E-10
Ni-59	2.2E-07	0.0E+00	
Ni-63	5.2E-07	0.0E+00	
Se-79	3.1E-06	1.4E-11	
Sr-90	1.5E-04	3.5E-10	
Zr-93	2.9E-05	0.0E+00	
Nb-93m	1.6E-06	1.1E-11	
Nb-94	4.5E-05	2.6E-07	
Tc-99	3.9E-06	1.0E-10	
Ru-106	6.2E-05	0.0E+00	
Pd-107	5.5E-07	0.0E+00	
Ag-108m	3.5E-05	2.6E-07	
Ag-108	3.5E-05 ^d	4.5E-09	
Cd-113m	1.3E-04	3.3E-10	
Sn-121m	4.2E-06	1.9E-10	
Sn-126	2.7E-05	6.6E-09	
Sb-125	4.5E-06	6.7E-08	
Te-125m	3.3E-06	1.2E-09	
I-129	5.1E-05	1.0E-09	
Cs-134	9.6E-06	2.5E-07	
Cs-135	9.9E-07	3.4E-11	
Cs-137	6.7E-06	3.3E-10	5.4E-14

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Radionuclides	Worker Receptors		
	Inhalation ^a (mSv/Bq)	Air Immersion ^b (mSv per Bq/m ³)	Water Immersion ^{c,d} (mSv per Bq/L)
Pm-147	4.7E-06	3.1E-11	
Sm-151	3.7E-06	8.9E-14	
Eu-152	3.9E-05	1.9E-07	
Eu-154	5.0E-05	2.1E-07	
Eu-155	6.5E-06	7.7E-09	
Ho-166m	1.1E-04	2.8E-07	
U-232	3.5E-02	4.2E-11	
U-233	8.7E-03	5.1E-11	
U-234	8.5E-03	2.2E-11	
U-235	7.7E-03	2.3E-08	
U-236	7.9E-03	1.4E-11	
U-238	7.3E-03	9.0E-12	
Np-237	2.1E-02	3.2E-09	
Pu-238	4.3E-02	1.3E-11	
Pu-239	4.7E-02	1.3E-11	
Pu-240	4.7E-02	1.2E-11	
Pu-241	8.5E-04	2.3E-13	
Pu-242	4.4E-02	1.0E-11	
Am-241	3.9E-02	2.4E-09	
Am-242m	3.5E-02	9.0E-11	
Am-243	3.9E-02	6.7E-09	
Cm-243	2.9E-02	1.9E-08	
Cm-244	2.5E-02	1.2E-11	
Cm-245	4.0E-02	1.3E-08	
Cm-246	4.0E-02	1.1E-11	

Notes:

^a Ref: ICRP #119 (2012) DC Compilation

^b Ref: Health Canada (1999)

^c Ref: US EPA (1993) Federal Guidance Report 12

^d note that for worker water immersions only relevant for scenario 10, and only for select isotopes, and as such only the required DCs have been reported here

^e Value for Ag-108 not available – assumed equal to Ag-108m

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Non-Radiological Stressors – Inhalation

Worker exposure to all non-radiological stressors is evaluated using a comparison of the airborne concentration of a chemical to the respective benchmark value (which is also expressed as a concentration – criteria are outlined in 4.1.6).

9.4.1.3 Immersion

Worker radionuclide air immersion doses are calculated using the following equation:

$$WD_{IMMAir} = C_{AirW} \times T_{EXP_AirW} \times DC_{IMMAirW}$$

Where,

WD_{IMMa}	Dose to Workers through Immersion in Air (mSv);
C_{AirW}	Air Concentration near Workers (Bq/m ³) [varies for each bounding scenario];
T_{EXP_AirW}	Time of Exposure (hr) [see Section 9.4.1.4];
$DC_{IMMAirW}$	Dose Coefficient for Immersion in Air, for Workers [see Table 9-30].

In addition to the air immersion dose, the dose for worker from immersion in water was also needed for scenario 10. The water immersion rate for Cs-137 and Co-60 were taken from US EPA (1993), and the dose was calculated in the same way as for air immersion, but using water concentration. However, the dose coefficient for HTO in US EPA (1993) was 0, which does not account for the potential absorption of tritiated water through the skin. So, in order to account for this gap, an external HTO immersion DC was derived (following the approach laid out for the public in N288.1-14 (CSA 2018)) as shown below:

$$DC_{HTO} = S_a * D_s * (DCF)_f * OF$$

Where:

$$S_a = \text{the skin surface area} = 2.19 \text{ m}^2 \text{ for adults (N288.1-14)}$$

$$D_s = \text{diffusion rate for water wetted skin} = 105 \frac{L}{a \text{ m}^2} \text{ (N288.1-14)}$$

$$(DCF)_f = \text{ingestion dose coefficient} = 2.0E - 11 \frac{Sv}{Bq} \text{ (N288.1-14)}$$

$$OF = \text{fraction of the year spent in the water} = 0.00011 \frac{y}{h}$$

The fraction of time spent in the water was set to be 1 hour, such that the resulting DC would be in units of $\frac{Sv}{h}$ per $\frac{Bq}{L}$.

This HTO water immersion DC was then used in the same manner as the air immersion DC, but using the water concentration.

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9.4.1.4 Exposure Time – Worker Receptors

Table 9-31 presents information on exposure times used for calculating doses to worker receptors.

It is important to note that the facility SAR outlines a bounding worker evacuation time of 15 minutes, encompassing evacuation from underground facility locations such as the boiler room. This 15 minute evacuation time is generally used for bounding scenarios that would involve worker evacuation/departure; though select scenarios also assess other evacuation times (e.g. 5-minute evacuation time, 16-hour exposure, etc.) as relevant to the location of the receptor and the nature of the bounding scenario.

Table 9-31 Worker Receptors – Exposure Times

Bounding Scenario No.	Brief Description	Exposure Time	Notes
1	Forest Fire (Rad.)	15 minutes	Regardless of the duration of the fire, the nominal 15-minute worker evacuation time is used, at which time the worker's exposure would cease.
2	Forest Fire (Non-Rad.)		
3	Tornado (Rad.)	15 minutes	Regardless of the duration of the tornado release, the nominal 15-minute worker evacuation time is used, at which time the worker's exposure would cease.
4	Tornado (Non-Rad.)		
5	Flood (Rad.)	Not Applicable – the dose calculation for this scenario is described in Section 9.5.5, it does not require a defined exposure time.	
6	Accidental Exposure (Drilling; Rad.)	32 hours	Corresponding to <i>double</i> CNL's estimated two-day drilling duration, i.e. based on four (4) 8-hour days, for a total of 32 hours.
7	Exposure (Drilling; Non-Rad.)	Not Applicable (No MAR is identified for this scenario – see Table 9-6).	
8	Indoor Fire (Rad.) [FM Room]	5 minutes	Regardless of the duration of the fire, the worker evacuation time is the same, because once evacuated, the worker's exposure would cease. For a fire in the boiler room (scenario 9b) the evacuation is expected to take 15-minutes. For a fire in the fueling machine room (scenarios 8 and 9a) it is expected to take 5 minutes to leave the area. (based on Athauda-Arachchige, 2015)
9a	Indoor Fire (Non-Rad.) [FM Room]	5 minutes	
9b	Indoor Fire (Non-Rad.) [Boiler Room]	15 minutes	
10	Stack Collapse (Rad.)	15 minutes & 1 hour for water immersion	Regardless of the duration of the release, the nominal 15-minute worker evacuation time is used, at which time the worker's exposure would cease. Worker immersion in water is assumed to continue for 1 hour, assuming that the worker takes 1 hour to reach a decontamination shower and change clothes. This is conservative.

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9.4.2 Public Receptors

9.4.2.1 Relevant Pathways

For accidents, relevant exposure pathways for public receptors primarily include:

- inhalation (see Table 9-32, as per CSA N288.2); and,
- air immersion (Table 9-32, as per CSA N288.2).

As discussed above for workers, the ingestion pathway is not considered essential for safety assessments, due to the short-term nature of accident events, and assuming that countermeasures put in place after an accident will avoid exposure from ingestion of contaminated foodstuffs and water (CSA 2014c).

Nevertheless, in response to review feedback, public receptors' exposure to contaminants via soil pathways (including ingestion of foodstuffs, dermal soil exposure, and incidental soil ingestion) is assessed, by comparing estimated soil concentrations against soil screening criteria that are protective of human health (see Section 4.1.6 and Section 9.4.2.4 for details).

Table 9-32 Public Receptors – Exposure Pathways

Public Pathways	Radionuclides	Non-Radiological Species
Inhalation	Included	Included
Immersion	Included	Not Applicable to Non-Radiological Species (Dermal exposure from soil is included)
External radiation	Not Significant <i>(relative to inhalation and immersion)</i>	Not Applicable to Non-Radiological Species
Soil Pathways	Included (in response to review feedback - see discussion above)	Included (in response to review feedback - see discussion above)

The pathways included in this assessment are described in greater in following subsections.

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9.4.2.2 Inhalation

Radionuclides - Inhalation

Doses to public receptors from inhalation of radionuclides are calculated using the following equation:

$$PD_{INH} = C_{AirP} \times INH_{AirP} \times T_{EXP_AirP} \times DC_{INHHP}$$

Where,

- PD_{INH} Dose to Members of the Public through Inhalation (mSv);
- C_{AirP} Air Concentration near Members of the Public (Bq/m³);
- INH_{AirP} Public Receptor Inhalation Rate (m³/hr) [0.96 m³/hr, converted from CSA (2018) N288.1 95th percentile value for public receptors (8,400 m³/yr)];
- T_{EXP_AirP} Time of Exposure (hr) [members of the public are assumed to be exposed for 1 hour; for longer times the release will have likely been terminated through emergency response];
- DC_{INHHP} Inhalation Dose Coefficient (DC) for Public Receptors [see Table 9-33].

For C-14, DCs are available for either particulate form or for vapour form. This assessment uses DCs for particulate form, as these impart a greater dose per-Becquerel, and therefore produce conservative dose estimates.

For tritium, DCs for HTO are used in dose calculations whenever available, as these impart a greater dose per-Becquerel and therefore produce conservative dose estimates.

Dose coefficients for inhalation and air immersion – for public receptors - are shown in Table 9-33.

Table 9-33 Public Receptors – Dose Coefficients

Radionuclides	Public Receptors		
	Inhalation ^a (mSv/Bq)	Air Immersion (Effective) ^a (mSv per Bq/m ³)	Immersion (Skin) ^a (mSv per Bq/m ³)
H-3	8.0E-08 (HTO DC)	0.00E+00	Not Applicable
C-14	6.6E-06	9.37E-12	Not Applicable
Cl-36	2.6E-05	5.97E-10	Not Applicable
Ar-39	Not Available	4.58E-10 ^b	8.76E-10
Ca-41	6.0E-07 ^b	0.00E+00 ^c	Not Applicable
Fe-55	1.4E-06	0.00E+00	Not Applicable
Co-60	3.4E-05	5.58E-07	1.62E-07
Ni-59	1.5E-06 ^b	0.00E+00 ^c	1.05E-09
Ni-63	1.9E-06	0.00E+00	5.30E-08
Se-79	2.0E-05 ^b	1.09E-12 ^c	Not Applicable
Sr-90	1.1E-04	3.21E-09 ^d	Not Applicable
Zr-93	2.5E-05 ^b	0.00E+00 ^c	Not Applicable
Nb-93m	6.5E-06 ^b	1.60E-11 ^c	Not Applicable

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Radionuclides	Public Receptors		
	Inhalation ^a (mSv/Bq)	Air Immersion (Effective) ^a (mSv per Bq/m ³)	Immersion (Skin) ^a (mSv per Bq/m ³)
Nb-94	3.7E-05	3.37E-07	Not Applicable
Tc-99	1.3E-05	1.03E-10	Not Applicable
Ru-106	1.1E-04	4.95E-08 ^d	Not Applicable
Pd-107	2.0E-06 ^b	0.00E+00 ^c	Not Applicable
Ag-108m	8.7E-05 ^b	2.81E-07 ^c	Not Applicable
Ag-108	8.7E-05 ^e	3.34E-09 ^c	Not Applicable
Cd-113m	2.4E-04 ^b	2.50E-11 ^c	Not Applicable
Sn-121m	1.5E-05 ^b	2.17E-10 ^c	Not Applicable
Sn-126	1.0E-04 ^b	7.60E-09 ^c	Not Applicable
Sb-125	1.6E-05	8.76E-08	Not Applicable
Te-125m	1.3E-05 ^b	1.58E-09	Not Applicable
I-129	2.0E-04	1.31E-09	4.76E-08
Cs-134	7.3E-06	3.31E-07	Not Applicable
Cs-135	9.9E-07	3.42E-11	Not Applicable
Cs-137	5.4E-06	1.20E-07 ^d	Not Applicable
Pm-147	1.8E-05	3.13E-11	Not Applicable
Sm-151	1.0E-05 ^b	1.30E-13 ^c	Not Applicable
Eu-152	1.0E-04	2.48E-07	1.32E-07
Eu-154	1.5E-04	2.68E-07	3.31E-08
Eu-155	2.3E-05	1.00E-08	2.25E-07
Ho-166m	2.5E-04 ^b	3.04E-07 ^c	2.58E-07
U-232	2.4E-02	5.48E-11	1.39E-07
U-233	1.1E-02	6.64E-11	Not Applicable
U-234	1.1E-02	2.87E-11	Not Applicable
U-235	1.0E-02	3.03E-08	Not Applicable
U-236	1.0E-02	1.82E-11	Not Applicable
U-238	9.4E-03	1.18E-11	Not Applicable
Np-237	4.0E-02	4.16E-09	9.87E-09
Pu-238	7.4E-02	1.63E-11	Not Applicable
Pu-239	7.7E-02	1.63E-11	Not Applicable
Pu-240	7.7E-02	1.60E-11	Not Applicable
Pu-241	9.7E-04	2.97E-13	Not Applicable
Pu-242	7.3E-02	1.36E-11	Not Applicable
Am-241	6.9E-02	3.16E-09	Not Applicable
Am-242m	1.5E-01 ^b	1.14E-10 ^c	Not Applicable
Am-243	6.8E-02	8.66E-09	Not Applicable
Cm-243	1.5E-01 ^b	2.12E-08 ^c	Not Applicable
Cm-244	5.7E-02	1.59E-11	Not Applicable
Cm-245	1.8E-01 ^b	1.43E-08 ^c	Not Applicable
Cm-246	1.8E-01 ^b	1.61E-11 ^c	Not Applicable

Notes:

^a Ref: CSA N288.1 (2018).

^b Not available in CSA N288.1 (2018); obtained from ICRP #119 (2012) DC Compilation, for public receptors.

^c Not available in CSA N288.1 (2018) or ICRP (2012); obtained from US EPA (1993) Federal Guidance Report 12.

^d Indicates a DC that includes the contribution of progeny (i.e. a "DCF+" value from CSA N288.1 (2018)).

^e DC for Ag-108 not available; assumed equal to DC for Ag-108m.

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Non-Radiological Stressors – Inhalation

Similar to workers, public receptors' exposure to all non-radiological stressors is evaluated using a comparison of the airborne concentration of a chemical to the respective benchmark value (which is also expressed as a concentration – criteria are outlined in Section 4.1.6).

9.4.2.3 Immersion

Radionuclides - Immersion

Doses to public receptors from immersion in air containing radionuclides are calculated using the following equation:

$$PD_{IMMa} = C_{AirP} \times T_{EXP_AirP} \times DC_{IMMAirP}$$

Where,

PD_{IMMa}	Dose to Public Receptors from Immersion in Air (mSv);
C_{AirP}	Air Concentration near Public Receptors (Bq/m ³);
T_{EXP_AirP}	Time of Exposure (hr);
$DC_{IMMAirP}$	Air Immersion Dose Coefficient for Public Receptors [see Table 9-33].

For tritium, DCs for HTO are used throughout dose calculations.

9.4.2.4 Soil Related Pathway – Public Receptors

Public receptors may be exposed to contaminants in soil through the following pathways:

- Dermal exposure to soil;
- Incidental ingestion of soil; and,
- Consumption of food that has taken up contaminants from the soil.

For radioactive contaminants, soil concentrations are first evaluated by comparing calculated soil concentrations to corresponding Unconditional Clearance Levels (UCLs) (presented in Section 5.1.1.5) and the sum of screening indices at each location is compared to 1.

For non-radioactive contaminants, soil exposure is evaluated by comparing calculated soil concentrations to corresponding soil criteria that are protective of human health (presented in Section 4.1.6).

9.4.2.5 Exposure Time – Public Receptors

Table 9-34 presents information on exposure times used for calculating doses to public receptors.

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Table 9-34 Public Receptors – Exposure Times

Bounding Scenario No.	Brief Description	Exposure Time	Notes
1	Forest Fire (Rad.)	1 hour	Public receptors are assessed using a 1-hour exposure period, after which the exposure is assumed to have subsided by the receptor evacuating the area or the fire releases being controlled through emergency response.
2	Forest Fire (Non.-Rad.)		The 1-hour exposure period represents the time for CNL to notify nearby resident receptors that an accident involving releases has occurred and communicate the necessary countermeasures. Because this 1-hour exposure time is equal to the fire duration, the receptor is exposed to the entire released source term (dispersed according to their location ADF) within this 1-hour period. This is conservative.
3	Tornado (Rad.)	1 hour	Public receptors are assessed using a 1 hour exposure period, after which the exposure is assumed to have subsided by the receptor evacuating the area or the tornado event ending.
4	Tornado (Non.-Rad.)		The 1-hour exposure period represents the time for CNL to notify nearby resident receptors that an accident involving releases has occurred and communicate the necessary countermeasures. Because this 1-hour exposure time is equal to the tornado duration, the receptor is exposed to the entire released source term (dispersed according to their location ADF) within this 1-hour period. This is conservative.
5	Flood (Rad.)	<i>Not Applicable</i>	
6	Exposure (Drilling; Rad.)	Not Applicable – public receptors are not involved in this scenario. The receptors engaged in such activities are workers.	
7	Exposure (Drilling; Non.-Rad.)		
8	Indoor Fire (Rad.) (FM Room)	1 hour	Public receptors are assessed using a 1 hour exposure period, after which the exposure is assumed to have subsided by the fire event ending.
9a	Indoor Fire (Non.-Rad.) (FM Room)	1 hour	The 1-hour exposure period represents the time for CNL to notify nearby resident receptors that an accident involving releases has occurred and communicate the necessary countermeasures.
9b	Indoor Fire (Non.-Rad.) (Boiler Room)	1 hour	Because this 1-hour exposure time is equal to the fire duration, the receptor is exposed to the entire released source term (dispersed according to their location ADF) within this 1-hour period. This is conservative.
10	Stack Collapse (Rad.)	1 hour	Note that the corresponding release rate for this scenario is instantaneous, not over time. Receptor exposure is calculated using a 1-hour exposure time in which the receptor is exposed to the entire released source term (dispersed according to their location ADF).

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9.4.2.6 Age Group – Public Receptors

As discussed previously, the inhalation dose to members of the public is dependent on a number of different variables, including inhalation rate and dose coefficient, which are age dependent. The values selected for these variables were the highest value across all age groups, i.e. adult inhalation rate and infant dose coefficients. This conservative treatment of the variables indirectly accounts for age groups, as the total dose calculated will be higher than any individual age group.

9.4.3 External Gamma

External gamma calculations were performed for Bounding Scenario 6 (accidental exposure to radioactivity).

This scenario has similar conditions as used for normal drilling operations (discussed in Section 8.4.4.4 to 8.4.4.6) and therefore builds off the results of that simulation, however, it is assumed that the worker will remain in that location for 32 hours in contrast to the normal 16 hours (thereby increasing their exposure time to the dose rate). This is conservative, as it assumes that the worker is standing directly above the hole and is exposed for the entire 32-hour drilling period.

This calculation builds off of the *per-hour* dose rate estimates presented in Table 8-2.

9.5 Consequence (Dose) Assessment

This section presents the estimated total dose results for each bounding scenario. For radiological bounding scenarios, total doses are summed and presented. For non-radiological scenarios, hazard indices (i.e. the product of the estimated concentration divided by the criterion) are presented.

9.5.1 Bounding Scenario 1: Forest Fire and Release of Radioactivity

Table 9-35 presents the soil screening indices for bounding scenario 1, for each receptor locations. Screening indices are calculated by comparing estimated soil concentrations to corresponding Unconditional Clearance Levels, as described in Section 9.4. See Appendix E for calculation details. Table 9-36 presents the total dose estimates for bounding scenario 1, for each receptor location. Total dose is calculated as the sum of immersion dose and inhalation dose, across all radionuclides, as outlined in Section 9.4. See Appendix E for dose calculation details.

Table 9-35 Bounding Scenario 1 – Forest Fire – Soil Screening Indices

Parameter	Soil Screening Index <i>[unitless; comparison of estimated soil concentrations to Unconditional Clearance Levels]</i>												
	<i>Worker* (Near-Field)</i>	<i>Worker* (Far-Field)</i>	<i>Res. 1</i>	<i>Res. 2</i>	<i>Res. 3</i>	<i>Rec. (Res. 4)</i>	<i>Guardhouse</i>	<i>Rapides Des Joachims</i>	<i>Pt. Stewart Res.</i>	<i>Cottage</i>	<i>Rolphon Res.</i>	<i>Mackey Beef Farm</i>	<i>Bass Lake Beef Farm</i>
H-3 (Soil)	Not Applicable	Not Applicable	5.76E-04	5.76E-04	6.58E-04	5.26E-04	8.56E-03	4.77E-04	4.28E-04	4.61E-04	6.42E-04	1.97E-04	3.45E-04
C-14 (Soil)	Not Applicable	Not Applicable	1.90E-04	1.90E-04	2.18E-04	1.74E-04	2.83E-03	1.58E-04	1.41E-04	1.52E-04	2.12E-04	6.53E-05	1.14E-04
Sum of Fractions	Not Applicable	Not Applicable	7.66E-04	7.66E-04	8.76E-04	7.01E-04	1.14E-02	6.35E-04	5.69E-04	6.13E-04	8.54E-04	2.63E-04	4.60E-04

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

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Table 9-36 Bounding Scenario 1 – Forest Fire - Total Dose

Total Dose (Inhalation + Immersion) [in mSv]	
Worker (Near-Field)	1.48E-05
Worker (Far-Field)	1.48E-05
Res. 1	7.83E-07
Res. 2	7.83E-07
Res. 3	8.94E-07
Rec. (Res. 4)	7.15E-07
Guardhouse	1.16E-05
Rapides Des Joachims	6.48E-07
Pt. Stewart Res.	5.81E-07
Cottage	6.26E-07
Rolphton Res.	8.72E-07
Mackey Beef Farm	2.68E-07
Bass Lake Beef Farm	4.70E-07

9.5.2 Bounding Scenario 2: Forest Fire and Release of Chemical Contaminants

Table 9-37 presents the screening index results for bounding scenario 2, for each receptor location. Screening indices are calculated by comparing estimated airborne and soil concentrations to corresponding worker or public concentration criteria, as described in Section 9.4. See Appendix E for calculation details. As discussed in Section 9.2.1, asbestos and lead are identified as MAR.

Table 9-37 Bounding Scenario 2 – Forest Fire - Screening Indices

Hazardous Chemicals	Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	<i>Worker* (Near-Field)</i>	<i>Worker* (Far-Field)</i>	<i>Res. 1</i>	<i>Res. 2</i>	<i>Res. 3</i>	<i>Rec. (Res. 4)</i>	<i>Guardhouse</i>	<i>Rapides Des Joachims</i>	<i>Pt. Stewart Res.</i>	<i>Cottage</i>	<i>Rolphon Res.</i>	<i>Mackey Beef Farm</i>	<i>Bass Lake Beef Farm</i>
Asbestos (Inhalation)	6.00E-01	6.00E-01	4.20E-03	4.20E-03	4.80E-03	3.84E-03	6.24E-02	3.48E-03	3.12E-03	3.36E-03	4.68E-03	1.44E-03	2.52E-03
Lead (Inhalation)	2.33E-05	2.33E-05	1.09E-04	1.09E-04	1.24E-04	9.93E-05	1.61E-03	9.00E-05	8.06E-05	8.69E-05	1.21E-04	3.72E-05	6.51E-05
Lead (Soil)	Not Applicable	Not Applicable	9.77E-10	9.77E-10	1.12E-09	8.93E-10	1.45E-08	8.09E-10	7.26E-10	7.82E-10	1.09E-09	3.35E-10	5.86E-10

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

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9.5.3 Bounding Scenario 3: Tornado and Release of Radioactivity

Table 9-38 presents the soil screening indices for bounding scenario 3, for each receptor locations. Screening indices are calculated by comparing estimated soil concentrations to corresponding Unconditional Clearance Levels, as described in Section 9.4. See Appendix E for calculation details. Table 9-39 presents the total dose estimates for bounding scenario 3, for each receptor location. These results are based on an EF-2 class tornado. Total dose is calculated as the sum of immersion dose and inhalation dose, across all radionuclides, as outlined in Section 9.4. See Appendix E for dose calculation details.

Table 9-38 Bounding Scenario 3 – Tornado (EF-2)– Soil Screening Indices

Parameter	Soil Screening Index <i>[unitless; comparison of estimated soil concentrations to Unconditional Clearance Levels]</i>												
	<i>Worker* (Near-Field)</i>	<i>Worker* (Far-Field)</i>	<i>Res. 1</i>	<i>Res. 2</i>	<i>Res. 3</i>	<i>Rec. (Res. 4)</i>	<i>Guardhouse</i>	<i>Rapides Des Joachims</i>	<i>Pt. Stewart Res.</i>	<i>Cottage</i>	<i>Rolphon Res.</i>	<i>Mackey Beef Farm</i>	<i>Bass Lake Beef Farm</i>
H-3 (Soil)	Not Applicable	Not Applicable	3.76E-11	3.76E-11	3.76E-11	3.76E-11	3.76E-11	1.69E-03	3.76E-11	3.76E-11	1.69E-03	5.64E-05	5.64E-05
C-14 (Soil)	Not Applicable	Not Applicable	5.44E-14	5.44E-14	5.44E-14	5.44E-14	5.44E-14	2.45E-06	5.44E-14	5.44E-14	2.45E-06	8.16E-08	8.16E-08
Sum of Fraction	Not Applicable	Not Applicable	3.76E-11	3.76E-11	3.76E-11	3.76E-11	3.76E-11	1.69E-03	3.76E-11	3.76E-11	1.69E-03	5.64E-05	5.64E-05

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

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Table 9-39 Bounding Scenario 3 – Tornado (EF-2) - Total Dose

Total Dose (Inhalation + Immersion) [mSv]	
Worker (Near-Field)	6.43E-15
Worker (Far-Field)	6.43E-15
Res. 1	4.02E-14
Res. 2	4.02E-14
Res. 3	4.02E-14
Rec. (Res. 4)	4.02E-14
Guardhouse	4.02E-14
Rapides Des Joachims	1.81E-06
Pt. Stewart Res.	4.02E-14
Cottage	4.02E-14
Rolphon Res.	1.81E-06
Mackey Beef Farm	6.02E-08
Bass Lake Beef Farm	6.02E-08

9.5.4 Bounding Scenario 4: Tornado and Release of Chemical Contaminants

Table 9-40 presents the screening indexes for bounding scenario 4, for each receptor location. These results are based on a conservative worst-case EF-2 class tornado. Screening indices are calculated by comparing estimated airborne and soil concentrations to corresponding worker or public concentration criteria, as described in Section 9.4. See Appendix E for calculation details. As discussed in Section 9.2.1, asbestos and lead are identified as MAR.

Table 9-40 Bounding Scenario 4 – Tornado (EF-2) - Screening Indexes

Hazardous Chemicals	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	<i>Worker* (Near-Field)</i>	<i>Worker* (Far-Field)</i>	<i>Res. 1</i>	<i>Res. 2</i>	<i>Res. 3</i>	<i>Rec. (Res. 4)</i>	<i>Guardhouse</i>	<i>Rapides Des Joachims</i>	<i>Pt. Stewart Res.</i>	<i>Cottage</i>	<i>Rolphon Res.</i>	<i>Mackey Beef Farm</i>	<i>Bass Lake Beef Farm</i>
Asbestos (Inhalation)	1.47E-08	1.47E-08	1.47E-08	1.47E-08	1.47E-08	1.47E-08	1.47E-08	6.60E-01	1.47E-08	1.47E-08	6.60E-01	2.20E-02	2.20E-02
Lead (Inhalation)	9.31E-14	9.31E-14	6.20E-11	6.20E-11	6.20E-11	6.20E-11	6.20E-11	2.79E-03	6.20E-11	6.20E-11	2.79E-03	9.31E-05	9.31E-05
Lead (Soil)	Not Applicable	Not Applicable	5.58E-16	5.58E-16	5.58E-16	5.58E-16	5.58E-16	2.51E-08	5.58E-16	5.58E-16	2.51E-08	8.37E-10	8.37E-10

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

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9.5.5 Bounding Scenario 5: Major Flood and Release of Radioactivity

The effects of external flooding due to a precipitation event are assessed in the facility SAR (Athauda-Arachchige 2015; Section 10.5.3.2). The facility SAR acknowledges that external flooding could occur as a result of heavy precipitation, high river-water levels, or failure of water-controlled structures (dams). However, localized flooding due to surface run-off of meteorological extremes and or spring thaw conditions is extremely unlikely because of the good drainage provided by the site topography. The NPD site’s landscape diverts heavy precipitation from the facility to the Ottawa River.

The facility SAR notes that the anticipated levels of loose contamination released from such an event are minimal. The conclusion reached by the facility SAR is that the doses that could result from liquid releases are low (with no discernable effects) due to the small source term and large quantity of water, and therefore, the dose acceptance criteria (see Section 4.1.5) have been met.

It is important to note that as part of planned decommissioning, the facility roof will be removed. However, chronologically, the lower levels of the facility – including the reactor vault, boiler room, and FM room – will already be grouted and solidified before roof removal occurs.

9.5.6 Bounding Scenario 6: Accidental Exposure to Radioactivity

Table 9-41, below, presents the gamma dose rates that a worker is estimated to be exposed to during an accidental exposure scenario involving 32 hours of drilling (in contrast to the normal 16 hours of drilling). The methodology used to calculate the total gamma dose is presented in Section 8.4.4.4, and builds off of the *per-hour* dose rate estimates presented in Table 8-2.

Table 9-41 Scenario 6 - 32-hour Drilling - Gamma Dose

Location	Total Dose (mSv)	Dose Limit (mSv) (Max Per Year)	Dose Limit (mSv) (Maximum per 5 Years)	Action Dose Level (mSv) (Per 4-week Period)
Hole A <i>(including ambient)</i>	1.053	50	100	6
Hole B <i>(including ambient)</i>	0.672	50	100	6
Hole C <i>(including ambient)</i>	0.672	50	100	6

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Table 9-42, below, shows the dose received from drilling dust inhalation and air immersion for workers located in the near-field and far-field locations. This dose is calculated as the sum of the immersion dose and inhalation dose, across all radionuclides (see Section 9.4 for description of dose calculation methods). Further details of the dose calculation components are available in Appendix E.

Table 9-42 Scenario 6 – 32-hour Drilling – Dust Inhalation and Immersion Dose

Receptor	Total Dose from Drilling Dust (Inhalation + Immersion) [in mSv]	
	Worker (Near-Field)	Worker (Far-Field)
H-3	1.29E-03	1.26E-03
C-14	3.10E-04	3.03E-04
Ag-108m	3.10E-09	3.04E-09
Ba-133	6.45E-08	6.32E-08
Ca-41	3.22E-05	3.15E-05
Cd-113m	6.21E-11	6.09E-11
Cl-36	2.67E-05	2.62E-05
Co-60	2.08E-01	2.03E-01
Cs-135	8.50E-13	8.33E-13
Cs-137	1.20E-05	1.17E-05
Eu-152	1.07E-01	1.05E-01
Eu-154	2.74E-05	2.69E-05
La-137	2.62E-12	2.57E-12
Nb-93m	8.01E-11	7.84E-11
Nb-94	1.63E-07	1.60E-07
Ni-59	8.22E-09	8.05E-09
Ni-63	7.90E-04	7.74E-04
Pu-238	7.94E-01	7.78E-01
Pu-239	2.15E-02	2.11E-02
Pu-240	2.39E-08	2.34E-08
Sb-125	1.57E-12	1.54E-12
Se-79	1.42E-13	1.39E-13
Sm-151	4.53E-08	4.44E-08
Sn-121m	1.49E-11	1.46E-11
Sn-126	1.99E-12	1.95E-12
Sr-90	3.37E-06	3.30E-06
Tc-99	3.42E-11	3.35E-11
Th-229	4.95E-07	4.85E-07
Th-230	2.80E-06	2.75E-06
Th-232	2.93E-04	2.87E-04
U-233	1.11E-05	1.08E-05
U-234	8.22E-05	8.06E-05
U-235	3.46E-06	3.39E-06
U-236	1.79E-09	1.76E-09
U-238	7.14E-05	7.00E-05
Zr-93	1.81E-09	1.77E-09
Total	1.13E+00	1.11E+00

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Table 9-43, below, presents the total estimated dose received by a worker engaged in the 32-hour drilling activity – i.e. the sum of the dust dose (inhalation and immersion, from Table 9-42) and the gamma dose (from Table 9-41). See Appendix E for calculation details. Gamma dose contribution is based on the dose rate from Hole A because it is the highest (more conservative) among Hole A, B, and C locations.

Table 9-43 Scenario 6 – 32-hour Drilling – Total Dose
(The sum of gamma, inhalation, and immersion)

Receptor	Total Dose [in mSv]	
	Worker (Near-Field)	Worker (Far-Field)
Total	2.19E+00	2.16E+00

9.5.7 Bounding Scenario 7: Accidental Exposure to Chemicals

Bounding scenario 7 is the same as bounding scenario 6, but focuses on exposure to hazardous chemicals rather than radioactivity.

As discussed in Section 9.2.1, there is no exposure route to hazardous chemicals from the assessed activities. This is due to the timing of activities and the form of the hazardous chemicals: asbestos will have been abated and removed before drilling occurs; lead is present in shielding blocks and other equipment (e.g. shielding blankets); mercury is present as a residual contaminant in the sump; and, PCBs are present in light ballasts, all of which are equipment that will not be drilled or cut open. Therefore, no exposure to hazardous chemicals is expected in this bounding scenario.

9.5.8 Bounding Scenario 8: Underground (Indoor) Fire and Release of Radioactivity

Table 9-44 presents the soil screening indices for bounding scenario 8, for each receptor locations. Screening indices are calculated by comparing estimated soil concentrations to corresponding Unconditional Clearance Levels, as described in Section 9.4. See Appendix E for calculation details. Table 9-45 presents the total dose estimates for bounding scenario 8, for each receptor location. Total dose is calculated as the sum of immersion dose and inhalation dose, across all radionuclides, as outlined in Section 9.4. See Appendix E for dose calculation details.

Table 9-44 Bounding Scenario 8 – Underground (Indoor) Fire – Soil Screening Indices

Parameter	Soil Screening Index <i>[unitless; comparison of estimated soil concentrations to Unconditional Clearance Levels]</i>												
	<i>Worker* (Near-Field)</i>	<i>Worker* (Far-Field)</i>	<i>Res. 1</i>	<i>Res. 2</i>	<i>Res. 3</i>	<i>Rec. (Res. 4)</i>	<i>Guardhouse</i>	<i>Rapides Des Joachims</i>	<i>Pt. Stewart Res.</i>	<i>Cottage</i>	<i>Rolphon Res.</i>	<i>Mackey Beef Farm</i>	<i>Bass Lake Beef Farm</i>
Cs-137 (Soil)	Not Applicable	Not Applicable	5.47E-07	5.47E-07	6.25E-07	5.00E-07	8.12E-04	4.53E-07	4.06E-07	4.37E-07	6.09E-07	1.87E-07	3.28E-07
Co-60 (Soil)	Not Applicable	Not Applicable	8.61E-08	8.61E-08	9.84E-08	7.87E-08	1.28E-04	7.13E-08	6.39E-08	6.89E-08	9.59E-08	2.95E-08	5.16E-08
Sum of Fractions	Not Applicable	Not Applicable	6.33E-07	6.33E-07	7.23E-07	5.78E-07	9.40E-06	5.24E-07	4.70E-07	5.06E-07	7.05E-07	2.17E-07	3.80E-07

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

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Table 9-45 Scenario 8 Total Dose (Inhalation and Immersion)

Total Dose (Inhalation and Immersion) [in mSv]	
Worker (Near-Field)	1.12E-03
Worker (Far-Field)	1.10E-03
Res. 1	7.99E-11
Res. 2	7.99E-11
Res. 3	9.13E-11
Rec. (Res. 4)	7.30E-11
Guardhouse	1.19E-09
Rapides Des Joachims	6.62E-11
Pt. Stewart Res.	5.93E-11
Cottage	6.39E-11
Rolphon Res.	8.90E-11
Mackey Beef Farm	2.74E-11
Bass Lake Beef Farm	4.79E-11

9.5.9 Bounding Scenario 9: Underground (Indoor) Fire and Release of Chemicals

Table 9-46 and Table 9-47 present the total dose rates for bounding scenario 9, for each receptor location. Screening indices are calculated by comparing estimated airborne and soil concentration to corresponding worker or public concentration criteria, as described in Section 9.4. See Appendix E for calculation details. As discussed in Section 9.2.1, PCBs (and therefore resulting dioxins and furans) are not identified as MAR, whereas asbestos is identified as MAR but with a DR of zero.

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Table 9-46 Scenario 9a (FM Room) - Screening Index

Hazardous Chemicals	Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
Lead (Inhalation)	7.95E-01	7.79E-01	4.07E-06	4.07E-06	4.66E-06	3.72E-06	6.05E-05	3.38E-06	3.03E-06	3.26E-06	4.54E-06	1.40E-06	2.44E-06
Lead (Soil)	Not Applicable	Not Applicable	4.40E-09	4.40E-09	5.03E-09	4.02E-09		3.64E-09	3.27E-09	3.52E-09	4.90E-09	1.51E-09	2.64E-09

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

Table 9-47 Scenario 9b (Boiler Room) - Inhalation Screening Index

Hazardous Chemicals	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
Asbestos	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mercury	2.39E-01	2.38E-01	6.48E-07	6.48E-07	7.41E-07	5.93E-07	9.63E-06	5.37E-07	4.81E-07	5.19E-07	7.22E-07	2.22E-07	3.89E-07

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9.5.10 Bounding Scenario 10: Stack Collapse and Release of Radioactivity

Table 9-48 presents the soil screening indices for bounding scenario 10, for each receptor locations. Screening indices are calculated by comparing estimated soil concentrations to corresponding Unconditional Clearance Levels, as described in Section 9.4. See Appendix E for calculation details.

Table 9-49 presents the total dose estimates for bounding scenario 10, for each receptor location, based on air concentrations and stack water exposure. Total dose is calculated as the sum of air immersion dose and inhalation dose, across all radionuclides, as outlined in Section 9.4. Additionally, for the worker, the water immersion dose for the stack water splashing is also included in the total dose. See Appendix E for dose calculation details.

Table 9-48 Bounding Scenario 10 – Stack Collapse – Soil Screening Indices

Radionuclide	Soil Screening Index <i>[unitless; comparison of estimated soil concentrations to Unconditional Clearance Levels]</i>												
	<i>Worker* (Near-Field)</i>	<i>Worker* (Far-Field)</i>	<i>Res. 1</i>	<i>Res. 2</i>	<i>Res. 3</i>	<i>Rec. (Res. 4)</i>	<i>Guardhouse</i>	<i>Rapides Des Joachims</i>	<i>Pt. Stewart Res.</i>	<i>Cottage</i>	<i>Rolphon Res.</i>	<i>Mackey Beef Farm</i>	<i>Bass Lake Beef Farm</i>
H-3 (Soil)	Not Applicable	Not Applicable	4.54E-04	4.28E-04	3.76E-04	3.76E-04	1.56E-02	1.43E-04	1.19E-04	2.59E-04	1.09E-04	2.07E-04	7.26E-06
C-14 (Soil)	Not Applicable	Not Applicable	2.80E-02	2.64E-02	2.32E-02	2.32E-02	9.60E-01	8.80E-03	7.36E-03	1.60E-02	6.72E-03	1.28E-02	4.48E-04
Sum of Fractions	Not Applicable	Not Applicable	2.28E-02	2.15E-02	1.89E-02	1.89E-02	9.75E-01	7.15E-03	5.98E-03	1.30E-02	5.46E-03	1.04E-02	3.64E-04

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

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Table 9-49 Scenario 10 Total Dose (Inhalation and Immersion, and Splash (for worker))

Total Dose [in mSv]	
Worker (Near-Field)	3.74E-04
Worker (Far-Field)	3.74E-04
Res. 1	1.20E-03
Res. 2	1.14E-03
Res. 3	9.98E-04
Rec. (Res. 4)	9.98E-04
Guardhouse	5.16E-02
Rapides Des Joachims	3.79E-04
Pt. Stewart Res.	3.17E-04
Cottage	6.88E-04
Rolphton Res.	2.89E-04
Mackey Beef Farm	5.51E-04
Bass Lake Beef Farm	1.93E-05

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9.6 Frequency Assessment

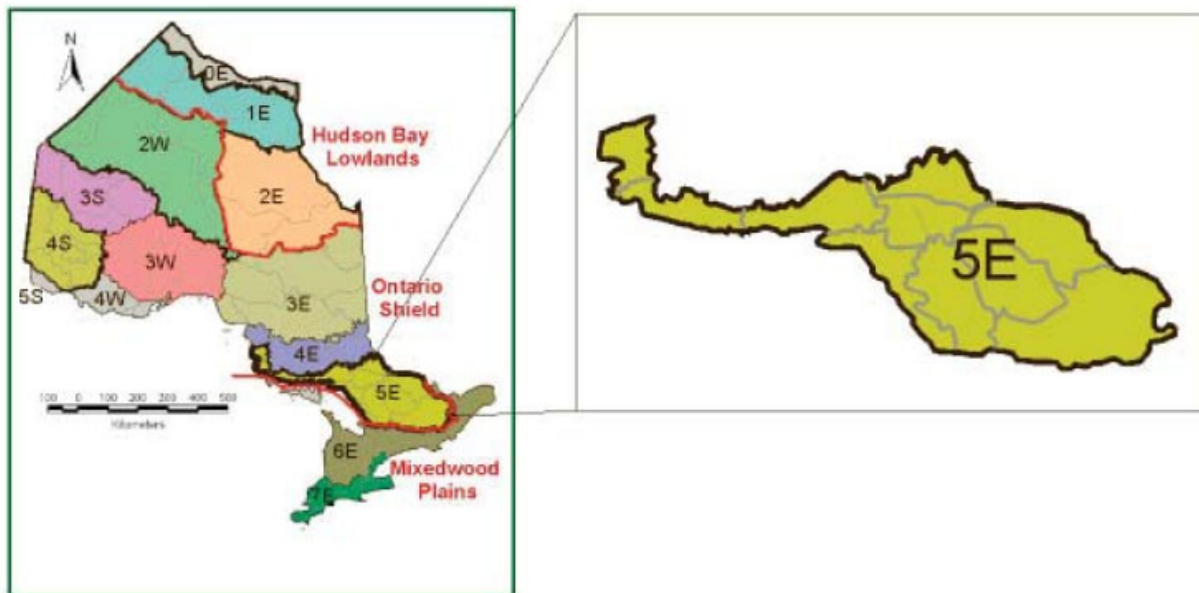
This section examines the likelihood of the identified bounding scenarios.

9.6.1 Scenarios 1 and 2: Forest Fire and Release of Radioactive and Chemical Contaminants

Forest fire frequency at NPD is estimated using the approach and data outlined in Wotton and Martell (2005). Overall, Wotton and Martell (2005) developed a model for calculating: (1) the probability that a lightning strike causes a sustainable ignition on the forest floor and (2) the probability of an ignition being detected and reported to the fire management agency for each ecoregion in the province of Ontario.

NPD is located in Ecoregion 5E of Ontario (Crins *et al.* 2009), which is denoted as Ecoregion 98 in Wotton and Martell (2005). The total area of Ecoregion 5E is 7.45×10^6 hectares (74,500 km²) (Crins *et al.* 2009).

Figure 9-1 The Ecoregions of Ontario (Crins *et al.* 2009)



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A simple approach was taken to estimate the average frequency of fires caused by lightning strikes, using data presented in Wotton and Martell (2005). Table 3 of Wotton and Martell (2005) indicates that there were 622 reported lightning caused fires in Ecoregion 5E over the 9-year period 1992–2001 (excluding 1999). This is equivalent to an annual average of 69 lightning-caused fires. The range of annual observed fires during this time period was 17 to 167.

The frequency of lightning caused fires in the region of NPD were determined from these data. Using the average annual number of lightning-caused fires (i.e. 69) and the area of Ecoregion 5E (i.e. 74,500 km²), the annual frequency of observed fires (due to lightning strikes) is 9.3×10^{-4} per square kilometer in Ecoregion 5E. Based on the data in Table 3 of Wotton and Martell (2005), the annual frequency of observed fires (due to lightning strikes) ranges from 2.3×10^{-4} to 2.2×10^{-3} per square kilometer.

These frequency values can be used to determine the probability of a lightning caused fire during the NPD decommissioning period when a forest fire could potentially lead to contaminant releases from NPD. Note that in using this frequency, it is assumed that the forest fires are caused by lightning strikes.

Regarding the area of the site, the main site area is about 1.25 km², based on Figure 3-3. Thus, the average frequency of a lightning-caused fire occurring given the site area is 1.2×10^{-3} per year, with a range of 2.9×10^{-4} to 2.8×10^{-3} per year.

9.6.2 Scenarios 3 and 4: Tornado and Release of Radioactivity and of Chemical Contaminants

Prior to April 2013, tornadoes were officially ranked in Canada using the Fujita (F) scale. The enhanced Fujita (EF) scale began operational use in the United States on February 1, 2007, followed by Canada on April 1, 2013 replacing the Fujita scale.

The Wind Science and Engineering Research Center at Texas Tech University developed the EF scale to address the major limitations of the original Fujita scale with regard to the degree of damage at various wind speed categories. The WISE report indicated that winds slower than originally estimated could still cause the respective degrees of damage, thus the wind speeds on the original Fujita scale were deemed as being too high. The wind speed associated with the new scale for scale 5 tornado (EF5) was found to be sufficient to cause the damage previously ascribed to the F5 range of wind speeds (WISE TTU, 2004).

The wind speed associated with Fujita and enhanced Fujita scales are shown in Table 9-50. The enhanced F-scale is still an estimate of wind speed (not measurements) based on damage.

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Table 9-50 Wind Speed for Fujita and Enhanced Fujita Scales

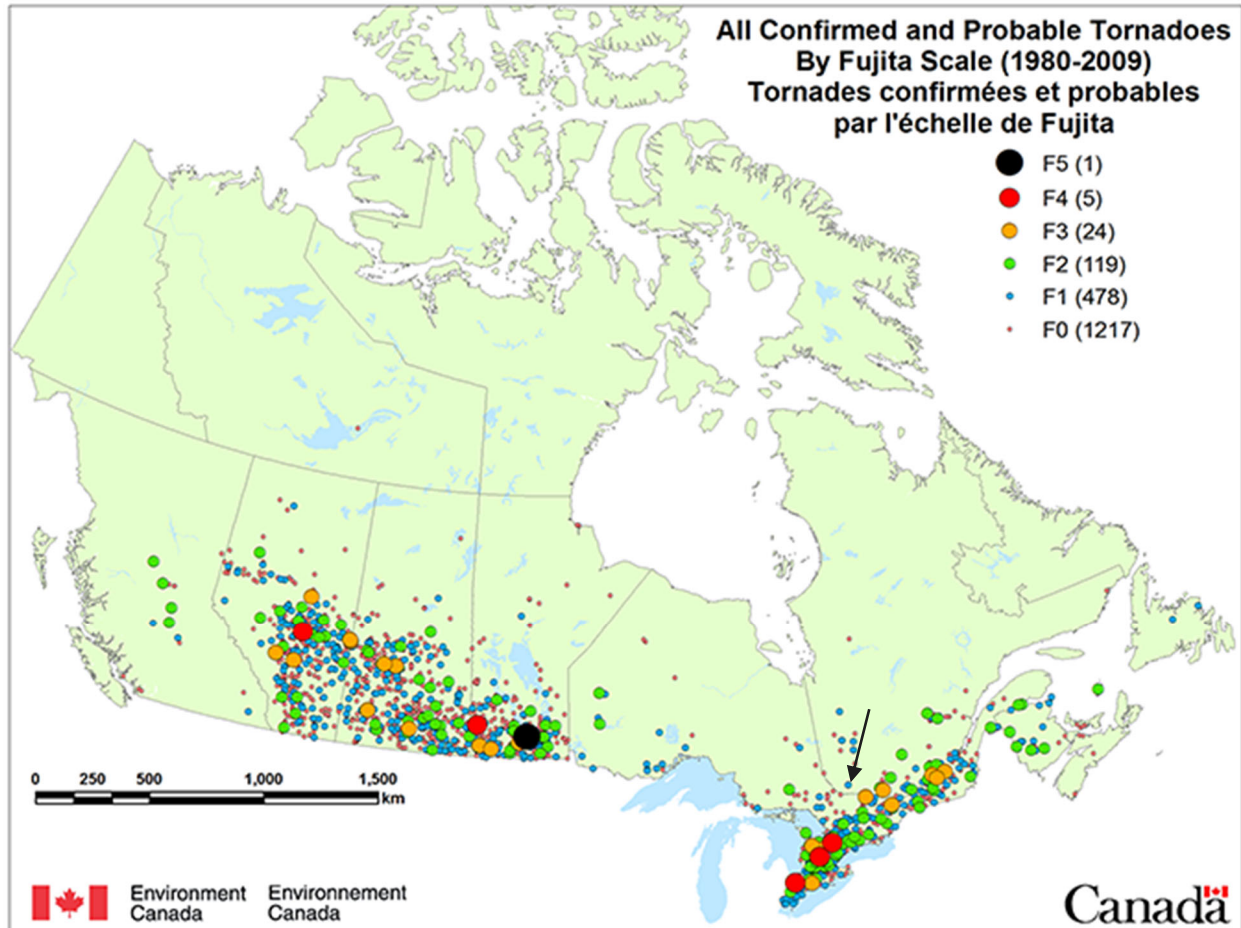
Fujita Scale			Derived Enhanced Fujita Scale		Operational Enhanced Fujita Scale	
F Number	Fastest 1/4-mile (mph)	3 Second Gust (mph)	EF Number	3 Second Gust (mph)	EF Number	3 Second Gust (mph)
0	40-72	45-78	0	65-85	0	65-85
1	73-112	79-117	1	86-109	1	86-110
2	113-157	118-161	2	110-137	2	111-135
3	158-207	162-209	3	138-167	3	136-165
4	208-260	210-261	4	168-199	4	166-200
5	261-318	262-317	5	200-234	5	Over 200

The occurrence of tornadoes within a distance of 200 km of the site was assessed using data obtained from the Emergency Management Ontario (EMO 2016). Information from prior to 1918 may not be complete, and may cause an underestimation of the annual frequency of the occurrence of tornadoes. As can be seen from Figure 9-2, the site is located within the tornado alley in Canada. Therefore, using Canadian average tornado statistics to calculate the tornado frequency would largely underestimate this frequency at the site. Therefore, we use tornado statistics for southern Ontario for this calculation. Confirmed and probable tornados in Ontario between 1918 and 2009 are shown in Figure 9-3.

The number of confirmed and probable tornadoes from 1976 to 2015 in Southern Ontario is shown in Table 9-51. Information from prior to 1976 may not be complete and may cause an underestimation of the annual frequency of the occurrence of tornado. The Southern Ontario tornado inventory over the 40 years from 1976 to 2015 yields approximately 4.8 tornadoes per 100,000 km² per year or 0.6 EF2 and higher tornadoes per 100,000 km² per year (EMO, 2016). The area within 200 km of the NPD site is shown with a red circle on Figure 9-3.

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**Figure 9-2 Confirmed and Probable Tornadoes between 1980 and 2009 in Canada
(Cheng et al., 2012)**



It is also noted that based on information from local media reports on tornadoes, Athauda-Arachchige (2015) identified that in 1984 a tornado touched down in the area between Deep River and Rolphton causing one death, many injuries and extensive damage along the Upper Ottawa Valley and Quebec. This tornado lasted approximately 10 minutes, and the trees were flattened in the path of the tornado along the Ottawa River to just north of the Ontario Highway 17. The damage seemed to be limited to an area about 2 km wide. The estimate of property damage was low, and the damage was confirmed mainly to outbuildings and a personal vehicle. The potential hazards posed by tornadoes are those due to air pressure changes and flying missiles.

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Figure 9-3 Confirmed and Probable Tornadoes between 1918 and 2009 in Ontario (EMO, 2016)

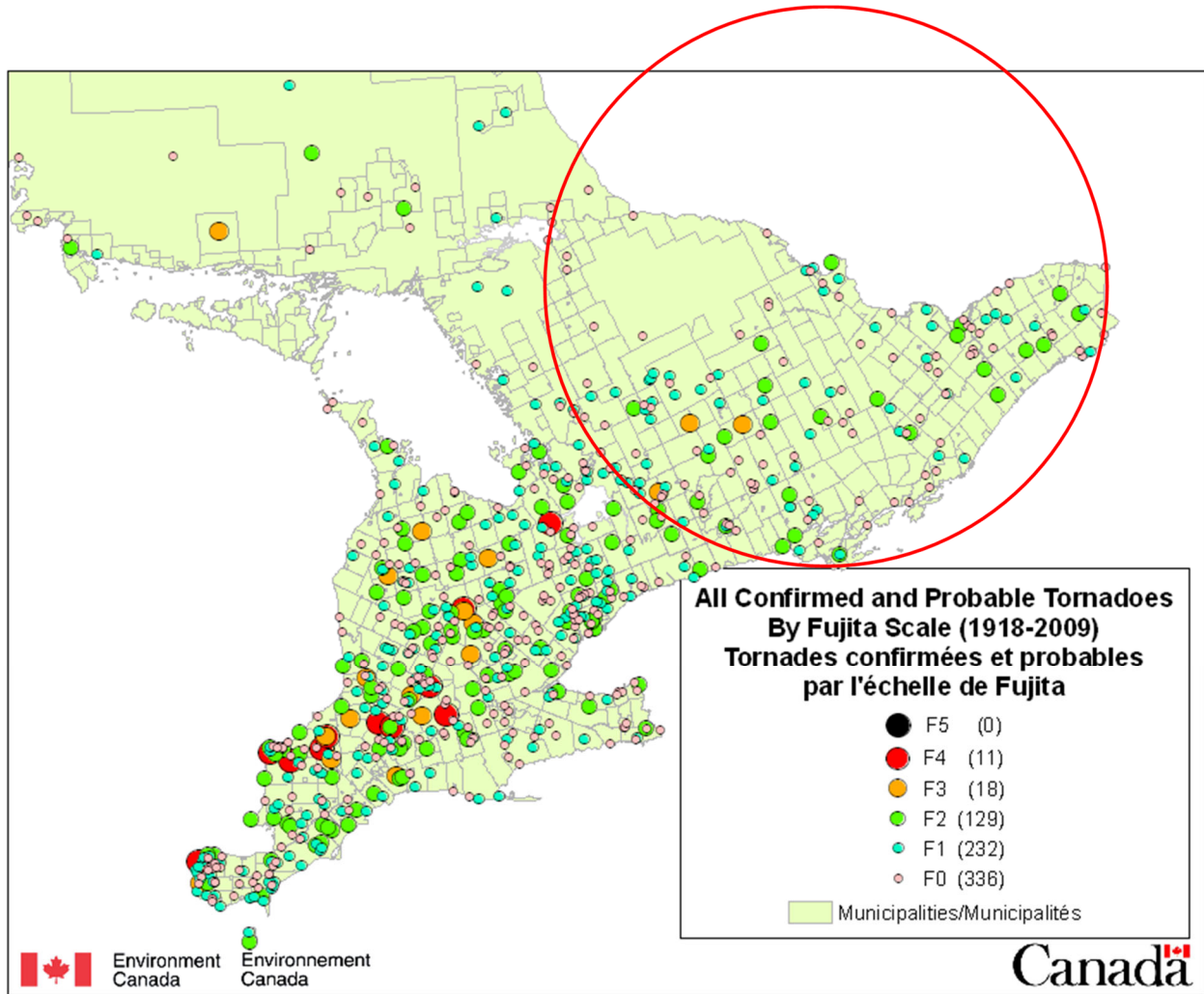


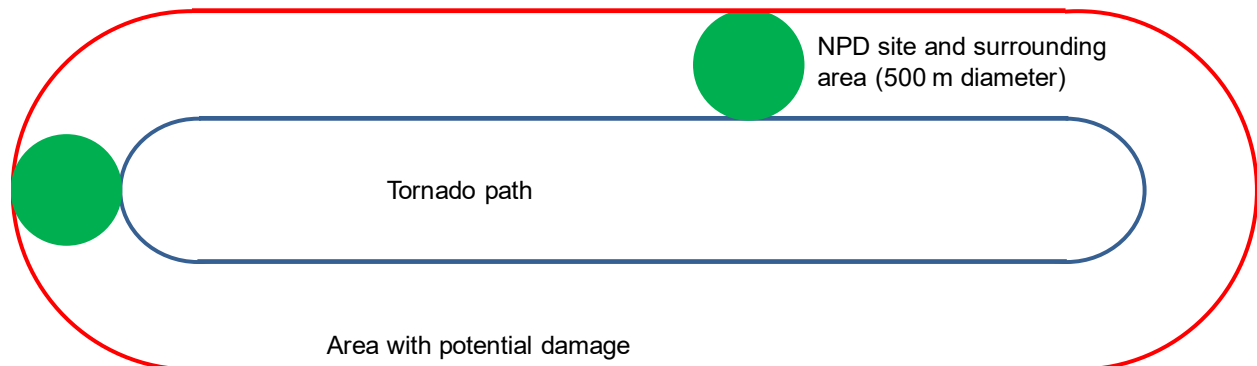
Table 9-51 Number of Confirmed and Probable Tornadoes from 1974 to 2015 in Southern Ontario (EMO, 2016)

F / EF Number	Number of Tornadoes
0	157
1	73
2	25
3	5
4	2
5	0
Total	262

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The area affected by tornadoes depends on the frequency as well as the width and length of the tornado paths. The area near a target facility that has a potential to generate projectiles during a tornado event should be considered. Figure 9-4 shows areas affected by a tornado considering an area of approximately 500 m diameter near the NPD site. A 500-m margin was considered in order to account for the areas surrounding the NPD site where projectiles may be generated.

Figure 9-4 Areas Affected by a Tornado



A report prepared for Ontario Power Generation, AMEC (2009) summarized the path length and path width for all U.S. tornadoes within a radius of 500 km of the Darlington site between 1950 and 2006. This information is shown in Table 9-52.

Table 9-52 Path Length and Path width for all Tornadoes (1950-2006) (AMEC 2009)

F/EF Number	Path Length (km)		Path Width (m)	
	Average	Maximum	Average	Maximum
0	1.9	40.2	48	1097
1	4.3	93.2	87	914
2	8.6	93.7	146	2286
3	21.2	135.3	220	1372
4	48.6	189.9	576	3045

In a separate report, Brooks (2004) used a dataset that consists of all tornadoes in the National Weather Service (NWS) Storm Prediction Center (SPC) database of tornadoes in the United States from 1950–2001 and fitted Weibull distributions to the observed path length and width data. Figure 9-5 and Figure 9-6 show the path length and path width resulted from Brooks study (Note: Tops and bottoms of boxes represent 75th and 25th percentiles, respectively. Tops and bottoms of whiskers represent 90th and 10th percentiles, respectively). Table 9-53 shows the summary of the results from the Brooks study. The information provided in Table 9-53 is very similar to the information shown in Table 9-52.

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Figure 9-5 Cumulative Distribution Functions for Path Length and Path Width of Tornadoes by Fujita Scale (Brooks 2004)

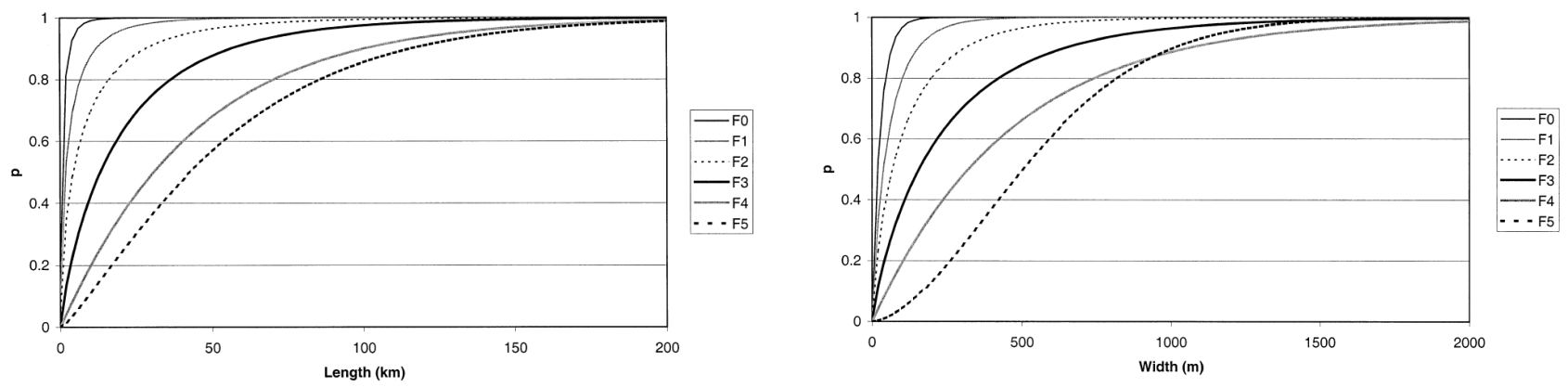
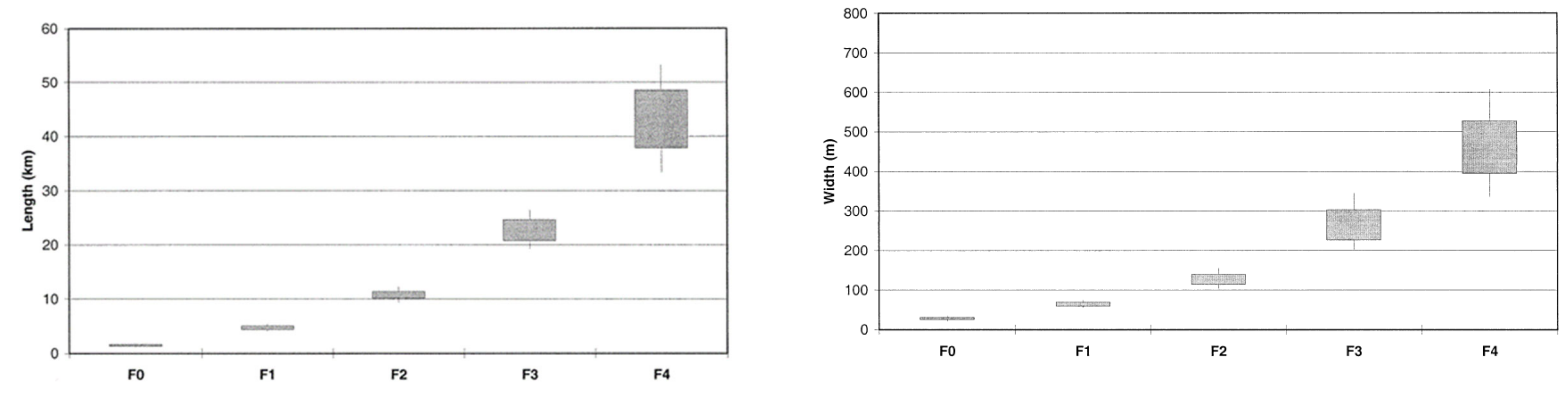


Figure 9-6 Distribution of Mean Path Length and Mean Path Width Estimates (Brooks 2004).



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Table 9-53 Summary of Path Length and Path Width from Brooks Study

Fujita Scale	Path Length (km)	Path Width (km)
EF0	2	0.03
EF1	5	0.08
EF2	11	0.13
EF3	23	0.27
EF4	44	0.46
EF5	50	0.6

The sizes of the affected areas for each tornado scale, considering a 500 m margin potential generation of missiles outside of the tornado path and width, are shown in Table 9-54.

Table 9-54 Sizes of the Affected Areas for Each Tornado Scale

Fujita Scale	Tornado Size		Area Affected			Number of Tornadoes in 40 Years within 200 km	Total Affected Area (km ²)
	Path Length (km)	Path Width (km)	Length (km)	Width (km)	Area (km ²)		
EF0	2	0.03	3	1.03	3.1	157	486.7
EF1	5	0.08	6	1.08	6.5	73	474.5
EF2	11	0.13	12	1.13	13.6	25	340
EF3	23	0.27	24	1.27	30.5	5	152.5
EF4	44	0.46	45	1.46	65.7	2	131.4
EF5	50	0.6	51	1.6	81.6	0	<81.6

The probability that the NPD site falls within the affected areas was based on forty years of tornado statistics are calculated by dividing by the total affected area (number of tornados multiplied by area affected by each tornado as calculated in Table 9-54) by the entire area in Southern Ontario (137,000 km²). The annual probabilities (frequencies) are calculated by dividing the number of years the tornados data was collected for, which is forty years. This calculation assumes tornadoes are distributed equally by geography within the total area. The resulting annual probabilities (frequencies) of the NPD site falling within the affected areas for each tornado scale are shown in Table 9-55.

Table 9-55 Annual Probabilities of NPD being within the Affected Area of Tornado's

Fujita Scale	Total Affected Area (km ²)	Probabilities of NPD being within Affected Area in 40 years	Annual Probabilities of NPD being within Affected Area
EF0	486.7	3.55E-03	8.88E-05
EF1	474.5	3.46E-03	8.66E-05
EF2	340	2.48E-03	6.20E-05
EF3	152.5	1.11E-03	2.78E-05
EF4	131.4	9.59E-04	2.40E-05
EF5*	<81.6	<6E-04	<1.49E-05
Total	-	<1.22E-02	<3.04E-04

* Tornado scale EF5 has never occurred in Ontario

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9.6.3 Scenario 5: Major Flood and Release of Radioactivity

Flooding of the NPD site could occur due to:

- Flooding from the Ottawa River (i.e. river level rise);
- Heavy precipitation; or,
- Failure of the dams on the Ottawa River upstream of the site.

Flooding From the Ottawa River (High-Water Flooding)

As described in the SAR (Athauda-Arachchige 2015), the probability of flooding by river water is not considered likely because control of the river water is exercised by Ontario Power Generation's (OPG's) Des Joachims Generating Station, located approximately 3 km upstream from NPD. The highest recorded level of the Ottawa River at NPD is 114 m above sea level (asl). Seasonal fluctuations in the level of the river, between 110 m and 114 m asl, do not affect NPD. The only possibility for the river water to enter the nuclear portion of the facility would be for the river level to rise above 118 m and enter the process drainage pipe; this would mean a rise of 4 m above its maximum level.

Flooding From Heavy Precipitation

In the facility SAR (Athauda-Arachchige 2015), localized flooding due to surface run-off of meteorological extremes and or spring thaw conditions was identified as extremely unlikely because of the good drainage provided by the site topography. The SAR also notes that the NPD landscape diverts heavy precipitation from the facility to the Ottawa River. Several engineered drainage features, such as ditches, drainage slopes and berms, are present around the facility to increase drainage. The building foundation also extends above ground level, preventing surface runoff from draining into the facility's below-grade areas.

Nevertheless, precipitation does have the potential to fall inside the partially-grouted facility during the brief period in which the superstructure is removed but the final grout elevations are not yet poured. However, CNL has planned the decommissioning tasks so as to reduce this period of time, primarily by keeping the superstructure and roof in place for much of the grouting process. Decommissioning of the superstructure and roof will not begin until all of the nuclear area has been grouted, and since grouting of the nuclear and non-nuclear areas proceeds in parallel, the majority of the non-nuclear areas will also have been grouted by this point in time, excluding the condenser pit into which the building rubble will be placed. Superstructure that does *not* support the roof over the condenser pit is demolished and emplaced first, maximizing the protection offered by the roof over the condenser pit. The roof over the condenser pit is then taken down last, in pieces, emplaced and grouted in tandem. This is planned to take place over only a few weeks.

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Therefore, due to the topography of the site, the drainage features present, the surface runoff protection offered by the foundation walls, and the short period in time in which the facility roof will be down, the likelihood of the facility flooding from heavy precipitation is considered to be very low. It has been assigned a frequency rating of “rare” (3×10^{-2} to 10^{-4}).

Flooding from dam failure

Based on the findings of the 1999 *Ottawa River Dam Break and Inundation Mapping Study* performed by OPG, Athauda-Arachchige (2015) reports that a probable maximum precipitation event combined with a 100-year snow-pack condition gives rise to the highest estimated flood level (i.e. the river study’s worse-case flood scenario). The results show that the Des Joachims dam would be capable of generating dam-break flood waves. Probable maximum flood flows would be several times greater than the normal river flows and, the flood volumes would exceed the storage capacity of the reservoir, causing significant flooding.

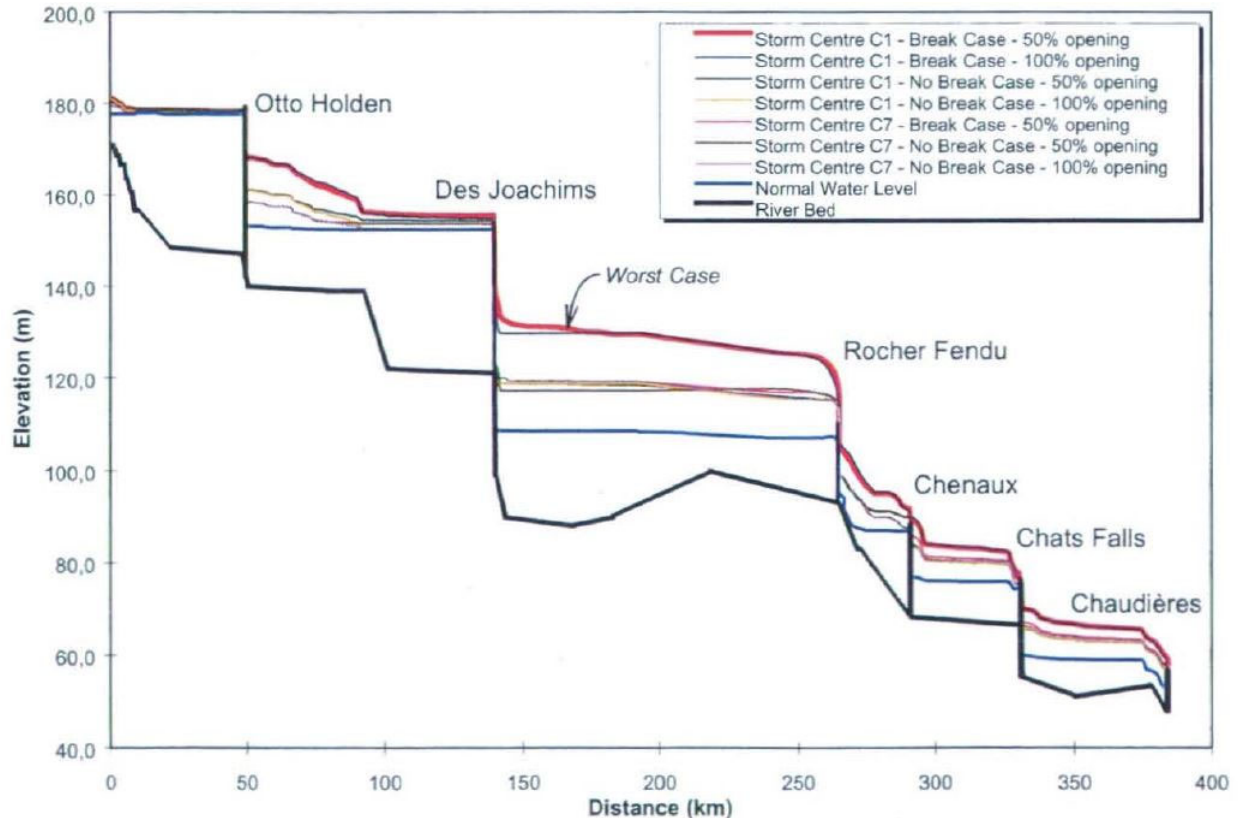
In the event the failure of the Timiskaming dam (about 193 km northwest of NPD) were to occur, the flood wave resulting from this dam failure would fill the Otto Holden dam (about 145 km northwest of NPD) and Des Joachims dam (about 3 km northwest of NPD) reservoirs causing overtopping and potential failure of the Otto Holden and Des Joachims dams. In the event of the failure of these main three dams, the river basin has to drain the flows from its tributaries as well as additional large and abrupt flows due to failure of dams. If sufficient time elapses between the dam failure event and the time when outflows from the basin begins to exceed the inflows, the water in the basin may back up all the way to the NPD site causing severe flooding at the facility.

Because of the distances between these dams and because of the enormous storage capacity of the reservoir behind the Des Joachims dam, failure of the Timiskaming and Otto Holden dams will not automatically produce failure of the Des Joachims dam due to an arriving, but diffused, flood wave. Within design basis climatic conditions, the discharge works at the dams are capable of maintaining reservoir levels behind the Des Joachims dam below without overtopping the dam. The time for the flood wave to reach Des Joachims from Otto Holden is approximately 2.3 hours after the breach at Otto Holden, so it can be expected that the staff at Des Joachims would have some time to progressively open some extra sections of the discharge works there and help discharge the additional flows arriving at the dam. Therefore, failure of the Otto Holden dam will *not* automatically result in failure of the Des Joachims dam.

However, in the event that a cascading failure of the three main dams *does* occur, the potential flood zone will include higher elevations, a large volume of water will be released leading to significant flooding and the consequences for communities downstream of these dams will be catastrophic. In such a worst-case scenario, the corresponding flood level estimated at the NPD site is 132.2 m (i.e. a water level increase of 23.5 m), as shown in Figure 9-7 (reproduced from OPG (1999)). Since the NPD site is located at an elevation of approximately 129 m asl, the NPD facility would be within the flooded zone and would be flooded.

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Figure 9-7 Dambreak Modelling Results - Profiles of Maximum Flood Levels - Worst-Case Scenario (OPG 1999)



The worst-case flood conditions (those described above, and shown in Figure 9-7) require a 100-year snow accumulation event combined with a maximum precipitation event from a storm centred on the Lake Temiskaming basin. According to Athauda-Arachchige (2015), supporting information indicates that these combined conditions have a frequency of occurrence of 10^{-7} per year. Athauda-Arachchige (2015) concluded that the probability of a 3-dam failure occurring falls into the F0 frequency category of 'extremely rare' (i.e. 10^{-4} to 10^{-6} per year).

There are no readily available, reliable statistics regarding dam failure and resulting floods in Canada that could be used to obtain statistically meaningful dam failure frequency. According to data gathered by Association of State Dam Safety Officials in the United States, there have been 25 dam failures resulting in major floods in the past 80 years (ASDSO, 2016). There are nearly 8100 major dams in the United States in 2006. The National Inventory of Dams (maintained by the U.S. Geological Survey (USGS 2016)) defines a major dam as 50 feet (15 m) tall with a storage capacity of at least 5,000 acre feet (6,200,000 m^3), or of any height with a storage capacity of 25,000 acre feet (31,000,000 m^3) (Gertman *et al.*, 2005). This results in an annual failure frequency (for major dams, resulting in major flooding) of 3.7×10^{-5} per dam. It is important to note that this does not distinguish between the cause of dam failure, i.e. it includes dam failures caused by flood conditions, as well as failures that resulted from other non-flood related causes.

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Overall, when viewed together, both of these estimates (the SAR's range of 10^{-4} to 10^{-6} , and the statistical derivation of 3.7×10^{-5} per dam) are negligible compared with the frequency of a flood from heavy precipitation on site.

9.6.4 Scenarios 6 and 7: Accidental Exposure to Radioactivity and Chemicals

The most reliable method for deriving the frequency of human error for this case is provided by Gertman *et al.* (2005), and uses the concept of Performance-Shaping Factors (PSFs) to modify a base-case or Nominal Human Error Probability (NHEP) to estimate the Human Error Probability (HEP) for a specific activity. The method provided by the US NRC is called the Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) method (Gertman, 2005). The SPAR-H framework considers the contribution of both diagnosis failures and action failures in the probability. The base-case or nominal human error probabilities are 1.0×10^{-2} for diagnosis failure, and 1.0×10^{-3} for action failure. Examples of action tasks include operating equipment, starting pumps, conducting calibration or testing, and other activities performed during the course of following work orders. Diagnosis tasks consist of reliance on knowledge and experience to understand existing conditions, planning and prioritizing activities, and determining appropriate courses of action. This method accounts for the context associated with human failure events by using PSFs to adjust NHEPs. PSFs are defined for time constraints, stress levels, complexity of tasks, experience and level of training, procedures, ergonomics, and work processes.

The SPAR-H method offers a simple modification of the nominal human error probability (NHEP) using the following equation:

$$HEP = \frac{NHEP \times PSF_{Composite}}{NHEP \times (PSF_{Composite} - 1) + 1}$$

where:

NHEP is the nominal HEP

PSF_{Composite} is the composite PSF

The composite PSF is calculated as the product of the multipliers of all relevant. The multipliers are multiplied by one another, regardless of whether the PSF influence is positive or negative. Table 9-56 provides the PSF levels and associated multipliers.

Table 9-56 PSF Level Assignment and Associated Multipliers

PSF	Status	Factor (From Gertman 2005, Appendix C, Page C-5)
Stress	Nominal	1
Training	High	0.5
Work Process	Nominal	1
Available Time	Nominal	1

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$$PSF_{composite} = (1 \times 0.5 \times 1 \times 1 \times 1) = 0.5$$

The NHEP were considered as 1.0×10^{-2} for diagnosis, failure, and 1.0×10^{-3} for action failure in the SPAR-H method. The action NHEP value of 1×10^{-3} are used in this scenario. The number of times that there is a potential for accidental exposure for each worker depends on the tasks performed by each worker. At this moment, there is no task description for various workers at the site. Therefore, 100 activities are assumed to be performed for each worker during a year where there is a potential for accidental exposure to radioactivity and chemicals. Therefore, the frequency of exposure for each activity is:

$$HEP = \frac{NHEP \times PSF_{Composite}}{NHEP \times (PSF_{Composite} - 1) + 1} = \frac{1 \times 10^{-3} \times 5 \times 10^{-1}}{1 \times 10^{-3} \times (5 \times 10^{-1} - 1) + 1} = 5 \times 10^{-4}$$

And for 100 activities is:

$$HEP = 100 \times 5 \times 10^{-4} = 5 \times 10^{-2}$$

9.6.5 Scenarios 8 and 9: Underground (Indoor) Fire and Release of Radioactivity and Chemicals

Underground fire could be the result of electrical system malfunction, or human error during various activities, particularly open flame tasks such as torch cutting. At the moment, there is no detailed information regarding the nature and arrangement of electrical components within the facility. Therefore, it is not possible to calculate the frequency for this action. A more probable cause of underground fire would be human error. Therefore, the same base NHEP and composite PSF used in Section 9.6.4 are applicable here as well (noting that not all human errors necessarily lead to a fire). The number of times that there is a potential for underground fire depends on the tasks performed by each worker (hot work or electrical isolation / connection). At this conceptual stage in the project planning, there is no task description for various workers at the site. Therefore, 100 activities is assumed for each worker during a year where there is a potential for indoor fire. Therefore, the frequency of indoor fire (per worker, per year) is the same as that for Scenario in Section 9.6.4, i.e. 5×10^{-2} per year.

9.6.6 Scenario 10: Stack Collapse during Dismantling and Release of Radioactivity

The frequency of stack collapse was estimated based on the frequency of several initiating events that could cause such a collapse to occur. These include:

- Earthquake (beyond-design-basis);
- Tornado (beyond-design-basis); and,

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- Heavy equipment (e.g. large crane) collision, including both equipment malfunction and operator error.

Earthquake

The National Building Code of Canada (NBCC) defines earthquake design criteria in terms of both spectral acceleration parameters (Sa(T)) and Peak Ground Acceleration (PGA, also expressed as a ratio of gravitational acceleration, 'g') for an earthquake, based on a 2% probability of exceedance in 50 years (i.e. a return period of 1 in 2,500) (NRCAN 2020). Sa(T) is a series of factors summarized as being the 5%-damped horizontal spectral acceleration values for various time periods, 'T'. The minimum and maximum PGAs for Canada are 0.036 g and 1.2 g, respectively (NRCAN 2020).

PGA and Sa(T) values for 2%-per-50 years (i.e. 4×10^{-4} per annum) frequency for various lengths of time (in seconds) intended for the building code for Deep River are as follows (NRCAN 2020):

- PGA = 0.25 g
- Sa(0.2) = 0.39
- Sa(0.5) = 0.21
- Sa(1.0) = 0.1
- Sa(2.0) = 0.049

Considering a minimum PGA of 0.036 g and a maximum PGA of 1.2 g across Canada, a PGA of 0.25 g for Deep River represents medium seismic activity in Canada. Note though, that the stack was built before the mandate of the existing Canada building code. And, while assessments of the stack's condition and integrity have been completed (e.g. AECL 2014; CNL 2016b), these assessments were not completed to verify the stack's capability as per the building code. Therefore, in the absence of specific documentation to confirm its capabilities, it has been assumed that the stack meets the requirement of the Canada building code with respect to seismic forces.

The seismic criteria presented above mean that the frequency of occurrence of a beyond-design-basis earthquake that could cause damage to structures (including the stack) is less than 4×10^{-4} per year.

Tornado

In the facility SAR, a tornado representing the upper limits of intensity in the EF-2 range on the Enhanced Fujita scale was used as the design-basis tornado for safety evaluations. The facility SAR notes that the consequences of a design basis tornado in the vicinity of the facility would include, among other consequences, damage to above-ground buildings. As shown in Table 9-55, the frequency of an EF-2 tornado occurring and affecting the facility is estimated to

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be 6.2×10^{-5} per year. Therefore, the frequency of a *beyond*-design-basis tornado (i.e. a tornado of greater intensity) that could lead to the collapse of the stack is *less* than 10^{-5} per year.

Heavy Equipment (Large Crane) operation

A report prepared for U.S. Nuclear Regulatory Commission (Lloyd 2002) showed that, based on actual crane operating experience data from commercial U.S. nuclear power plants, the frequency of load drops per demand for very heavy loads was found to be 5.6×10^{-5} . The report indicated that this estimate was an industry average, and may be higher or lower at a given facility because of varying human error rates which appear to dominate the causes of the load drop events.

Assuming that 1 crane operation occurs per year, and it occurs in the vicinity of the stack, and it is of a nature that could cause significant damage to stack's structural integrity, then the frequency of stack fall would be 5.6×10^{-5} for that year.

The above frequency is for accidents involving all types of cranes. The accident rates for mobile cranes maybe greater, by as much as a factor of 3, thus, a frequency of 1.7×10^{-4} (i.e. $3 \times 5.6 \times 10^{-5}$) was selected for one crane.

If multiple cranes are in use at the site, the frequency of accident will increase proportionally. For three cranes, the frequency of crane fall due to crane strike or load fall will be 5×10^{-4} .

Overall Frequency

The overall frequency of stack collapse is the sum of the frequency of all 3 of the independent events discussed above. Therefore:

$$\text{Overall frequency of stack fall} = 4 \times 10^{-4} + 5 \times 10^{-4} + 1 \times 10^{-5} = 9.1 \times 10^{-4} \text{ per year}$$

9.7 Effects on Non-Human Biota

The assessment of effects on non-human biota from accident bounding scenarios is provided in the *Ecological Risk Assessment TSD* (Garisto *et al.*, 2020a), though its conclusions are reproduced in this DecomSA – at a high level - for completeness.

The *Ecological Risk Assessment TSD* (Garisto *et al.*, 2020a) found that there are no adverse effect on non-human biota from exposure to radioactive or chemical contaminants for any of the bounding accident scenarios.

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9.8 Risk Evaluation

In this section, each Bounding Scenario is assigned a frequency rating and a severity rating, which are then combined to determine an overall risk rating.

The frequency ratings, respective frequency ranges, and descriptions are shown in Table 7-4 (Section 7.6.1). The severity ratings are shown in Table 7-5 (Section 7.6.2), and are divided up into hazard types (external, radiological, and chemical), for different receptor categories. Risk ratings are assigned using the risk matrix shown in Table 7-6.

Lastly, summary tables are provided which compare the estimated doses (or concentrations, for non-radiological compounds) to their corresponding acceptance criteria.

9.8.1 Bounding Scenario 1: Forest Fire and Release of Radioactivity

As shown in Section 9.6.1, the annual frequency that a forest fire will affect the site was estimated to be 2.8×10^{-3} per year. This corresponds to a frequency rating of F1.

As shown in Section 9.5.1, estimated total doses are much less than 0.1 mSv for all receptors. This is less than the S1 worker dose criterion of 1 mSv. This is also less than the S1 public dose criterion of 0.1 mSv, but is greater than the S0 public dose criterion of 'no dose'. In addition, soil screening indices are much less than 1 for all contaminants (H-3, C-14) for all public receptor locations, and for comparison to UCLs, the Sum of Fractions is less than 1. Therefore, this scenario is assigned a severity rating of S1.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 1 is R0 - the risk is negligible, and no further action is required. Figure 9-8 shows where on the risk matrix Scenario 1 is located.

Figure 9-8 Risk Matrix for Scenario 1's Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	R0	Scenario 1 - R0	R0	R1	R2
F2	R0	R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

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9.8.2 Bounding Scenario 2: Forest Fire and Release of Chemical Contaminants

As shown in Section 9.6.1, the annual frequency that a forest fire will affect the site was estimated to be 2.8×10^{-3} per year. This corresponds to a frequency rating of F1.

As shown in Section 9.5.2, results for workers are less than S1 (i.e. are less than acceptance criterion) but greater than S0 (i.e. greater than 10% of the acceptance criterion), implying a rank of S1 should be assigned. For public, results are much less than 1 for all contaminants (asbestos, lead) for all receptor locations. Therefore, overall, this scenario is assigned a severity rating of S1.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 2 is R0 - the risk is negligible, and no further action is required. Figure 9-9, shows where on the risk matrix Scenario 2 is located.

Figure 9-9 Risk Matrix for Scenario 2's Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	R0	Scenario 2 - R0	R0	R1	R2
F2	R0	R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

9.8.3 Bounding Scenario 3: Tornado and Release of Radioactivity

As shown in Section 9.6.2, the annual frequency of an EF-2 tornado affecting the site is estimated to be 6.20×10^{-5} per year. The corresponding frequency rating for this scenario is F0.

As shown in Section 9.5.3, estimated total doses from an EF-2 tornado to all receptor locations are much less than 0.1 mSv/year. This is less than the S1 worker dose criterion of 1 mSv. This is also less than the S1 public dose criterion of 0.1 mSv, but is greater than the S0 public dose criterion of 'no dose'. In addition, soil screening indices are much less than 1 for all contaminants (H-3, C-14) for all public receptor locations, and for comparison to UCLs, the Sum of Fractions is less than 1. Therefore, this scenario is assigned a severity rating of S1.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 3 is R0 - the risk is negligible, and no further action is required. Figure 9-10 shows where on the risk matrix Scenario 3 is located.

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Figure 9-10 Risk Matrix for Scenario 3’s Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	Scenario 3 - R0	R0	R0	R1
F1	R0	R0	R0	R1	R2
F2	R0	R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

9.8.4 Bounding Scenario 4: Tornado and Release of Chemical Contaminants

This scenario is similar to Scenario 3 except it evaluates chemical releases. As shown in Section 9.6.2, the annual frequency of an EF-2 tornado affecting the site is estimated to be 6.20×10^{-5} per year. The corresponding frequency rating for this scenario is F0.

As shown in Section 9.5.4, results for workers are less than S0 (i.e. are less than 10% of the acceptance criterion), implying a rank of S0 should be assigned. For public, resulting concentrations are non-zero but are less than acceptance criterion for all contaminants (asbestos, lead) for all receptor locations – implying a rank of S1. Therefore, overall, this scenario is assigned a severity rating of S1.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 4 is R0 - the risk is negligible, and no further action is required. Figure 9-11 shows where on the risk matrix Scenario 4 is located.

Figure 9-11 Risk Matrix for Scenario 4’s Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	Scenario 4 - R0	R0	R0	R1
F1	R0	R0	R0	R1	R2
F2	R0	R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

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9.8.5 Bounding Scenario 5: Major Flood and Release of Radioactivity

As discussed in Section 9.6.3, the frequency that NPD falls within the affected area of a major flood is 7.3×10^{-3} per year, and, the likelihood assessment from the facility SAR identified that the frequency is rare (i.e. between 3×10^{-2} and 10^{-4} per year). These 2 frequency estimates correspond to a frequency rating of F1.

For consequence, as discussed in Section 9.5.5, the facility SAR concluded that the doses that could result from liquid releases are low (with no discernable effects) due to the small source term and large quantity of water, and therefore, the dose acceptance criteria has been met. From this, a severity rating of S0 is assigned.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 5 is R0 – the risk is negligible, and no further action is required. Figure 9-12 shows where on the risk matrix Scenario 5 is located.

Figure 9-12 Risk Matrix for Scenario 5's Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	Scenario 5 – R0	R0	R0	R1	R2
F2	R0	R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

9.8.6 Bounding Scenario 6: Accidental Exposure to Radioactivity

As discussed in Section 9.6.4, the frequency of human error causing accidental exposure was estimated to be 5×10^{-2} for 100 activities. The corresponding frequency rating for this scenario is F2.

The highest estimated gamma dose (including ambient room gamma) is obtained from drilling Hole A, which, combined with the drilling dust inhalation and immersion dose, produces a total dose of 2.19 mSv for the 32-hour activity duration (see Table 9-43). This corresponds to severity rating S2.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 6 is R1 - the risk is tolerable, further protective measures are not essential but should be considered (for example, during the preparation of work control and radiation protection plans, which are prepared before decommissioning tasks are undertaken). It should be noted that this risk

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assessment is very conservative, given the number of conservative assumptions that contribute to this ranking. These assumptions include:

- the fact that a bounding inventory of radionuclides in reactor vault concrete is used;
- PPE is ignored;
- the worker is assumed to be standing directly above the hole for the entire drilling duration;
- no dust reduction measures are employed; and,
- bounding parameter values for air dispersion and respirable fractions are used.

The risk is tolerable at this conservative level, and would be even more so under more realistic conditions.

Figure 9-13 shows where on the risk matrix Scenario 6 is located.

Figure 9-13 Risk Matrix for Scenario 6's Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	R0	R0	R0	R1	R2
F2	R0	R0	Scenario 6 – R1	R2	R3
F3	R0	R1	R2	R3	R3

9.8.7 Bounding Scenario 7: Accidental Exposure to Chemicals

As discussed in Section 9.6.4, the frequency of human error causing accidental exposure was estimated to be 5×10^{-2} for 100 activities. The corresponding frequency rating for this scenario is F2.

As discussed in Section 9.5.7, there is no expected interaction between decommissioning workers and chemical contaminants, owing the form and location of these chemicals. Therefore, the corresponding severity rating is S0, since there is no expected exposure.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 7 is R0 - the risk is negligible, and no further action is required. Figure 9-14 shows where on the risk matrix Scenario 7 is located.

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Figure 9-14 Risk Matrix for Scenario 7's Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	R0	R0	R0	R1	R2
F2	Scenario 7 - R0	R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

9.8.8 Bounding Scenario 8: Underground (Indoor) Fire and Release of Radioactivity

As discussed in Section 9.6.5, the frequency of human error causing an accidental indoor fire was estimated to be 5×10^{-2} for 100 activities. The corresponding frequency rating for this scenario is F2.

As shown in Section 9.5.8, estimated doses for worker receptors are well below 0.1 mSv dose criterion for S0 ranking (the highest dose is 3.3×10^{-3} mSv for 15-minute departure time). For public receptors, the highest estimated dose (1.19×10^{-9} mSv) is well below the 0.1 mSv dose criterion for S1 ranking, but is greater than the S0 public dose criterion of 'no dose'. In addition, soil screening indices are much less than 1 for all contaminants (Co-60, Cs-137) for all public receptor locations, and for comparison to UCLs, the Sum of Fractions is less than 1. Therefore, this scenario is assigned a severity rating of S1.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 8 is R0 - the risk is negligible, and no further action is required. Figure 9-15 shows where on the risk matrix Scenario 8 is located.

Figure 9-15 Risk Matrix for Scenario 8's Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	R0	R0	R0	R1	R2
F2	R0	Scenario 8 - R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

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9.8.9 Bounding Scenario 9: Underground (Indoor) Fire and Release of Chemicals

As discussed in Section 9.6.5, the frequency of human error causing an accidental indoor fire was estimated to be 5×10^{-2} for 100 activities. The corresponding frequency rating for this scenario is F2.

As shown in Section 9.5.9, results for workers are less than S1 (i.e. are less than acceptance criterion) but greater than S0 (i.e. greater than 10% of the acceptance criterion), implying a rank of S1 should be assigned. For public, results are much less than their acceptance criteria for all contaminants for all receptor locations. Therefore, overall, this scenario is assigned a severity rating of S1.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 9 is R0 - the risk is negligible, and no further action is required. Figure 9-16 shows where on the risk matrix Scenario 9 is located.

Figure 9-16 Risk Matrix for Scenario 9’s Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	R0	R0	R0	R1	R2
F2	R0	Scenario 9 - R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

9.8.10 Bounding Scenario 10: Stack Collapse and Release of Radioactivity

As discussed in Section 9.6.6, the combined frequency of accidental ventilation stack collapse was estimated to be approximately 4.66×10^{-4} per year. The corresponding frequency rating for this scenario is F1.

As shown in Section 9.5.10, estimated doses for worker receptors are well below 0.1 mSv dose criterion for S0 ranking. Similarly, for public receptors, the highest estimated dose (1.15×10^{-2} mSv at the guardhouse) is well below the 0.1 mSv dose criterion for S1 ranking, but greater than the S0 rank of ‘no dose’. In addition, soil screening indices are much less than 1 for all contaminants (H-3, C-14), and for comparison to UCLs, the Sum of Fractions is less than 1 for all public receptor locations. Therefore, the S1 rank has been assigned.

Therefore, from the risk matrix (Table 7-6), the corresponding risk level for Bounding Scenario 10 is R0 - the risk is negligible, and no further action is required. Figure 9-17 shows where on the risk matrix Scenario 10 is located.

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Figure 9-17 Risk Matrix for Scenario 10's Risk Level

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0	R0	R0	R1
F1	R0	Scenario 10 - R0	R0	R1	R2
F2	R0	R0	R1	R2	R3
F3	R0	R1	R2	R3	R3

9.8.11 Comparison of Doses to Acceptance Criteria

Table 9-57 compares the calculated radiological doses and non-radiological exposures for public receptors to corresponding criteria for accidents (outlined in Sections 4.1.5 and 4.1.6). Table 9-58 compares the calculated radiological doses and non-radiological exposures for worker receptors to corresponding criteria for accidents.

For all scenarios, there are no exceedances of the corresponding acceptance criteria.

Table 9-57 Comparison of Public Receptor Exposure to Acceptance Criteria

Public Receptors									
Scenario		Calculated				Acceptance Criteria			Meets Acceptance? (Y/N)
Scenario #	Scenario Name	Contaminant	Estimated Scenario Frequency (Per Year)	Estimated Exposure		Frequency Category (Per Year)	Exposure Criteria		
Bounding Scenario 1	Forest Fire (Rad)	Radiation	2.80E-03	1.16E-05	mSv	<3x10 ⁻² to 10 ⁻⁴	>0.5 to 5.0	mSv	Y
		H-3 (Soil)	2.80E-03	8.56E+02	Bq/kg	<3x10 ⁻² to 10 ⁻⁴	1.0E+05	Bq/kg	Y
		C-14 (Soil)	2.80E-03	2.83E+00	Bq/kg	<3x10 ⁻² to 10 ⁻⁴	1.0E+03	Bq/kg	Y
Bounding Scenario 2	Forest Fire (Non-Rad)	Asbestos	2.80E-03	3.12E-06	g/m ³	N/A	5.00E-05	g/m ³	Y
		Lead (Air)	2.80E-03	2.42E-07	g/m ³	N/A	1.50E-04	g/m ³	Y
		Lead (Soil)	2.80E-03	1.74E-06	µg/g	N/A	120	µg/g	Y
		Mercury	2.80E-03	0.00E+00	g/m ³	N/A	1.50E-04	g/m ³	Y
		PCBs	2.80E-03	0.00E+00	g/m ³	N/A	1.30E-02	g/m ³	Y
		Dioxins & Furans	2.80E-03	0.00E+00	g/m ³	N/A	1.30E-07	g/m ³	Y
Bounding Scenario 3	Tornado (Rad) (EF2)	Radiation	6.20E-05	1.81E-06	mSv	<10 ⁻⁴ to 10 ⁻⁵	>5 to 100	mSv	Y
		H-3 (Soil)	6.20E-05	1.69E+02	Bq/kg	<10 ⁻⁴ to 10 ⁻⁵	1.0E+05	Bq/kg	Y
		C-14 (Soil)	6.20E-05	2.45E-03	Bq/kg	<10 ⁻⁴ to 10 ⁻⁵	1.0E+03	Bq/kg	Y
Bounding Scenario 4	Tornado (Non-Rad) (EF2)	Asbestos	6.20E-05	3.30E-05	g/m ³	N/A	5.00E-05	g/m ³	Y
		Lead (Air)	6.20E-05	4.19E-07	g/m ³	N/A	1.50E-04	g/m ³	Y
		Lead (Soil)	6.20E-05	3.01E-06	µg/g	N/A	120	µg/g	Y
		Mercury	6.20E-05	0.00E+00	g/m ³	N/A	1.50E-04	g/m ³	Y
		PCBs	6.20E-05	0.00E+00	g/m ³	N/A	1.30E-02	g/m ³	Y
Bounding Scenario 5*	Flood (Rad)	Radiation	Rare (< 3x10 ⁻² to 10 ⁻⁴)*	No Discernible Effect*		<3x10 ⁻² to 10 ⁻⁴	>0.5 to 5.0	mSv	Y*
Bounding Scenario 6	Accidental Exposure (Rad)	Radiation	N/A	N/A	mSv	N/A	N/A	mSv	N/A
Bounding Scenario 7	Accidental Exposure (Non-Rad)	No Contaminants	N/A	N/A	g/m ³	N/A	N/A	g/m ³	N/A
Bounding Scenario 8	Indoor Fire (Rad)	Radiation	5.00E-02	1.19E-09	mSv	<3x10 ⁻¹ to 3x10 ⁻²	0.1 to 0.5	mSv	Y
		Cs-137 (Soil)	5.00E-02	8.12E-04	Bq/kg	<3x10 ⁻¹ to 3x10 ⁻²	1.0E+02	Bq/kg	Y
		Co-60 (Soil)	5.00E-02	1.28E-04	Bq/kg	<3x10 ⁻¹ to 3x10 ⁻²	1.0E+02	Bq/kg	Y
Bounding Scenario 9 (a & b)	Indoor Fire (Non-Rad)	Asbestos	5.00E-02	0.00E+00	g/m ³	N/A	5.00E-05	g/m ³	Y
		Lead (Air)	5.00E-02	9.08E-09	g/m ³	N/A	1.50E-04	g/m ³	Y
		Lead (Soil)	5.00E-02	6.53E-08	µg/g	N/A	120	µg/g	Y
		Mercury	5.00E-02	1.44E-09	g/m ³	N/A	1.50E-04	g/m ³	Y
		PCBs	5.00E-02	0.00E+00	g/m ³	N/A	1.30E-02	g/m ³	Y
		Dioxins & Furans	5.00E-02	0.00E+00	g/m ³	N/A	1.30E-07	g/m ³	Y
Bounding Scenario 10	Stack Collapse	Radiation	9.1E-04	5.16E-02	mSv	<3x10 ⁻² to 10 ⁻⁴	>0.5 to 5.0	mSv	Y
		H-3 (Soil)	9.1E-04	1.56E+03	Bq/kg	<3x10 ⁻² to 10 ⁻⁴	1.0E+05	Bq/kg	Y
		C-14 (Soil)	9.1E-04	9.60E+02	Bq/kg	<3x10 ⁻² to 10 ⁻⁴	1.0E+03	Bq/kg	Y

Note: "N/A" – Not Applicable – for the given scenario there is no exposure to *public* receptors.

* Based on the conclusions of the facility SAR's assessment (Athauda-Arachchige 2015; Table 10-8).

Table 9-58 Comparison of Worker Exposure to Acceptance Criteria

Worker Receptors									
Scenario		Calculated				Acceptance Criteria			Meets Acceptance? (Y/N)
Scenario #	Scenario Name	Contaminant	Estimated Frequency (Per Year)	Estimated Exposure		Frequency Category (Per Year)	Exposure Criteria		
Bounding Scenario 1	Forest Fire (Rad)	Radiation	2.80E-03	1.48E-05	mSv	<3x10 ⁻² to 10 ⁻⁴	>5 to 50	mSv	Y
		H-3 (Soil)	N/A	N/A	Bq/kg	N/A	N/A	Bq/kg	N/A
		C-14 (Soil)	N/A	N/A	Bq/kg	N/A	N/A	Bq/kg	N/A
Bounding Scenario 2	Forest Fire (Non-Rad)	Asbestos	2.80E-03	3.00E-05	g/m ³	N/A	5.00E-05	g/m ³	Y
		Lead (Air)	2.80E-03	2.33E-06	g/m ³	N/A	1.00E-01	g/m ³	Y
		Lead (Soil)	N/A	N/A	µg/g	N/A	N/A	µg/g	N/A
		Mercury	2.80E-03	0.00E+00	g/m ³	N/A	1.00E-02	g/m ³	Y
		PCBs	2.80E-03	0.00E+00	g/m ³	N/A	1.30E-02	g/m ³	Y
		Dioxins & Furans	2.80E-03	0.00E+00	g/m ³	N/A	1.30E-07	g/m ³	Y
Bounding Scenario 3	Tornado (Rad) (EF2)	Radiation	6.20E-05	6.43E-15	mSv	<10 ⁻⁴ to 10 ⁻⁵	>50 to 100	mSv	Y
		H-3 (Soil)	N/A	N/A	Bq/kg	N/A	N/A	Bq/kg	N/A
		C-14 (Soil)	N/A	N/A	Bq/kg	N/A	N/A	Bq/kg	N/A
Bounding Scenario 4	Tornado (Non-Rad) (EF2)	Asbestos	6.20E-05	6.12E-17	g/m ³	N/A	5.00E-05	g/m ³	Y
		Lead (Air)	6.20E-05	9.31E-14	g/m ³	N/A	1.00E-01	g/m ³	Y
		Lead (Soil)	N/A	N/A	µg/g	N/A	N/A	µg/g	N/A
		Mercury	6.20E-05	0.00E+00	g/m ³	N/A	1.00E-02	g/m ³	Y
		PCBs	6.20E-05	0.00E+00	g/m ³	N/A	1.30E-02	g/m ³	Y
Bounding Scenario 5*	Flood (Rad)	Radiation	Rare (< 3x10 ⁻² to 10 ⁻⁴)	No Discernible Effect*		<3x10 ⁻² to 10 ⁻⁴	>5 to 50	mSv	Y*
Bounding Scenario 6	Accidental Exposure (Rad)	Radiation	5.00E-02	2.19E+00	mSv	3x10 ⁻¹ to 3x10 ⁻²	1 to 5	mSv	Y
Bounding Scenario 7	Accidental Exposure (Non-Rad)	No Contaminants	N/A	N/A	g/m ³	N/A	N/A	g/m ³	N/A
Bounding Scenario 8	Indoor Fire (Rad)	Radiation	5.00E-02	1.12E-03	mSv	3x10 ⁻¹ to 3x10 ⁻²	1 to 5	mSv	Y
		Cs-137 (Soil)	N/A	N/A	Bq/kg	N/A	N/A	Bq/kg	N/A
		Co-60 (Soil)	N/A	N/A	Bq/kg	N/A	N/A	Bq/kg	N/A
Bounding Scenario 9 (a & b)	Indoor Fire (Non-Rad)	Asbestos	5.00E-02	0.00E+00	g/m ³	N/A	5.00E-05	g/m ³	Y
		Lead (Air)	5.00E-02	7.95E-02	g/m ³	N/A	1.00E-01	g/m ³	Y
		Lead (Soil)	N/A	N/A	µg/g	N/A	N/A	µg/g	N/A
		Mercury	5.00E-02	2.39E-03	g/m ³	N/A	1.00E-02	g/m ³	Y
		PCBs	5.00E-02	0.00E+00	g/m ³	N/A	1.30E-02	g/m ³	Y
		Dioxins & Furans	5.00E-02	0.00E+00	g/m ³	N/A	1.30E-07	g/m ³	Y
Bounding Scenario 10	Stack Collapse	Radiation	9.1E-04	3.74E-04	mSv	<3x10 ⁻² to 10 ⁻⁴	>5 to 50	mSv	Y
		H-3 (Soil)	N/A	N/A	Bq/kg	N/A	N/A	Bq/kg	N/A
		C-14 (Soil)	N/A	N/A	Bq/kg	N/A	N/A	Bq/kg	N/A

Note: "N/A" – Not Applicable – for the given scenario there is no exposure to *worker* receptors. (e.g. Lead (soil) is not applicable to worker receptor locations because those locations are indoors within the main facility).

* Based on the conclusions of the facility SAR's assessment (Athauda-Arachchige 2015; Table 10-8).

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9.9 Accidents Assessment Conclusions

The accidents assessment reviewed the planned list of decommissioning activities (according to the work breakdown structure) to develop a list of potential hazards and hazardous events. The hazardous events were grouped into scenarios, which were assigned potential risk ratings and underwent a screening process through which 10 bounding scenarios were identified, encompassing fire, non-fire (e.g. tornado events, system failure events, exposure events), and flooding events (among others). The accidents assessment also identified and accounted for numerous safeguards for the planned activities.

For conventional accidents, it is important to note that *several* safeguards are - or will be - in place, as discussed in Section 7.4. These include preventative measures to reduce the probability that conventional accidents will occur, as well as mitigative measures to reduce the severity of accidents, where they do occur. As discussed in Section 8.3.3, the many safeguards in place render the likelihood of these events as low as reasonably practicable.

Each of the 10 bounding scenarios underwent a consequence assessment to determine the source term (radiological and chemical) involved, estimated dispersion/transport to receptor locations, and corresponding dose estimates at each receptor location. These dose estimates were assigned severity ratings. Each of the 10 bounding scenarios then underwent a frequency assessment. These frequency estimates were assigned frequency ratings. Lastly, the severity ratings and frequency ratings for each bounding scenario were used, in conjunction with a risk matrix, to calculate a risk rating for each bounding scenario. Figure 9-18 presents the risk matrix overlaid with all 10 bounding scenarios, according to their severity, frequency, and risk ratings.

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Figure 9-18 Risk Matrix Showing all Bounding Scenarios

Frequency Ratings	Severity Ratings				
	S0	S1	S2	S3	S4
F0	R0	R0 B.Scen.#3 B.Scen.#4	R0	R0	R1
F1	R0 B.Scen.#5	R0 B.Scen.#1 B.Scen.#2 B.Scen.#10	R0	R1	R2
F2	R0 B.Scen.#7	R0 B.Scen.#8 B.Scen.#9	R1 B.Scen.#6	R2	R3
F3	R0	R1	R2	R3	R3

Notes:

- Bounding Scenario #1 – Forest Fire (radiological releases)
- Bounding Scenario #2 – Forest Fire (chemical releases)
- Bounding Scenario #3 – Tornado (radiological releases)
- Bounding Scenario #4 – Tornado (radiological releases)
- Bounding Scenario #5 – Flood (radiological releases)
- Bounding Scenario #6 – Drilling (exposure accident) (radiological releases)
- Bounding Scenario #7 – Drilling (exposure accident) (chemical releases)
- Bounding Scenario #8 – Indoor Fire (radiological releases)
- Bounding Scenario #9 – Indoor Fire (chemical releases)
- Bounding Scenario #10 – Collapse of Ventilation Stack (radiological releases)
- See Table 7-4 for descriptions of Frequency Ratings
- See Table 7-5 for descriptions of Severity Ratings
- See Table 7-6 for descriptions of Risk Ratings

As shown in Figure 9-18, all bounding scenarios were assessed to have negligible risk scores, with the exception of scenario 6, which is a tolerable risk even given the conservative assumptions associated with the scenario. The potential risks to non-human biota are evaluated in the *Ecological Risk Assessment TSD* (Garisto *et al.*, 2020a), which identified no adverse effect on non-human biota from exposure to radioactive or chemical contaminants.

Overview of Hazards and their Assessments

The HI process (Section 7.0) identified a range of potentially hazardous events associated with the planned decommissioning activities (Appendix B). These hazards included normal operations hazards, potential accidents scenarios, and conventional hazards. Table 9-59, below, summarizes all hazard events that the HI process identified as having potentially high risk scores - as well as the identified bounding scenarios - and outlines how each of these have been addressed in this assessment. Table 9-59 offers a concise summary of how these hazard events were assessed, and that they were shown to have low risks.

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Table 9-59 Assessment Conclusions – Bounding Scenarios & ‘R2’ Hazards

Haz. ID No.	Hazardous Event	Consequence (C)	Prelim. Risk Rank	How Assessed	Conclusions	Follow-up Actions
General 2	Conventional construction accident	Work place fatality due to typical project activities such as working at heights, working with heavy equipment. Potential injuries include falls, trips, crushing, etc.	R2	Conventional Safety Assessed in Section 8.3.3	The risk is inherent to the activities. No additional action is required	-
General 7	Transportation accident, offsite	Fatalities	R2	Conventional Safety Assessed in Section 8.3.3	The risk is inherent to the transportation activities. No additional action is required	-
General 10	Forest fire	Release of radioactivity (from aboveground portion only) due to fire spreading to the building and mobilizing the radionuclides	R1	Assessed as a Bounding Scenario: Forest Fire (Rad.) See Section 9.0	Assessment results indicate R0. The risk is inherent to the natural event (forest fire).	<ul style="list-style-type: none"> - Continue to maintain fire breaks clear of vegetation. - Consider additional fire breaks / extending existing breaks via removal of nearby trees - Keep emergency access routes clear
General 11	Forest fire	Smoke inhalation, chemical exposure (chemicals in the above ground portion only), and worker injuries due to burning of combustibles.	R1	Assessed as a Bounding Scenario: Forest Fire (Non-Rad.) See Section 9.0	Assessment results indicate R0. The risk is inherent to the natural event (forest fire).	
General 13	Forest fire	Fatality	R2	Conventional Safety Assessed in Section 8.3.3	The risk is inherent to the natural event (forest fire).	
General 14	Tornado	Release of radioactivity (from aboveground portion only) due to damage to the building and mobilizing the radionuclides	R2	Assessed as a Bounding Scenario: Tornado (Rad.) See Section 9.0	Assessment results indicate R0. The risk is inherent to the natural event (tornado).	<ul style="list-style-type: none"> - Keep emergency routes clear - Review tornado

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Haz. ID No.	Hazardous Event	Consequence (C)	Prelim. Risk Rank	How Assessed	Conclusions	Follow-up Actions
General 15	Tornado	Exposure to chemicals (chemicals in the aboveground portion only) released due to damage to the building and mobilizing the radionuclides	R2	Assessed as a Bounding Scenario: Tornado (Non-Rad.) See Section 9.0	Assessment results indicate R0. The risk is inherent to the natural event (tornado).	response procedure if needed – e.g. to account for new on-site trailers and activities; account for time period where the NPD structure is partially dismantled.
General 17	Tornado	Fatality	R2	Conventional Safety Assessed in Section 8.3.3	The risk is inherent to the natural event (tornado).	
General 19	Heavy precipitation, Flood	Release of radioactivity due to water ingress and subsequent mobilization of radionuclides	R2	Assessed as a Bounding Scenario: Flood (Rad.) See Section 9.0	Bounded by precipitation flood assessment in the facility SAR - concluded that such an event would be rare, with no discernable effect, and that dose criteria would be met (i.e. R0). The risk is inherent to the natural event (heavy precip. flood).	-
General 21	Heavy precipitation, Flood	Fatality, site access	R2	Conventional Safety Assessed in Section 8.3.3	The risk is inherent to the natural event (flood). No additional action is required.	-
General 25	Earthquake	Fatality	R2	Conventional Safety Assessed in Section 8.3.3	The risk is inherent to the natural event (earthquake). No additional action is required.	-

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Haz. ID No.	Hazardous Event	Consequence (C)	Prelim. Risk Rank	How Assessed	Conclusions	Follow-up Actions
General 30	Failure to isolate power, general construction activity	Electrocution (Fatality)	R2	Conventional Safety Assessed in Section 8.3.3	No additional action is required.	-
Opp. Batch Plant 2	Equipment failure while setting up batch mixing plant	Drop of heavy equipment and fatality	R2	Conventional Safety Assessed in Section 8.3.3	No additional action is required.	-
Grout Below Grade Structures 3	Contact of grout with aluminum materials from the reactor	Hydrogen generation and potential for fire or explosion	R1	Assessed as part of Normal Operations (see Section 8.0).	Based on the findings of Hongqiang (2017), and assuming that the measures to address hydrogen safety are implemented, adverse effects on workers are not anticipated.	Monitor during grouting, and implement measures to address hydrogen safety, as needed.
Grout Below Grade Structures 8	Working underground and confined spaces in IDLH (e.g. low oxygen)	Fatality	R2	Conventional Safety Assessed in Section 8.3.3	No additional action is required.	-
Grout Below Grade Structures 9	Accidental exposure to radioactivity	Exposure to radiological dose during demolition of walls, cutting holes, cutting vessels and pipes (this is the exposure beyond the level expected during planned demolition activities which will be assessed under "Normal Conditions").	R1	Assessed as a Bounding Scenario: Exposure to Radioactivity. See Section 9.0	Assessment results indicate R1.	Continue to prepare work control and radiation protection plans before decommissioning tasks are undertaken.
Grout Below Grade Structures 10	Underground fire (e.g. from small equipment fuel spill)	Airborne release of radionuclides	R0	Assessed as a Bounding Scenario: Underground Fire (Rad.) See Section 9.0	Assessment results indicate R0.	Continue to minimize the amount of combustible

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Haz. ID No.	Hazardous Event	Consequence (C)	Prelim. Risk Rank	How Assessed	Conclusions	Follow-up Actions
Grout Below Grade Structures 11	Underground fire (e.g. from small equipment fuel spill)	Smoke inhalation and workers injuries due to burning of combustibles	R1	Assessed as a Bounding Scenario: Underground Fire (Non-Rad.) See Section 9.0	Assessment results indicate R0.	material in rooms.
Demol. Above Grade Structures 8	Accidental exposure	Chemical exposure	R1	Assessed as a Bounding Scenario: Exposure to Hazardous Chemicals. See Section 9.0	Assessment results indicate R0.	-
Demol. Above Grade Structures 10	Collapse of unstable structures*	Fatality	R2	Conventional Safety Assessed in Section 8.3.3	No additional action is required.	-
Demol. Above Grade Structures 15	Accidental collapse of stack*	Fatality	R2	Conventional Safety Assessed in Section 8.3.3	No additional action is required.	-
Demol. Above Grade Structures 16	Accidental collapse of stack*	Release of radioactivity	R0	Assessed as a Bounding Scenario: Stack Collapse & Exposure to Radioactivity. See Section 9.0	Assessment results indicate R0.	-
Remove Guard House 5	Collapse of unstable structures*	Personal injury, fatality	R2	Conventional Safety Assessed in Section 8.3.3	No additional action is required.	-

Notes:

*Safe demolition will be performed following a demolition plan, prepared in accordance with demolition plan guidelines outlined by the Professional Engineers of Ontario and stamped by an engineer (see Section 8.3.2 for additional details).

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10.0 DISCUSSION

Section 8.9 outlines the conclusions of the normal operation assessment and Section 9.9 outlines the conclusions of the accidents assessment. These are discussed further below.

10.1 Normal Operations Assessment

Normal operations were assessed by evaluating the planned decommissioning activities and descriptions from the project's DDP, and reviewing these for potential interactions with key environmental components and receptors from the EIS.

The activities assessed include:

- Batch mixing plant (set up, operation, and transporting mixed grout);
- Grouting of below-grade structures (preparation, and grouting);
- Removal of above-grade structures (demolition, sizing, clearance surveying, and emplacement into below-grade areas for grouting);
- Concrete cap and engineered barriers; and,
- Final site restoration.

The environmental components assessed include:

- Atmospheric Environment;
- Surface Water Environment;
- Geological & Hydrogeological Environment;
- Radiation & Radioactivity Environment;
- Effects on Public Health;
- Effects on Worker Health; and
- Effects on Non-Human Biota.

Those activities (or groups of activities) that were identified as having a potential interaction with one or more environmental components underwent more detailed assessment.

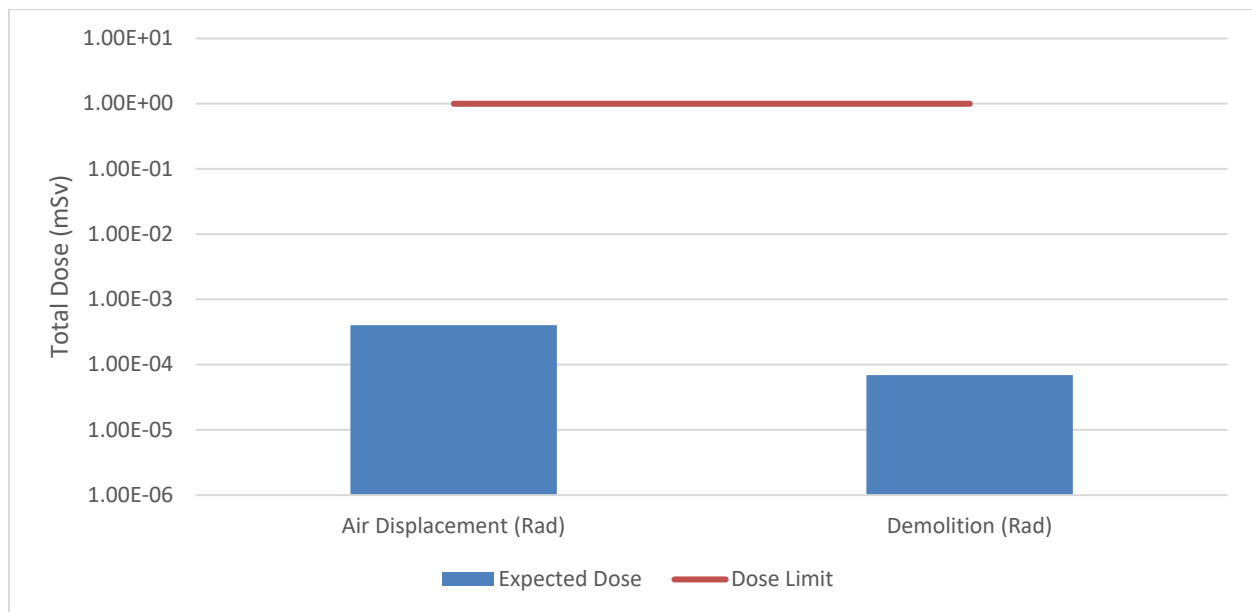
Exposure Effects – radiological & non-radiological – were assessed as follows:

- *Atmospheric Environment:*
Potential effects on the atmospheric environment component were assessed for each group of activities, with results indicating that no adverse effects are expected.

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- Surface Water Environment:**
Standard practices typical of construction projects – as discussed in Section 8.3.2 - will be implemented. Once implemented, these control measures will reduce surface water runoff/releases and dust releases, and as such, no adverse effects are expected.
- Geological/Hydrogeological Environment:**
Standard practices typical of construction projects – as discussed in Section 8.3.2 - will be implemented. Once implemented, these control measures will reduce surface water runoff/releases and dust releases, and as such, no adverse effects are expected.
- Radiation & Radioactivity Environment:**
Demolition and grouting activities were found to have associated radiological releases to the environment. The potential effects of these releases are assessed via effects assessments of the other environmental components (i.e. atmospheric environment, surface water environment, geological/hydrogeological environment, public health, worker health, and non-human biota).
- Public Health:**
For all activities, radiological dose estimates were below corresponding public criteria, and as such, no adverse effects are expected to the 'Public Health' environmental component. These results are shown in the figures below.

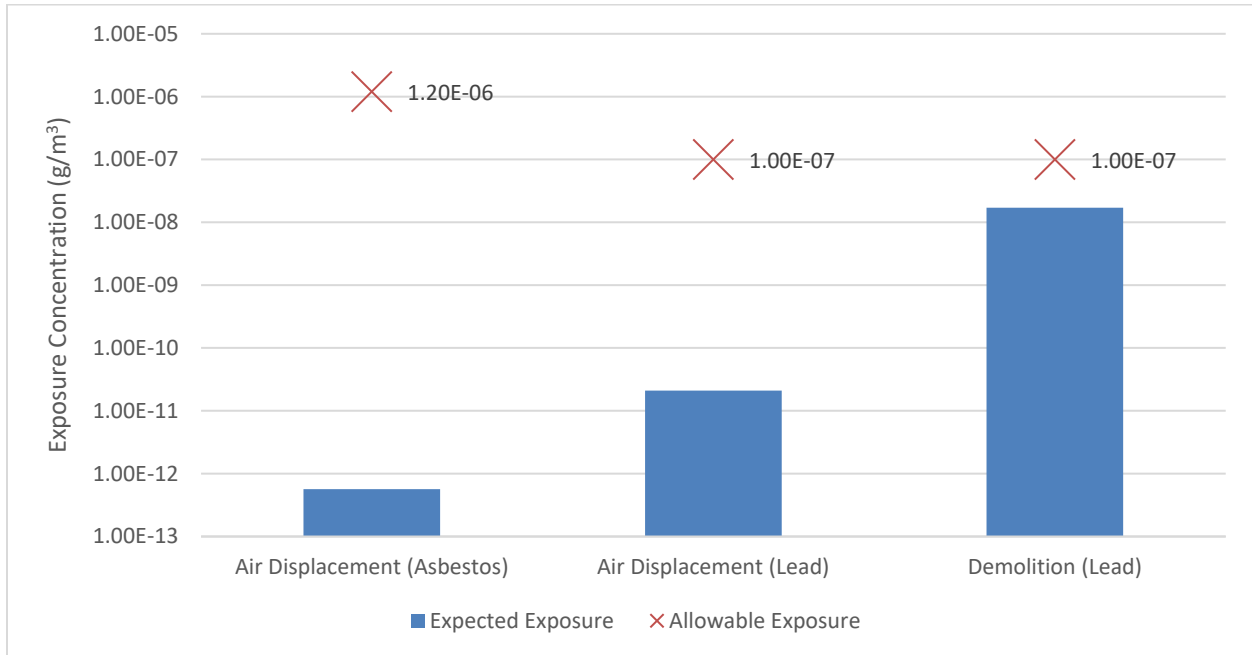
Figure 10-1 Normal Operations – Public - Radiological Dose Comparison



Note: log scale.

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Figure 10-2 Normal Operations – Public – Non-Radiological Airborne Exposure Comparison (Asbestos, Lead)

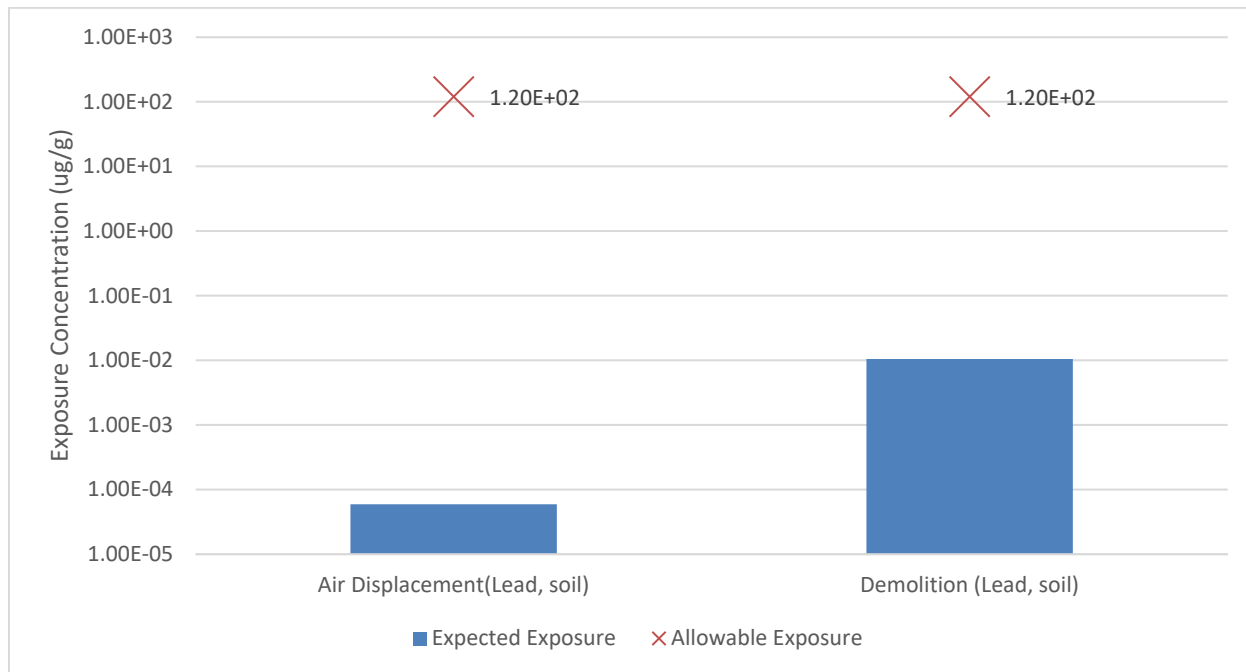


Note: log scale.

Note: Allowable Exposure: See Section 4.1.6.1 for asbestos and lead public criteria.

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Figure 10-3 Normal Operations – Public – Non-Radiological Soil Exposure Comparison (Lead)



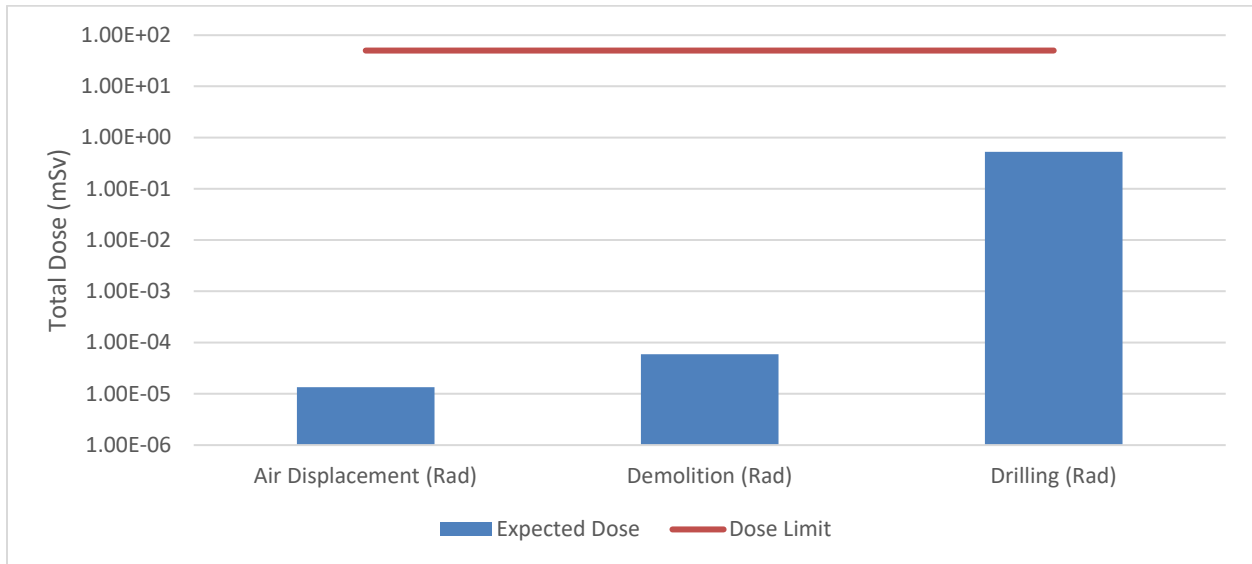
Note: log scale.

Note: Allowable Exposure: See Section 4.1.6.1 for lead public criteria.

- Worker Health:**
For all activities, radiological dose estimates were below corresponding worker criteria (for hydrogen gas, the estimated concentration was below the flammability limit), and as such, no adverse radiological effects are expected to the ‘Worker Health’ environmental component. These results are shown in the figures below.

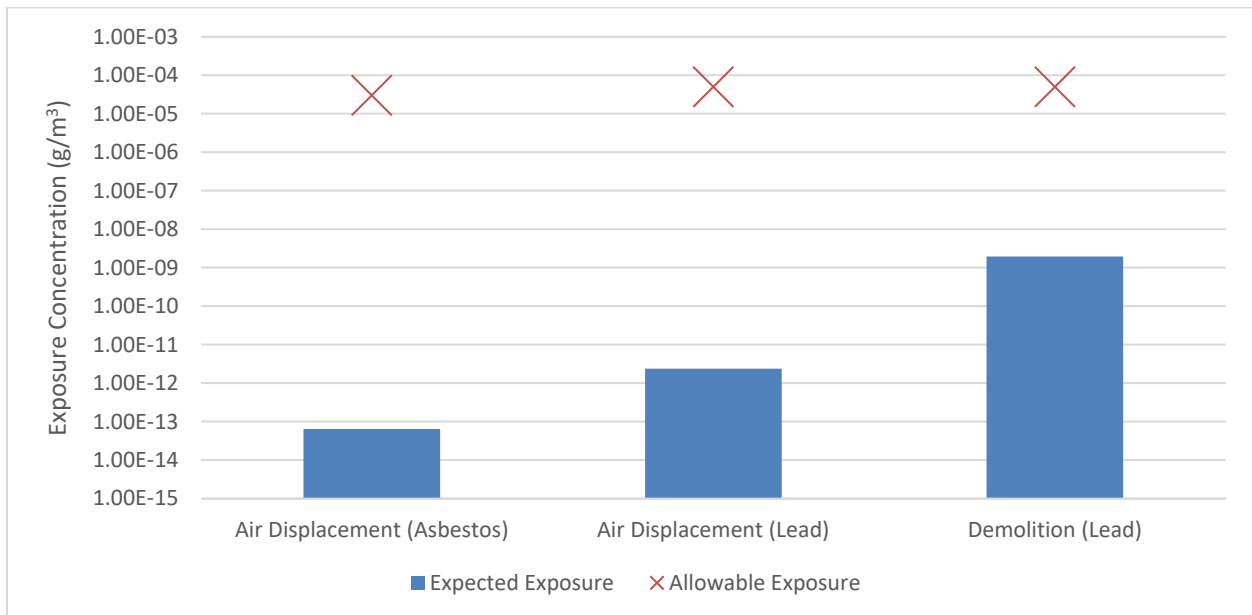
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Figure 10-4 Normal Operations – Workers – Radiological Dose Comparison



Note: log scale.

Figure 10-5 Normal Operations – Workers – Demolition Non-Radiological Airborne Exposure Comparison (Asbestos, Lead)

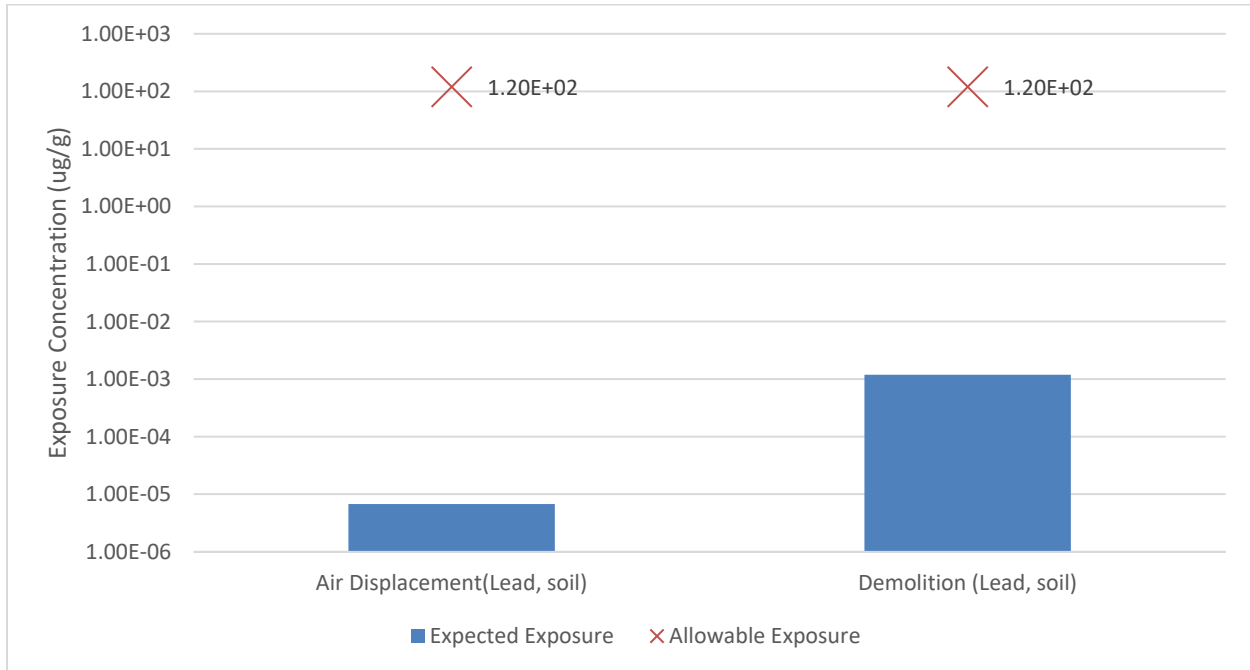


Note: log scale.

Note: Allowable Exposure: See Section 4.1.6.1 for asbestos and lead worker criteria.

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Figure 10-6 Normal Operations – Workers – Demolition Non-Radiological Soil Exposure Comparison (Lead)



Note: log scale.

Note: Allowable Exposure: See Section 4.1.6.1 for lead worker criteria.

- Non-Human Biota:**
As outlined in Section 1.2, exposure effects on non-human biota are assessed in the *Ecological Risk Assessment TSD* (Garisto *et al.*, 2020a), which identified no adverse effects for non-human biota. As outlined in Section 1.2, non-exposure effects (e.g. habitat-based effects) on non-human biota are assessed in the EIS.

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10.2 Malfunctions & Accidents Assessment

Summary

The accidents assessment involved completion of the following steps:

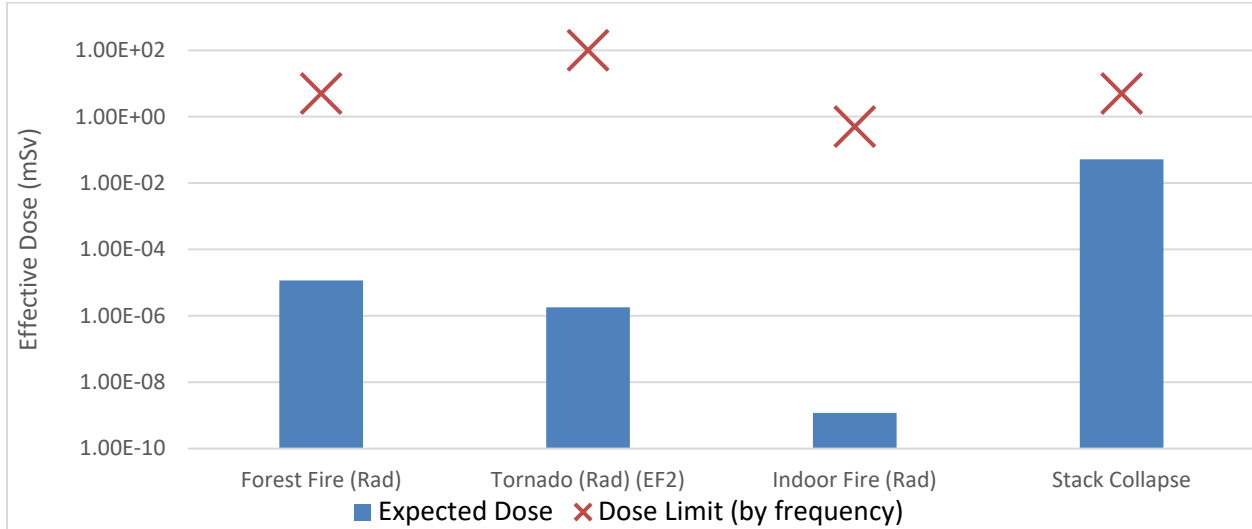
1. **Hazard Identification:** the list of planned decommissioning activities was reviewed to develop a list of potential hazards and hazardous events.
2. **Development of Bounding Scenarios:** the list of hazardous events (from above) underwent a screening process through which 10 bounding scenarios were identified:

Bounding Scenario #1: Forest Fire (Radiological Releases);
Bounding Scenario #2: Forest Fire (Chemical Releases);
Bounding Scenario #3: Tornado (Radiological Releases);
Bounding Scenario #4: Tornado (Chemical Releases);
Bounding Scenario #5: Flood (Radiological Releases);
Bounding Scenario #6: Drilling (exposure accident) (Radiological Releases);
Bounding Scenario #7: Drilling (exposure accident) (Chemical Releases);
Bounding Scenario #8: Indoor Fire (Radiological Releases);
Bounding Scenario #9: Indoor Fire (Chemical Releases);
Bounding Scenario #10: Collapse of Ventilation Stack (Radiological Releases).

3. **Consequence Assessment:** each of the 10 bounding scenarios underwent a consequence assessment to estimate radiological doses as well as non-radiological exposure to public and worker receptors. The results are shown in Figure 10-7 to Figure 10-10 below.

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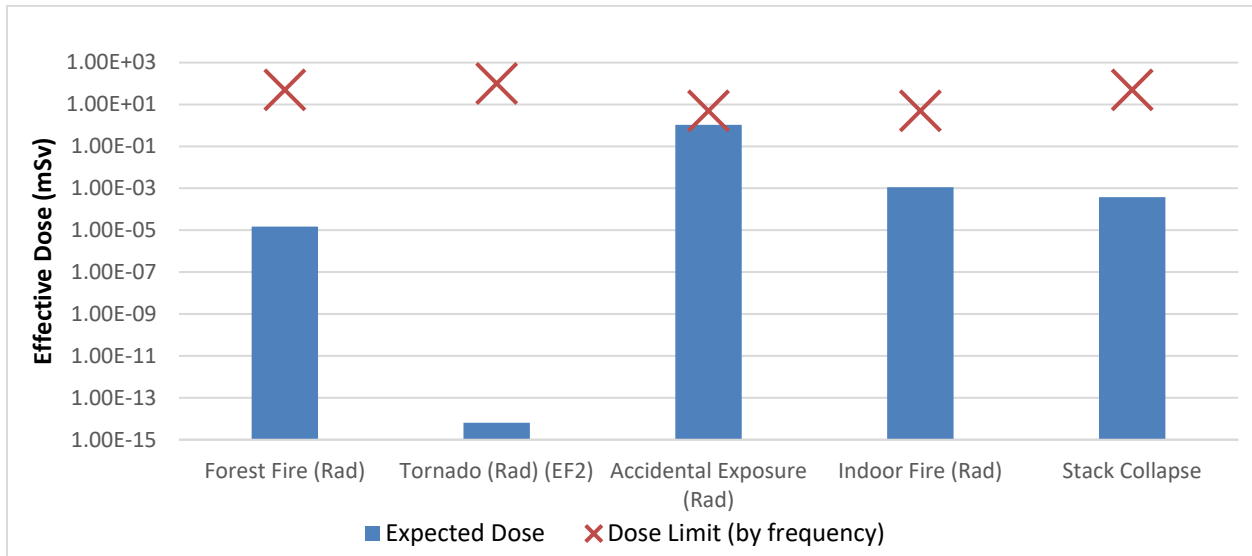
Figure 10-7 Consequence Assessment Results – Public – Radiological Dose Comparison



Note: log scale.

Note: Dose Acceptance Criteria by Frequency: see Section 4.1.5.

Figure 10-8 Consequence Assessment Results – Workers – Radiological Dose Comparison



Note: log scale.

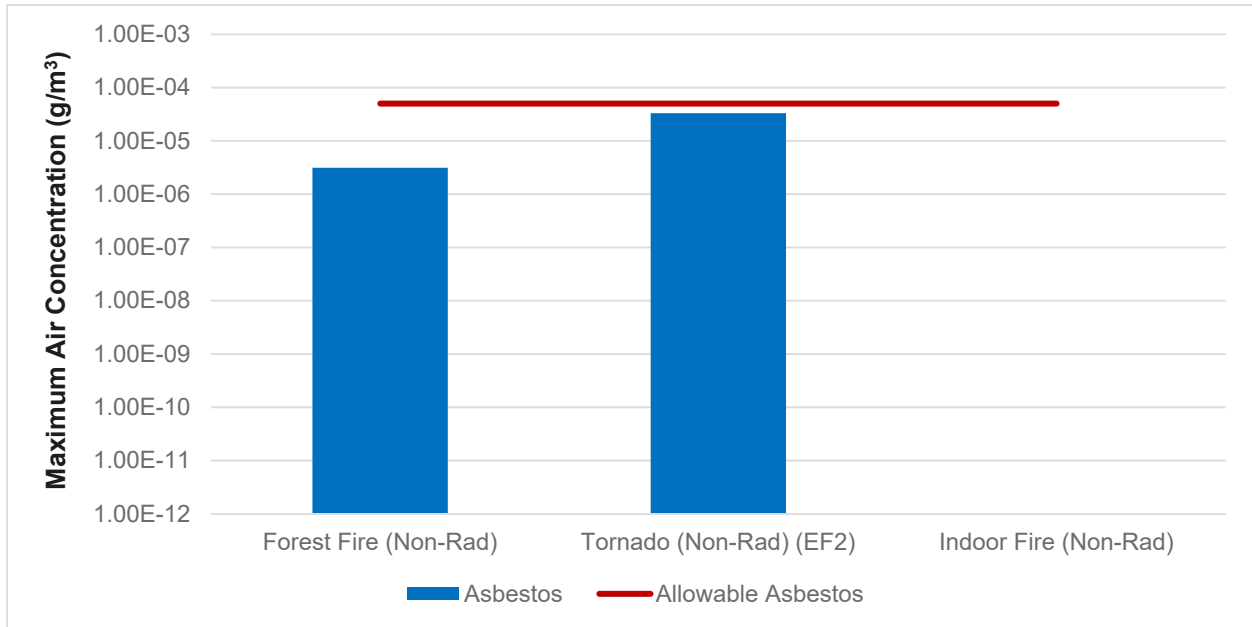
Note: Dose Acceptance Criteria by Frequency: see Section 4.1.5.

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Figure 10-9 Consequence Assessment Results – Public – Non-Radiological Exposure Comparison

(By hazardous chemical; for applicable scenarios)

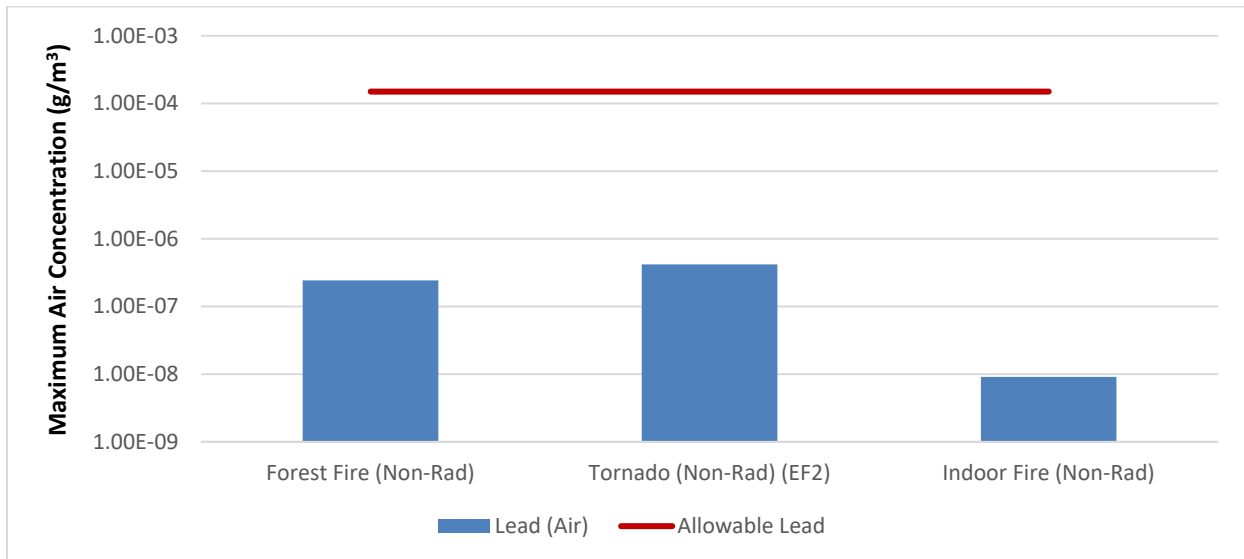
a) Asbestos



Note: log scale.

Note: Criterion - see Section 4.1.6.2.

b) Lead, air

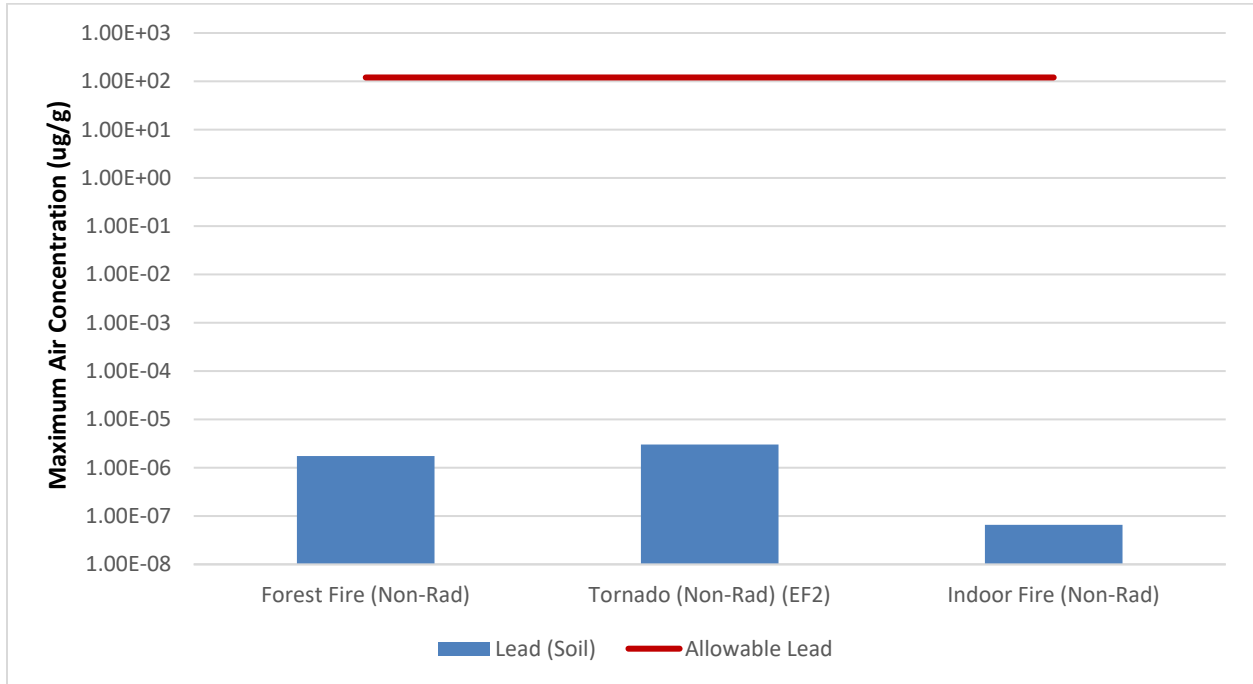


Note: log scale.

Note: Criterion - see Section 4.1.6.2.

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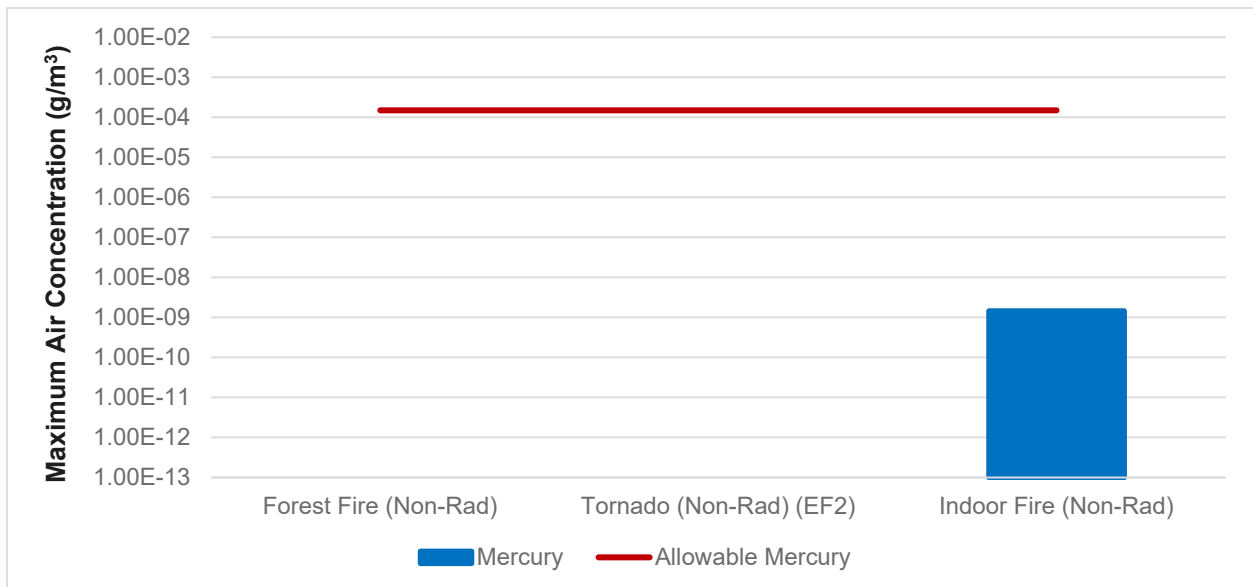
c) Lead, soil



Note: log scale.

Note: Criterion - see Section 4.1.6.2.

d) Mercury



Note: log scale.

Note: Criterion - see Section 4.1.6.2.

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d) PCBs

As identified in Section 9.2.1, PCBs are not considered to be part of the MAR for any of the scenarios.

e) Dioxins & Furans

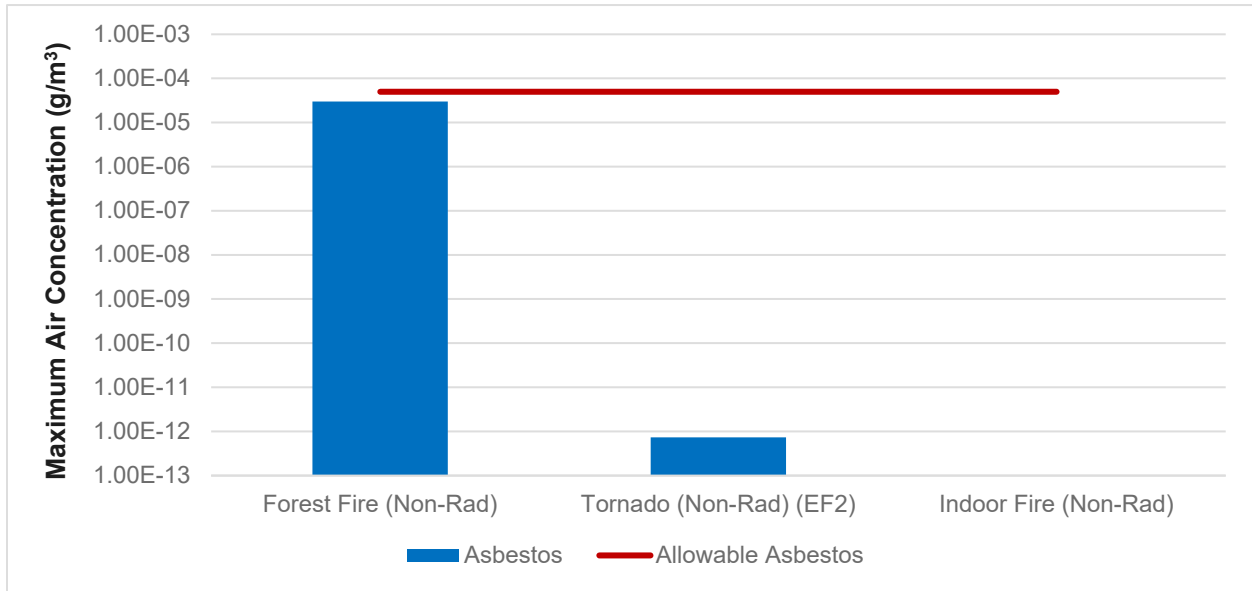
As identified in Section 9.2.1, PCBs are not considered to be part of the MAR for any of the scenarios, and as such, no Dioxins and Furans are produced.

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Figure 10-10 Consequence Assessment Results – Workers – Non-Radiological Exposure Comparison

(By hazardous chemical; for applicable scenarios)

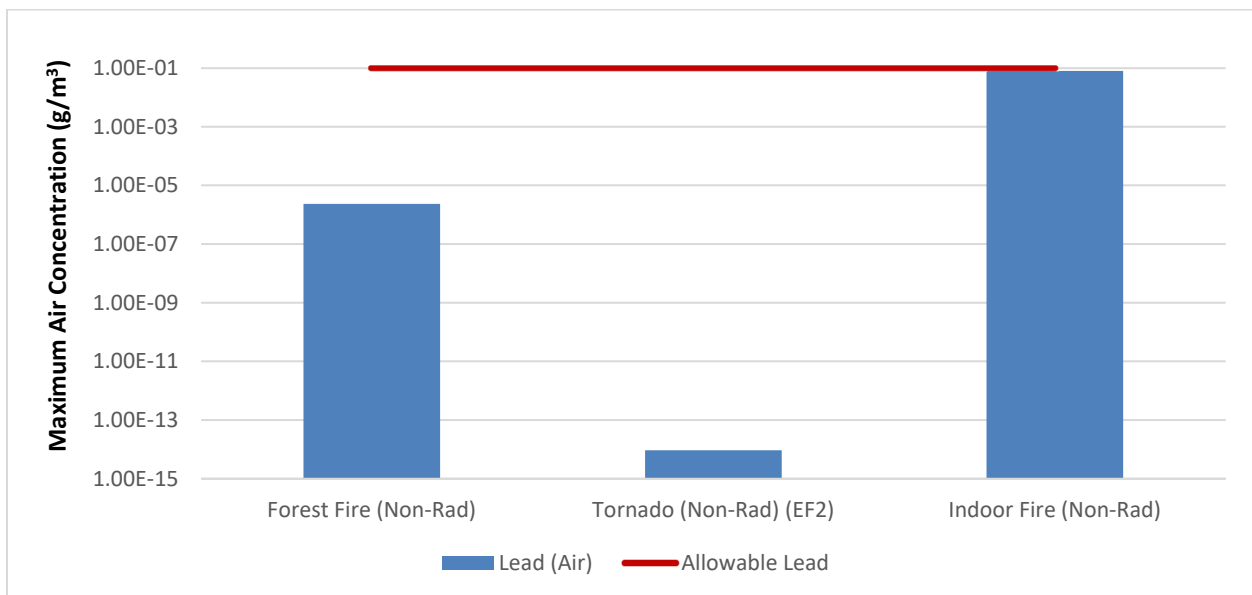
a) Asbestos



Note: log scale.

Note: Criterion - see Section 4.1.6.2.

b) Lead, air

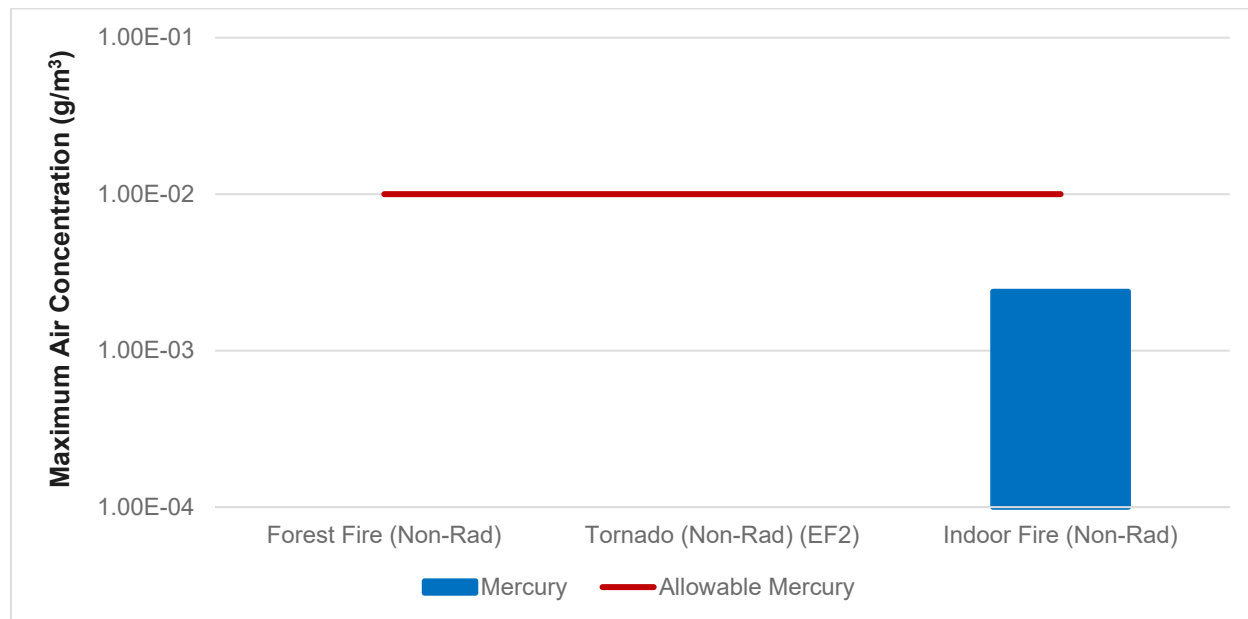


Note: log scale.

Note: Criterion - see Section 4.1.6.2.

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c) Mercury



Note: log scale.

Notes: Criterion - see Section 4.1.6.2.

d) PCBs

As identified in Section 9.2.1, PCBs are not considered to be part of the MAR for any of the scenarios.

e) Dioxins & Furans

As identified in Section 9.2.1, PCBs are not considered to be part of the MAR for any of the scenarios, and as such, no Dioxins and Furans are produced.

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4. **Frequency Assessment:** each of the 10 bounding scenarios underwent a frequency assessment to estimate the likelihood of their occurrence and the mechanisms involved.
5. **Risk Characterization:** each of the 10 bounding scenarios were assigned a severity rank based on their estimated consequences, and a frequency rank based on their estimated frequency. These ranks were then combined using a risk matrix (outlined in Section 7.6.3) in order to produce a risk score for each bounding scenario.

All 10 bounding scenarios were assessed to have risk scores corresponding to negligible risks. This is shown graphically in Figure 9-18.

Conventional Accidents & Conventional Safety:

Finally, with respect to conventional safety, Fundamental Safety Principles will be followed, to ensure that safety is incorporated into all phases of the work from planning through to execution. To further emphasize the role of safety, a non-exhaustive list outlining many examples of safeguards that will be applied to the project was presented in Section 7.4 covering conventional accident safeguards, routing/transportation safeguards, fueling safeguards, weather and natural event safeguards, security safeguards, grouting safeguards, and many other topics. Therefore, given the fundamental safety principles that govern project planning and execution, and the many safeguards involved, conventional accidents are considered to be managed to as low as reasonably practicable.

10.3 Operational Limits

The following list outlines notable actions, plans, or assumptions that are being credited in this DecomSA and therefore need to be carried forward into future planning and execution:

- **Planned Activities:** the DecomSA assesses the planned activities outlined in Section 7.0, and therefore significant changes or deviations from these planned activities would require reassessment. Notably the DecomSA assumes that no in-water works are required, and no un-assessed liquid effluents are released to the Ottawa River.
- **Planned Inventory:** the DecomSA assesses the estimated inventory outlined in Section 5.0. Therefore, significant changes to this inventory would require reassessment.
- **Safeguards & Related Plans/Programs:** several safeguards and plans are assumed to be in place for normal operations, and have been credited in this assessment. Section 7.4 outlines several examples of safeguards related to conventional accidents, site transportation, fueling, security, radiation protection, design and construction. Included among these safeguards are several safety-related plans or programs, notably: Grout Fill Plan, Demolition Plan, Health & Safety Program(s), Contractor's Health & Safety Program(s), Site Plan, Road Maintenance Program, Staging & Transportation Plan, Radiation Protection Plan, and other future work control documents. It is assumed that these safeguards and plans/programs will be implemented and adhered to.

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- **Misting:** the use of misting to control airborne releases (dust) is credited in the DecomSA's analyses for normal operations.
- **Combustible Materials:** the NPD main structure current contains low levels of combustible material. The DecomSA's analyses are based on continuing to maintaining a low amount of combustible material within the facility.
- **Runoff Management:** the DecomSA's analysis of normal operations is based on the assumption that systems are implemented to manage surface water runoff.
- **Hydrogen Gas Safeguards:** the DecomSA's analysis of normal operations is based on the assumption that measures are implemented to manage hydrogen gas released during grouting activities. Active ventilation will be the primary measure used to maintain hydrogen levels at a safe concentration, though Hongqiang (2017) outlines additional measures that could be considered, if needed.
- **No Fuel or Gas-Powered Equipment During Final Removal of PCB-Containing Light Ballasts:** As mentioned in Section 5.2.4, there is the possibility that a select few light ballasts will be removed *during* decommissioning (as opposed to being removed *before* decommissioning begins). The DecomSA's analysis of normal operations and accidents are based on the assumption that light ballasts do remain, and thus are removed during decommissioning. If this is the case, then no fuel or gas-powered equipment is to be present in the room during the final removal of the remaining PCB-containing light ballasts (i.e. while the floor level has been raised by prior grouting).

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11.0 DEALING WITH UNCERTAINTIES: CONSERVATISM & ROBUSTNESS IN THE SAFETY ASSESSMENT

This section acknowledges sources of uncertainty in the DecomSA and how these uncertainties are addressed. The treatment of uncertainty is a key issue because of the predictive nature of the assessment and the range and nature of processes involved. Overall, uncertainties in this iteration of the DecomSA can be categorized into three types:

- 1 **Scope Uncertainty:** uncertainty in the planned activities and in the system;
- 2 **Model Uncertainty:** uncertainty in the models used to perform calculations;
- 3 **Data Uncertainty:** uncertainty in the data and parameters used in the modelling.

These are discussed separately below.

Scope Uncertainties

The DecomSA is based on two hazard identification workshops (May 31st, 2016; March 7, 2017), a site walk-down (October 18th, 2016), the planned project activity list the general approach to in-situ disposal at the site, and a description of the overall decommissioning plan in the DDP (Section 7). These sources provide information on the overall decommissioning plan and key decisions regarding site features and structures. However, some uncertainties do remain regarding the execution of certain tasks; for example, there is some uncertainty in the time required to complete demolition of the above-grade structure, and, there is some uncertainty in the time required to drill access holes for grout and venting.

In general, scope uncertainties are managed in the current assessment by evaluating a range of conservative bounding scenarios, using a suite of different calculation variants, and by using conservative models and conservative data inputs. An overall attitude towards conservatism is also applied throughout the analysis, though, where possible, scientifically informed, realistic assumptions are made. In addition, where measurement data are available, they are used as inputs to calculations, or for performing a comparison between results, or to limiting the range of variants for a scenario.

Where there are high levels of uncertainty, conservative assumptions are adopted. As such, it is acknowledged that the combined effect of many conservative assumptions can lead to unrealistic consequence estimates.

Model Uncertainties

The DecomSA addresses model uncertainties by using defensible models and equations that are supported by guidelines or standards wherever possible. Examples include:

- Using the source term derivation equation from the US Department of Energy (DOE 1994;

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- Using AERMOD (EPA 2001) and CALPUFF (Scire *et al.* 1990, 2000) for air dispersion calculations, which are credible codes recognized by Ontario Ministry of Environment and Climate Change (MOECC) and CSA N288.6 (CSA 2012);
- Relying on results from the existing DRL (Chouhan and Scheier 2011) for NPD, which is conservative and consistent with CSA N288.1 (CSA 2018).

Nevertheless, there are model uncertainties that should be acknowledged. For example:

- **Near-Field Dispersion Calculations:**

Near-field dispersion calculations presently rely on a simple two-zone box model. The two-zone box model is used because standard air models such as AERMOD (EPA 2001) and CALPUFF (Scire *et al.* 1990, 2000) are generally appropriate for far-field air dispersion calculations but are not valid close to the source. Uncertainties in the use of the two-zone box model method can be addressed using sensitivity analysis. If the effects results are close to the benchmark, more sophisticated modelling (i.e. computational fluid dynamics) can be considered. Though simple, the two-zone model is desirable over assuming complete and uniform dispersion into a receiving volume, which does not account for potentially higher concentrations closer to the release point.

- **Far-field Air Dispersion Calculations:**

The meteorological data set used to perform the AERMOD (EPA 2001) and CALPUFF (Scire *et al.* 1990, 2000) dispersion calculations is based on data from the Chalk River Site, supplemented with the MOECC approved dataset from Ottawa. Use of the MOECC approved Ottawa dataset has an advantage in that it gives a level of confidence to the quality/completeness of the data.

A meteorological dataset may be available from Petawawa - which is closer to NPD than Ottawa – to supplement the limited data from the Chalk River Site, but the Petawawa dataset would first require review for completeness to ensure that relevant parameters are measured and critical gaps do not exist as compared to the MOECC-approved Ottawa dataset. However, given that air dispersion is not a significant pathway - since it is only a risk during short-term decommissioning activities - and the exposure results for conditions associated with normal operations are well below their acceptance criteria indicating a large safety margin, the use of the current dataset is viewed by CNL as sufficient.

Data Uncertainties

The main parameter uncertainties in the DecomSA analyses relate to the radiological and chemical inventory. This includes (but is not limited to):

- Uncertainties in the quantity of asbestos that is inaccessible, located within structural components in the above-grade and below-grade portion of the facility;

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- Uncertainties in the emissions from cutting operations (beyond greenhouse gas releases);
- Uncertainties in the radionuclide inventory, notably, C-14 in steel (though bounding scenario 8 assess 2 variants of the inventory, as a sensitivity case);
- Uncertainties related to the overall variability and measurement accuracy of radionuclides in the facility and on surfaces.

Uncertainties related to radionuclide levels in the facility have been reduced through sampling and measurement surveys recently completed by CNL. Measurement data obtained from the facility supports the use of ORIGIN-modelled inventory as a conservative estimate. Also, radionuclide inventories used for the above-grade structure are obtained from measured values. The inventories used for normal and accidents calculations are conservative estimates, and produce dose estimates that are below corresponding dose limits by a safety margin. Lastly, CNL's process for detailed work planning generally re-evaluates the estimated doses again in the future, once the tasks are better defined and more details are available. This functions as an important verification step in the production of detailed procedures and work control documents. Any new measurement data obtained would also be used in future detailed work planning stage.

Uncertainties related to hazardous substances, particularly lead and asbestos, are address by using conservative inventory estimates and applying conservative source terms to release scenarios. Resulting calculations are therefore more likely to overestimate risk.

For data obtained from literature/guidance documents, associated input uncertainties are managed by using parameter values that are conservative and defensible. This includes for example, inhalation rates, dose coefficients, and receptor pathways. In particular, benchmark criteria (e.g. acceptance criteria) are obtained from studies, guidelines and standards that are credible and defensible, such as:

- CNSC regulatory dose limits (CNSC 2015);
- Occupational air concentration criteria from the Canada Occupational Safety & Health Regulations (including those recommended from the ACGIH);
- Ambient air quality standards from the Ontario Ministry of Environment and Climate Change (MOECC) (MOE 2012);
- Protective Action Criteria (PACs) from the US Department of Energy (DOE 2016); and,
- Established Derived Release Limits (DRLs) for the site (Chouhan and Scheier 2011).

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12.0 QUALITY ASSURANCE AND QUALITY CONTROL

Arcadis has an internal Quality Management System (QMS) that has been certified to ISO 9001:2015. This DecomSA has been developed under Arcadis' QMS; under a project specific Quality Assurance (QA) Plan (QAP); and, under CNL's overall Quality Management System as well as applicable regulations, standards and guidelines for the larger decommissioning project.

The project-specific QAP (including addendums) describes the specific provisions that are used to manage quality within the DecomSA. It encompasses:

- Roles and responsibilities, including quality roles (e.g. Project Director and Project Manager; Task Leads; and QA reviewers);
- Project management and file management;
- Subcontractor management;
- Processes for change managing;
- Project documentation and record keeping;
- Project communications;
- Key software tools used (with information such as descriptions, version numbers, user manual locations, validation, and verification);
- Outlining reviews of written deliverables, data, and calculations (as applicable);
- Quality reviews (checks).

QA Reviewers:

QA Reviewers are qualified personnel that review project work to ensure that material is complete, accurate, and appropriate, and that calculations are free of errors. The QAP identifies QA reviewers (and presents their qualifications) that are appropriate for the different types of reviews that are to be performed.

QA Reviews (Checks)

Several QA reviews (or 'checks') are completed as part of the DecomSA's development. These quality reviews involve checks of specific items to ensure correctness and completeness, and they generally apply to specific iterations of reports (i.e. written items), calculations, and data (e.g. inputs or outputs). In general:

- Calculation reviews focus on whether calculations are being performed correctly, according to the methods outlined in the report.

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- Data reviews focus on whether calculation *input data* has been transcribed correctly and completely from the report to the calculations, and, whether calculation *results* have been transcribed from the calculations to the report correctly and completely.
- Report reviews focus on the content of the report, and include reviewing the correctness and *appropriateness* of assumptions, methods/models chosen, parameters selected, and rationale provided. Report reviews are typically performed by senior technical specialists.

The QAP provides a clear and organized schedule of quality reviews for the DecomSA, as well as the QA records that accompany these reviews.

In addition to reviews completed under the QAP, the DecomSA has undergone several rounds of review by CNL's NPD project personnel.

Lastly, the DecomSA has undergone an additional external peer review contracted by CNL.

Software/Codes

The QAP and its addendums identify and characterize the software tools (computer codes) used as part of the DecomSA. Information presented for each software tool generally includes:

- A description of the computer code, including typical applications.
- The version used.
- Mention of the user manual or other code documentation, and where it can be found.
- Discussion of code validation or where such information can be found.
- Discussion of code verification (such as installation tests).

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APPENDIX A: COMMON TOOLS USED IN ACCIDENTS ASSESSMENT



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Appendix A: Common Tools used in Accidents Assessment

This Appendix identifies common tools – i.e. important guidance and reference documents - that are useful in conducting safety assessments. Brief overviews are provided for each key reference, which include:

- a. The Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AICE) Guidelines for Chemical Process Quantitative Risk Analysis (CCPS 2000);
- b. The Canadian Standards Association (CSA) N288.2 Guideline (CSA 2003); and
- c. The Health and Safety Laboratory (H&SL) of the UK Health and Safety Executive (UK H&SE) Review of Hazard Identification Techniques (HSL 2000).

The extent to which these documents (as well as others) are used will depend on their applicability to any given project. Therefore, it is expected that combinations of these documents may be used, on a case-by-case basis.

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The Canadian Standards Association (CSA) N288.2 Guidelines for Calculating Radiation Doses to the Public from a Release of Airborne Radioactive Material under Hypothetical Accident Conditions in Nuclear Reactors:

CSA (2003) provides methods for evaluating radiation doses received by the public from accidental airborne releases of radioactive material to the atmosphere. Given this focus, it is important to note that CSA (2003) therefore does not provide comprehensive guidance on assessing *all* types of accidents. CSA (2003) is typically applied when consequent radiation doses to the public, under severe hypothetical accident conditions, must be calculated and compared to criteria. It is important to note that CSA (2003) is premised on a CANDU reactor – as is the norm in Canada. However, it is also useful in calculating radiation doses from airborne releases that might arise from design-basis accidents in *other* types of nuclear facilities.

The information in CSA (2003) is most relevant (within the context of M&A Assessment) to consequence analysis, as the document focuses on detailed technical information and mathematical models for estimating dilution factors, cloud concentrations, wet and dry deposition, and doses.

Examples of relevant topics covered by CSA (2003) include:

- Dilution Factors & Dispersion:
 - Gaussian Dispersion Modelling;
 - Standard Deviations in plumes;
 - Building Wake Effects, Downwash, and Entrainment;
 - Boundary Layers.
- Calculating Cloud Concentrations:
 - Decay and Build-up;
 - Depletion Due to Deposition.
- Calculating Deposition to ground:
 - Dry deposition;
 - Wet deposition.
- Dose Calculations.

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The Health and Safety Laboratory (H&SL) of the UK Health and Safety Executive (UK H&SE) Review of Hazard Identification Techniques (HSL 2000):

HSL (2000) identifies several commonly used Hazard Identification methodologies (such as HAZOP) and performs a critical review and evaluation of their applicability, strengths, and weaknesses. The review includes both ability to identify 'hard' or 'physical' process hazards (e.g. hazards related to vehicles, equipment, vessels or other tangible items) but also includes ability to identify 'soft' hazards (e.g. software failures, or human failures). Its discussions on each methodology cover the basic premise of the method, the nature of its results (qualitative or quantitative), the points within a facility's lifecycle when it is most or least applicable (largely driven by data input requirements), and the advantages and disadvantages of the method.

Rather than identify a single all-encompassing or 'best' method, the findings of the study focus on being able to recognize, in any particular project, certain key items and knowing which method is most applicable to them. The main items are:

- Complexity of the project;
- Project 'phase' (i.e. at what point in the project's lifecycle is the assessment being completed);
- Data availability;
- Time, Resource, and Expertise availability;
- Type of output required.

For example, for a 'straightforward' operation that is at an early conceptualization phase with little information or drawings being available, with little resources to allocate, and requiring only qualitative outputs (e.g. to inform further decision-making), a 'What-If?' Analysis or Concept-Hazard Analysis is more applicable. A comprehensive method such as Fault-Tree Analysis is not desirable in this example because it: requires a large amount of detailed information or drawings (which are not available); demands large amounts of time, resources and expertise (which are not available), and, provides highly detailed quantitative results (which are more detailed than needed).

It is also important to note that the information in HSL (2000) does not focus on detailed frequency and consequence analysis. Rather the focus is on hazard identification, with some qualitative discussion of risk evaluation.

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CCPS 2000: The Center for Chemical Process Safety (CCPS) of the American Institute of Chemical Engineers (AIChE) Guidelines for Chemical Process Quantitative Risk Analysis:

CCPS (2000) provides large amount of valuable, detailed guidance on Quantitative Risk Analysis (QRA), covering several topics that are key components of M&A Assessments. Select guidance on topics of particular relevance to M&A Assessment include:

- Hazard Identification
 - Methods, tools, etc.
 - Initial screening of the hazard scenarios.
 - Worst-case scenarios.
 - Alternative scenarios.

- Mitigation measures.

- Probability & Failure Frequency Analysis:
 - Initiating events (e.g. equipment failure, power outage, etc.).
 - Incident frequencies from historical records.
 - Frequency calculation techniques (Fault-Tree Analysis; Event-Tree Analysis).
 - Common Cause Failure Analysis.
 - Human Reliability Analysis (e.g. human factors).
 - External Events Analysis (e.g. natural events; extreme weather).

- Consequence Analysis:
 - Models (e.g. discharge rate, flash, evaporation, dispersion).
 - Explosion and Fires (e.g. vapour cloud explosions, flash fires, physical explosion, pool fires, jet fires, etc.).
 - Toxic Effects Models (toxic gas effects, thermal effects, explosion effects).

- Risk Analysis:
 - Risk measures, including indices, individual risk (e.g. fatalities per year), societal/population risk (e.g. number of fatalities), injury risk, etc.
 - Risk presentation (e.g. mapping).
 - Selecting risk measures.
 - Risk calculations (indices, individual risk, societal risk, examples).
 - Risk uncertainty and sensitivity.

APPENDIX B: HAZARD IDENTIFICATION



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Appendix B: Hazard Identification

Tables B.1 to B.10 present the results of hazard identification for decommissioning WBSs as follows:

- **Table B.1:** General (i.e. activities applicable to several WBSs)
- **Table B.2:** Operation of Batch Mixing Plant
- **Table B.3:** Grouting of Below-Grade Structures
- **Table B.4:** Removal of Above-Grade Structures
- **Table B.5:** Removal of Guard House
- **Table B.6:** Removal of Emergency Generator
- **Table B.7:** Removal of Pressure Relief Pit
- **Table B.8:** Installation of Concrete Cap and Engineered Barrier
- **Table B.9:** Demobilization from the Site and Final Site Restoration
- **Table B.10:** Long-Term Care and Maintenance

Note: Detailed process of selecting bounding scenarios from these hazard events is shown in Appendix H.

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Table B.1 - General

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	General	N/A	Entire site	Non-radiological hazard	Physical	Conventional construction accident	Personnel injury due to typical project activities such as working at heights, working with heavy equipment. Potential injuries include falls, trips, strains, crushing, pinching, etc.	S2	F2	R1	1 - Staff and contractors will receive orientation to ensure they are aware of decommissioning activities, hazards, and emergency procedures. 2 - Signs will be posted to indicate where construction work is taking place and alert people to detours where applicable. 3 - Regular updates will be given to all site personnel on any changes in decommissioning work plans. 4 - CNL health and safety programs are in place to prevent and mitigate personnel injuries. 5 - NPD Emergency Procedure, consistent with CNL's Emergency Preparedness Program. 6 - Emergency response through local municipal Fire Department. 7 - Work control documents will be developed to guide safe execution of the decommissioning activities. Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 8 - Contractor's Health and Safety Management Program. 9 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i>
2	General	N/A	Entire site	Non-radiological hazard	Physical	Conventional construction accident	Work place fatality due to typical project activities such as working at heights, working with heavy equipment. Potential injuries include falls, trips, crushing, etc.	S4	F1	R2	1 - Staff and contractors will receive orientation to ensure they are aware of decommissioning activities, hazards, and emergency procedures. 2 - Signs will be posted to indicate where construction work is taking place and alert people to detours where applicable. 3 - Regular updates will be given to all site personnel on any changes in decommissioning work plans. 4 - CNL health and safety programs are in place to prevent and mitigate personnel injuries. 5 - NPD Emergency Procedure, consistent with CNL's Emergency Preparedness Program. 6 - Emergency response through local municipal Fire Department 7 - Work control documents will be developed to guide safe execution of the decommissioning activities. Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 8 - Contractor's Health and Safety Management Program. 9 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 10 - Vetting of contractors' training records.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i> Result: The risk is inherent to the activities and is as low as reasonably practicable. No additional action is required

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
3	General	N/A	Entire site	Non-radiological hazard	Physical	Physical situation – difficult access to below-grade areas	Restricted emergency response & departure	S1	F3	R1	1 - Staff and contractors will receive orientation to ensure they are aware of decommissioning activities, hazards, and emergency procedures. 2 - Marked emergency route. 3 - Alternative access routes will be provided. 4 - Facility Emergency Procedure (revised routinely). 5 - Site Plan and notification of responders.	None
4	General	N/A	Entire site	Non-radiological hazard	Physical	Presence of a construction zone on site	Restricted emergency response	S1	F3	R1	1 - Staff and contractors will receive orientation to ensure they are aware of decommissioning activities, hazards, and emergency procedures. 2 - Marked emergency route. 3 - A Staging and Transportation Plan will be developed and followed. 4 - Facility Emergency Procedure (revised routinely). 5 - Site Plan and notification of responders.	None
5	General	N/A	Entire site	Non-radiological hazard	Hydrocarbons	Transportation accident on-site	Potential release of oil or hydrocarbons to the environment causing contamination, fire, personal injury, road access restriction	S0	F2	R0	1 - Transportation restrictions will be put in place during poor weather conditions. 2 - Speed limits will be enforced. 3 - Emergency response through local municipal Fire Department. 4 - A road maintenance program is in place for the NPD site. 5 - Spill kits will be available. 6 - PHC and Spill Plans (CNL 2012; CNL 2013). 7 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 8 - Vetting of contractors' driving/operating records. 9 - Flagmen will be used for turning corners.	None
6	General	N/A	Entire site	Non-radiological hazard	Physical	Transportation accident, offsite	Injuries	S2	F2	R1	1 - Transportation/shipping restrictions will be put in place during poor weather conditions. 2 - Contractor's traffic control. 3 - Traffic control on duty during offsite transportation. 4 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 5 - Vetting of contractors' driving/operating records.	None
7	General	N/A	Entire site	Non-radiological hazard	Physical	Transportation accident, offsite	Fatalities	S4	F1	R2	1 - Transportation/shipping restrictions will be put in place during poor weather conditions. 2 - Contractor's traffic control. 3 - Traffic control on duty during offsite transportation. 4 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 5 - Vetting of contractors' driving/operating records.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i> Result: The risk is inherent to the transportation activities and is as low as reasonably practicable. No additional action is required

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
8	General	N/A	Entire site	Non-radiological hazard	Hydrocarbons	Fuel spill from mobile storage tank or during fueling activities	Site contamination	S0	F3	R0	1 - Spill response plan in place. 2 - Fuel spill kits will be required for on-site vehicles with large fuel tanks. 3 - Secondary containment structures will be used to prevent spills from storage tanks or during refueling activities where applicable. 4 - PHC and Spill Plans (CNL 2012; CNL 2013). 5 - Routine maintenance checks on equipment. 6 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements.	None
9	General	N/A	Entire site	Non-radiological hazard	Physical	Road access block due to forest fire, flood, traffic accident, winter storm, etc.	Restricted emergency response, limited site access	S2	F2	R1	1 - A road maintenance program is in place for the NPD site. 2 - Emergency routes will be planned and monitored. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	None
10	General	N/A	Entire site (Note: most contamination is in underground portion of the facility)	Radiological hazard	Radionuclides	Forest fire	Release of radioactivity (from aboveground portion only) due to fire spreading to the building and mobilizing the radionuclides	S3 (conservative)	F1	R1	1 - Stop work during forest fire. 2 - Fire index will be assessed as part of job planning. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 4 - Fire breaks maintained around the facility. 5 - Marked emergency route. 6 - A Staging and Transportation Plan will be developed and followed. 7 - Comprehensive and systematic reduction of combustible building materials prior to decommissioning activities. 8 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers.	Assess further (note: the assessment can be found in Section 9.0) Result: The risk is inherent to the natural event (forest fire) and is as low as reasonably practicable.
11	General	N/A	Entire site (Note: most contamination is in underground portion of the facility)	Non-radiological hazard	Hazardous chemicals	Forest fire	Smoke inhalation, chemical exposure (chemicals in the above ground portion only), and worker injuries due to burning of combustibles.	S3(conservative)	F1	R1	1 - Stop work during forest fire. 2 - Fire index will be assessed as part of job planning. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 4 - Fire breaks maintained around the facility. 5 - Marked emergency route. 6 - A Staging and Transportation Plan will be developed and followed. 7 - Comprehensive and systematic reduction of combustible building materials prior to decommissioning activities. 8 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers.	Assess further (note: the assessment can be found in Section 9.0) Result: the risk is inherent to the natural event (forest fire) and is as low as reasonably practicable.
12	General	N/A	Entire site (Note: most contamination is in underground portion of the facility)	Non-radiological hazard	Physical	Forest fire	Injury	S2	F1	R0	1 - Stop work during forest fire. 2 - Fire index will be assessed as part of job planning. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 4 - Fire breaks maintained around the facility. 5 - Marked emergency route. 6 - A Staging and Transportation Plan will be developed and followed. 7 - Comprehensive and systematic reduction of combustible building materials prior to decommissioning activities. 8 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers.	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
13	General	N/A	Entire site (Note: most contamination is in underground portion of the facility)	Non-radiological hazard	Physical	Forest fire	Fatality	S4	F1	R2	1 - Stop work during forest fire. 2 - Fire index will be assessed as part of job planning. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 4 - Fire breaks maintained around the facility. 5 - Marked emergency route. 6 - A Staging and Transportation Plan will be developed and followed. 7 - Comprehensive and systematic reduction of combustible building materials prior to decommissioning activities. 8 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers.	Assess further (note: the assessment can be found in Section 8.3.3) Result: The risk is inherent to the natural event (forest fire) and is as low as reasonably practicable. No additional action is required.
14	General	N/A	Entire site (Note: most contamination is in underground portion of the facility)	Radiological hazard	Radionuclides	Tornado	Release of radioactivity (from aboveground portion only) due to damage to the building and mobilizing the radionuclides	S3(conservative)	F2(conservative)	R2	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 3 - Maintain Integrity of superstructure until demolition begins 4 - Marked emergency route. 5 - A Staging and Transportation Plan will be developed and followed.	Assess further (note: the assessment can be found in Section 9.0) Result: The risk is inherent to the natural event (tornado) and is as low as reasonably practicable.
15	General	N/A	Entire site (Note: most contamination is in underground portion of the facility)	Non-radiological hazard	Hazardous chemicals	Tornado	Exposure to chemicals (chemicals in the aboveground portion only) released due to damage to the building and mobilizing the radionuclides	S3(conservative)	F2(conservative)	R2	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 3 - Maintain Integrity of superstructure until demolition begins. 4 - Marked emergency route. 5 - A Staging and Transportation Plan will be developed and followed.	Assess further (note: the assessment can be found in Section 9.0) Result: The risk is inherent to the natural event (tornado) and is as low as reasonably practicable.
16	General	N/A	Entire site (Note: most contamination is in underground portion of the facility)	Non-radiological hazard	Physical	Tornado	Injury	S2	F2	R1	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 3 - Environment Canada tornado warning. 4 - Marked emergency route. 5 - A Staging and Transportation Plan will be developed and followed.	None
17	General	N/A	Entire site (Note: most contamination is in underground portion of the facility)	Non-radiological hazard	Physical	Tornado	Fatality	S4	F1	R2	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 3 - Environment Canada tornado warning. 4 - Marked emergency route. 5 - A Staging and Transportation Plan will be developed and followed. 6 - NPD Emergency Procedure accounts for new on-site trailers and activities and time period where the NPD structure is partially dismantled.	Assess further (note: the assessment can be found in Section 8.3.3) Result: The risk is inherent to the natural event (tornado) and is as low as reasonably practicable. No additional action is required.

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
18	General	N/A	Entire site	Non-radiological hazard	Hazardous Chemicals	Heavy precipitation, Flood	Release of chemicals due to water ingress and mobilization (incl. release from their stored material forms)	S2	F2	R1	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 3 - Maintain Integrity of superstructure until demolition begins.	None
19	General	N/A	Entire site	Radiological hazard	Radionuclides	Heavy precipitation, Flood	Release of radioactivity due to water ingress and mobilization of radionuclides	S3(conservative)	F2	R2	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 3 - Maintain Integrity of superstructure until demolition begins.	Assess further <i>(note: the assessment can be found in Section 9.0)</i> Result: The risk is inherent to the natural event (heavy precipitation, flood) and is as low as reasonably practicable.
20	General	N/A	Entire site	Non-radiological hazard	Physical	Heavy precipitation, Flood	Injury	S2	F2	R1	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	
21	General	N/A	Entire site	Non-radiological hazard	Physical	Heavy precipitation, Flood	Fatality, site access	S4	F1	R2	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i> Result: The risk is inherent to the natural event (flood) and is as low as reasonably practicable. No additional action is required.
22	General	N/A	Entire site	Radiological hazard	Radionuclides	Ice storm/Severe winter storm	Release of radioactivity due to structural damage and loss of containment	S2	F1	R0	1 - Stop work at detrimental weather conditions. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 3 - Maintain Integrity of superstructure until demolition begins.	None
23	General	N/A	Entire site	Radiological hazard	Radionuclides	Earthquake	Release of radioactivity due to structural damage and loss of containment	S2	F2	R1	1 - Stop work. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	None
24	General	N/A	Entire site	Non-radiological hazard	Physical	Earthquake	Injury	S2	F2	R1	1 - Stop work. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
25	General	N/A	Entire site	Non-radiological hazard	Physical	Earthquake	Fatality	S4	F1	R2	1 - Stop work. 2 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	Assess further (note: the assessment can be found in Section 8.3.3) Result: The risk is inherent to the natural event (earthquake) and is as low as reasonably practicable. No additional action is required.
26	General	N/A	Entire site	Radiological hazard	Radionuclides	Dam failure and flooding	Release of radioactivity due to water ingress and mobilization of radionuclides	S3(conservative)	F0	R0	1 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	The risk is inherent to the natural event (flood) and is as low as reasonably practicable. No additional action is required.
27	General	N/A	Entire site	Non-radiological hazard	Physical	Dam failure and flooding	Injury	S2	F0	R0	1 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	None
28	General	N/A	Entire site	Non-radiological hazard	Physical	Dam failure and flooding	Fatality	S4	F0	R0	1 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	The risk is inherent to the natural event (flood) and is as low as reasonably practicable. No additional action is required.
29	General	N/A	Entire site	Non-radiological hazard	Electricity	Failure to isolate power, general construction activity	Electric shock (injury)	S2	F2	R1	1 - Grounding and Ground Fault Interrupter, CSA approved, built to Electrical Code. 2 - CNL health and safety programs are in place to prevent and mitigate personnel injuries (e.g. Electrical Safety). 3 - Regular updates will be given to all site personnel on any changes in decommissioning work plans. 4 - NPD Emergency Procedure, consistent with CNL's Emergency Preparedness Program. 5 - Emergency response through local municipal Fire Department. 6 - Work control documents will be developed to guide safe execution of the decommissioning activities. Hazards to personnel will be identified through planning and preparation of work control documents, and eliminated/controlled using engineered and administrative controls, and PPE. 7 - Contractor Management Program (incl. health & safety). 8 - DDP considers site-specific procedures for power isolation to reduce the potential for errors. 9 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements.	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
30	General	N/A	Entire site	Non-radiological hazard	Electricity	Failure to isolate power, general construction activity	Electrocution (Fatality)	S4	F1	R2	1 - Grounding and Ground Fault Interrupter, CSA approved, built to Electrical Code. 2 - CNL health and safety programs are in place to prevent and mitigate personnel injuries (e.g. Electrical Safety). 3 - Regular updates will be given to all site personnel on any changes in decommissioning work plans. 4 - NPD Emergency Procedure, consistent with CNL's Emergency Preparedness Program. 5 - Emergency response through local municipal Fire Department. 6 - Work control documents will be developed to guide safe execution of the decommissioning activities. Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 7 - Contractor Management Program (incl. health & safety). 8 - DDP considers site-specific procedures for power isolation to reduce the potential for errors. 9 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i> Result: The risk is as low as reasonably practicable. No additional action is required.
31	General	N/A	Entire site	Non-radiological hazard	Physical	Public intrusion	injuries	S1	F2	R0	1 - Security Protocols are in place. 2 - Control access fence will be provided.	None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

The site will be prepared for conventional construction activities. The cleared parking areas will be used to establish equipment lay down, parking for heavy equipment and services such as water tanks and diesel storage tank. Contractor trailers and washroom facilities are added to the existing trailers where required. Unnecessary fencing is removed. Construction zones are delineated with temporary fencing. Traffic zones and emergency routes are marked or barricaded for safety.

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Table B.2 – Operation of Batch Mixing Plant

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	Operation of batch mixing plant: 1.2 Assign raw material storage areas. 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations 1.10 Wash (trucks, sluices/pipes) 1.11 Dewater pit, emplace sediments into voids.	8.1 8.3.001	Batch mixing plant	Non-radiological hazard	Construction material	Spill of construction material	Site contamination	S0	F3	R0	1 - Response will be provided through contractors to rapidly respond to any accidental spills of construction material. 2 - Site supervision will be available to direct the movement of materials and batch mixing operation.	None
2	Operation of batch mixing plant: 1.3 Set up mixing stations (incl. electrical) 1.4 Truck in water supply 1.6 Construct wash pit 1.7 Level area for concrete pumper 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations 1.10 Wash (trucks, sluices/pipes) 1.12 Demobilize batch plant	8.1.003 8.3.001 8.4.006	Batch mixing plant	Non-radiological hazard	Physical	Equipment failure while setting up batch mixing plant	Drop of heavy equipment and personal injuries	S2	F2	R1	1 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 2 - Establishment of an exclusion zone. 3 - Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 4 - CNL health and safety programs are in place to prevent and mitigate personnel injuries. 5 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements.	None
3	Operation of batch mixing plant: 1.3 Set up mixing stations (incl. electrical) 1.4 Truck in water supply 1.6 Construct wash pit 1.7 Level area for concrete pumper 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations 1.10 Wash (trucks, sluices/pipes) 1.12 Demobilize batch plant	8.1.003 8.3.001 8.4.006	Batch mixing plant	Non-radiological hazard	Physical	Equipment failure while setting up batch mixing plant	Drop of heavy equipment and fatality	S4	F1	R2	1 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 2 - Establishment of an exclusion zone. 3 - Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 4 - CNL health and safety programs are in place to prevent and mitigate personnel injuries. 5 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i> Result: The risk is as low as reasonably practicable. No additional action is required.
4	Operation of batch mixing plant: 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations	8.1.003	Wash-out pit	Non-radiological hazard	Chemical	Overflow / failure of wash-out pit liner	Release of chemicals outside the pit (i.e. high pH water)	S0	F2	R0	1 - Inspection of the liner. 2 - Monitoring of water and sediments in the pit. 3 - Reuse of water for batch mixing.	None
5	Operation of batch mixing plant: 1.10 Wash (trucks, sluices/pipes)	8.1.003	Batch mixing plant	Non-radiological hazard	Physical	Contact with corrosive materials (cement or concrete)	Personal injuries (chemical burns)	S0	F3	R0	1 - CNL health and safety programs are in place to prevent and mitigate personnel injuries. 2 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements.	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
6	Operation of batch mixing plant: 1.2 Assign raw material storage areas.	8.1.003	Batch mixing plant	Non-radiological hazard	Construction materials	Uncontrolled release of these materials due to weather (heavy rain) or erosion causing the stock piles to collapse or have material slide toward the river		S0	F2	R0	1 - Laydown areas for materials will be designated to reduce impact on the environment. 2 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 3 - Stockpile management plan.	None
7	Operation of batch mixing plant: 1.3 Set up mixing stations (incl. electrical) 1.4 Truck in water supply 1.6 Construct wash pit 1.7 Level area for concrete pumper 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations 1.10 Wash (trucks, sluices/pipes) 1.12 Demobilize batch plant	8.1.003 8.3.001 8.4.006	Batch mixing plant	Non-radiological hazard		See General Items No. 1 to No. 9 (excl. 3)						None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

Due to the distances to the nearest concrete suppliers, a batch mixing plant will be assembled close to the facility. This will require the shipping by truck and stockpiling of aggregate, sand and grout near the batch plant. A water tank, piping, power and settling ponds for equipment wash out are constructed. A settling pond is an engineered catchment that collects water and allows sediments to collect. Water is sampled prior to pumping for release or recycled to the batch plant. Settled material will be placed and grouted into the facility. Any remaining aggregate or sand will be used as back fill in the facility before the final capping.

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Table B.3 – Grouting of Below-Grade Structures

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	Grouting of below grade structures: 2.3.5 fill used fuel storage bay. 2.3.6 fill lower areas 2.3.7 install slip pipes for reactor vault 2.3.8 fill reactor vault 2.3.9 fill end access and tube withdrawal rooms 2.3.10 fill boiler room 2.3.11 fill balance of nuclear area.	8.3.001	Nuclear area / Reactor underground building	Non-radiological hazard	Construction material	Spill of construction material	Site contamination	S0	F3	R0	1 - Response will be provided through contractors to rapidly respond to any accidental spills of construction material. 2 - Site supervision will be available to direct the movement of materials and batch mixing operation.	None
2	Grouting of below grade structures: 2.3.5 fill used fuel storage bay. 2.3.6 fill lower areas 2.3.7 install slip pipes for reactor vault 2.3.8 fill reactor vault 2.3.9 fill end access and tube withdrawal rooms 2.3.10 fill boiler room 2.3.11 fill balance of nuclear area.	8.3.001	Nuclear area / Reactor underground building	Radiological Hazard	Radionuclides	Failure of current structure (this does not include small cracks in the building walls or floors)	Release of radionuclides outside the structure	S2	F1	R0	1 - Monitoring with Disposable Cameras. 2 - Approved Fill Plan. 3 - structural analysis completed as part of fill plan.	Assessed in PostSA TSD
3	Grouting of below grade structures: 2.3.5 fill used fuel storage bay. 2.3.6 fill lower areas 2.3.7 install slip pipes for reactor vault 2.3.8 fill reactor vault 2.3.9 fill end access and tube withdrawal rooms 2.3.10 fill boiler room 2.3.11 fill balance of nuclear area.	8.3.001	Nuclear area / Reactor underground building	Non-radiological hazard	Hydrogen / radionuclides	Contact of grout with aluminum materials from the reactor	Hydrogen generation and potential for fire or explosion	S2	F1	R0	1 - Fill plan in-place. 2 - Pathways created during preparation of rooms allows for dissipation of heat and off-gassing during curing of the concrete. 4 - Active ventilation will be provided to minimize gas accumulation. 5 - Grout will be poured in batches.	Assessed as part of planned Normal Operations (Section 8.0)
4	Grouting of below grade structures: 2.1.1 Seal required holes from pipes, vents, etc. 2.3.10 fill boiler room 2.3.11 fill balance of nuclear area.	8.3.007 8.3.001	Nuclear area / Reactor underground building	Radiological Hazard	Radionuclides / Chemicals	Failure to seal all holes and pathways to outside of the building (this includes omitting a hole or pathway or failure of the seal)	Release of radionuclides and chemicals outside the building	S2	F1	R0	1 - Engineered Seals installed. 2 - pre-grouting room walk-downs would identify these, and the grout fill plan would account for these, and they would be properly sealed before pouring.	Assessed in PostSA TSD

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
5	Grouting of below grade structures: 2.1.3 Drill holes for grout passage, air release, heat dissipation. 2.2.1 Drill holes, top & bottom of Helium storage tanks 2.2.2 Drill holes, top and bottom of steam generator 2.2.3 Drill holes, top and bottom of boiler 2.2.4 Drill holes, top and bottom of dump tank 2.2.5 Drill holes, top and bottom of vault cooling vent runways 2.2.7 Drill access into reactor vault via fueling machine room	8.3.007 8.2.005	Nuclear area / Reactor underground building	Radiological Hazard	Radionuclides	Failure to drill hole for air release and heat dissipation (this results in partial grouting and poor containment in long-term)	Release of radionuclides outside the structure	S2	F2	R1	1 - Monitoring with Disposable Cameras. 2 - Pathways created during preparation of rooms ensure avoidance of voids and allows for dissipation of heat during curing of the concrete. 3 - Inspection before grouting.	Assessed in PostSA TSD
6	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Non-radiological hazard	Physical	Working underground and confined spaces in IDLH (e.g. low oxygen)	Injury and emergency escape restriction	S1	F2	R0	1 - Health and safety programs are in place to prevent and mitigate personnel injuries. 2 - Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 4 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements.	None
7	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Non-radiological hazard	Physical	Working underground and confined spaces in IDLH (e.g. low oxygen)	Injury	S2	F2	R1	1 - Health and safety programs are in place to prevent and mitigate personnel injuries. 2 - Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 4 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 5 - CNL health and safety programs includes procedures for confined space activities.	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
8	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Non-radiological hazard	Physical	Working underground and confined spaces in IDLH (e.g. low oxygen)	Fatality	S4	F1	R2	1 - Health and safety programs are in place to prevent and mitigate personnel injuries. 2 - Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program. 4 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 5 - CNL health and safety programs includes procedures for confined space activities.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i> Result: The risk is as low as reasonably practicable. No additional action is required.
9	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Radiological hazard	Radionuclides	Accidental exposure to radioactivity	Exposure to radiological dose during demolition of walls, cutting holes, cutting vessels and pipes (this is the exposure beyond the level expected during planned demolition activities which will be assessed under "Normal Conditions").	S3	F2	R1	1 - Radiation protection plan. 2 - Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.	Assess further <i>(note: the assessment can be found in Section 9.0)</i>
10	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Radiological hazard	Radionuclides	Underground fire (e.g. from small equipment fuel spill)	Airborne release of radionuclides	S1	F1	R0	1 - Fire hazard analysis report shows low probability and impact of fire due to lack of large amount of combustible materials in the building. 2 - Comprehensive and systematic reduction of combustible building materials prior to decommissioning activities. 3 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers. 4 - fire inspections, fire alarm system. 5 - Small fires can be put out with available hand-held fire extinguishers. 6 - Emergency response for larger fires through local municipal Fire Department. 7 - Use of a fire watch for hot-work.	Assess further <i>(note: the assessment can be found in Section 9.0)</i>

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
11	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Non-radiological hazard	Combustible materials	Underground fire (e.g. from small equipment fuel spill)	Smoke inhalation and workers injuries due to burning of combustibles	S2	F1	R0	1 - Fire hazard analysis report shows low probability and impact of fire due to lack of large amount of combustible materials in the building. 2 - Comprehensive and systematic reduction of combustible building materials prior to decommissioning activities. 3 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers. 4 - fire inspections, fire alarm system. 5 - Small fires can be put out with available hand-held fire extinguishers. 6 - Emergency response for larger fires through local municipal Fire Department. 7 - Use of a fire watch for hot-work.	Assess further <i>(note: the assessment can be found in Section 9.0)</i>
12	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Non-radiological hazard	Asbestos	Asbestos exposure during transfer and emplacement	Asbestos release and exposure	S1	F2	R0	1 - proper signage for asbestos laydown area. 2 - procedure for handling and storage of removed asbestos in place.	None
13	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Radiological hazard	Radionuclides	Release of radionuclides from removed contaminated equipment / components from laydown area	Release of radionuclides and worker exposure	S1	F1	R0	1 - Hazards to personnel will be identified through the planning and preparation of work control documents, and will be eliminated or controlled using engineered controls, administrative controls, and PPE. 2 - Radiation protection plan.	None
14	Removal of PCBs from Boiler Room Ceiling 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.007 8.2.005	Nuclear area / Reactor underground building	Non-radiological hazard	PCBs	PCBs exposure during removal of light ballasts	PCBs release and exposure	S0	F2	R0	1 - These sources of PCB are known and will be clearly identified prior to removal activities. 2 - The resultant waste will be managed according to a demolition and waste management plan and applicable regulatory requirements. 3 - Personal protection equipment. 4 - PCBs are contained within the solid light ballast. 5 - Work Control documents for PCB removal will be followed.	No gas-powered equipment to be used (to avoid presence of combustible fuels during this task).

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

All below grade areas are filled with grout. Using a master fill schedule, lifts of concrete pours are planned to systematically fill the entire structure. The concrete pours are designed to balance forces across walls and between rooms such that no failures of the current structures can occur. Pathways created during preparation of rooms ensure avoidance of voids and allows for dissipation of heat during curing of the concrete. Disposable cameras are used to monitor the fill operation.

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Table B.4 – Demolition of Above Grade Structures

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	<p>Demolition of Reactor Hall:</p> <p>3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room</p>	8.3.006	Reactor hall	Radiological hazard	Radionuclides	Accidental exposure to radioactivity	Exposure to radiological dose during demolition of walls, cutting steel beams, and pipes (this is the exposure beyond the level expected during planned demolition activities which will be assessed under "Normal Conditions").	S1	F2	R0	<p>1 - Radiation protection plan. 2 - Use of personal protection equipment. 3 - An NPD Emergency Procedure is in place, and is consistent with CNL's Emergency Preparedness Program.</p>	None
2	<p>Demolition of Reactor Hall:</p> <p>3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room</p>	8.3.006	Reactor hall	Non-radiological hazard	Combustible materials	Ignition of combustibles (e.g. from equipment fuel spill)	Smoke inhalation and workers injuries due to burning of combustibles	S1	F1	R0	<p>1 - Fire hazard analysis report shows low probability and impact of fire due to lack of large amount of combustible materials in the building. 2 - Comprehensive and systematic reduction of combustible building materials prior to decommissioning activities. 3 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers. 4 - fire inspections. 5 - Small fires can be put out with available hand-held fire extinguishers. 6 - Emergency response for larger fires through local municipal Fire Department. 7 - Use of a fire watch for hot-work. 8 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 9 - Vetting of contractors' qualifications and training.</p>	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
3	<p>Demolition of Reactor Hall:</p> <p>3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room</p>	8.3.006	Reactor hall	Radiological hazard	HEPA Filter medium	Combustion of HEPA filters	Release of radionuclides	S1	F1	R0	<p>1 - Filter medium was replaced in 2015 thus the inventory of radionuclides in the new filters is low. 2 - Fire hazard analysis report shows low probability and impact of fire due to lack of large amount of combustible materials in the building. 3 - Comprehensive and systematic reduction of combustible building materials prior to decommissioning activities. 4 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers. 5 - fire inspections. 6 - Small fires can be put out with available hand-held fire extinguishers. 7 - Emergency response for larger fires through local municipal Fire Department. 8 - Use of a fire watch for hot-work. 9 - Contractors' H&S plan is reviewed by supply chain management and meets CNL's requirements. 10 - Vetting of contractors' qualifications and training.</p>	None
4	<p>Demolition of Reactor Hall:</p> <p>3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room</p>	8.3.006	Reactor hall	Radiological hazard	Radioactivity	Ignition of combustibles including bitumen roofing materials	Airborne release of radioactivity	S1	F1	R0	<p>1 - The roof was replaced in 2000, and the amount of tritium in the roofing materials is limited. 2 - Use of a fire watch. 3 - Small fires can be put out with hand-held fire extinguishers 4 - Emergency response for larger fires through local municipal Fire Department. 5 - Storage of combustible equipment and material (e.g. fuel, clothing/PPE, etc.) occurs in separate outdoor metal sea containers.</p>	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
5	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Reactor hall	Non-radiological hazard	PCB	Accidental exposure	PCB exposure during removal of fluorescent light ballasts	S0	F0	R0	1 – PCBs <i>in the above-grade structure</i> will be removed prior to decommissioning beginning. (PCBs in below-grade structure – see Table B.3 above)	None
6	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Reactor hall	Non-radiological hazard	Lead	Accidental exposure	Lead exposure during removal of lead-based paint and from accidental release from laydown area	S0	F2	R0	1 - These sources of lead are known and will be clearly identified prior to demolition activities. 2 - The resultant waste will be managed according to a demolition and waste management plan and applicable regulatory requirements. 3 - Personal protection equipment.	None
7	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Reactor hall	Non-radiological hazard	Toxic / corrosive chemicals	Accidental exposure	Chemical exposure	S1	F2	R0	1 - Housekeeping (management of chemical storage), inspection of chemical cabinets. 2 - Personal protection equipment.	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
8	Demolition of Reactor Hall: 3.0 Removal transite from the building exterior. 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Reactor hall	Non-radiological hazard	Asbestos	Accidental exposure	Asbestos exposure during removal of insulation and old construction materials	S0	F2	R0	1 - These sources of asbestos are known and will be clearly identified prior to demolition activities. 2 - The resultant waste will be managed according to a demolition and waste management plan and applicable regulatory requirements. 3 - Personal protection equipment.	None
9	Demolition of Reactor Hall: 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms	8.3.006	Reactor hall	Non-radiological	Physical	Collapse of unstable structures	Personal injury	S2	F2	R1	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - Methods will be used during the demolition process to provide sufficient support to ensure that a structural failure does not occur. 3 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 4 - Demolition plan will be followed closely. 5- Exclusion zone will be established during demolition activities.	None
10	Demolition of Reactor Hall: 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms	8.3.006	Reactor hall	Non-radiological	Physical	Collapse of unstable structures	Fatality	S4	F1	R2	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - Methods will be used during the demolition process to provide sufficient support to ensure that a structural failure does not occur. 3 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 4 - Demolition plan will be followed closely. 5- Exclusion zone will be established during demolition activities.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i> Result: The risk is as low as reasonably practicable. No additional action is required.
11	Fill below grade structure with grout: 3.5 Grout first level in condenser pit 3.7 Grout 2nd level in condenser pit 3.9 Grout 3rd level in condenser pit	8.3.001	Reactor hall	Non-radiological hazard	Construction material	Spill of construction material	Site contamination	S0	F3	R0	1 - Response will be provided through contractors to rapidly respond to any accidental spills of construction material. 2 - Site supervision will be available to direct the movement of materials and batch mixing operation.	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
12	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Reactor hall	Radiological hazard	Radionuclides	Storm water entering the underground areas while the above ground structure is removed	Release of radionuclides	S1	F2	R0	1 - Demolition activities will be planned in conjunction with grouting operations to manage water infiltration into the facility.	None
13	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Reactor hall			See General Items No. 1, 2, 29, 30						None
14	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown.	8.3.006	Ventilation stack	Non-radiological hazard	Physical	Accidental collapse of stack	Personal injury	S2	F2	R1	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 3 - Demolition plan will be followed closely. 4 - Establishment of an exclusion zone.	None

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No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
15	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown.	8.3.006	Ventilation stack	Non-radiological hazard	Physical	Accidental collapse of stack	Fatality	S4	F1	R2	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 3 - Demolition plan will be followed closely. 4 - Establishment of an exclusion zone.	Assess further <i>(note: the assessment can be found in Section 8.3.3)</i> Result: The risk is as low as reasonably practicable. No additional action is required.
16	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown.	8.3.006	Ventilation stack	Radiological hazard	Radioactivity	Accidental collapse of stack	Release of radioactivity	S1	F1	R0	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 3 - Demolition plan will be followed closely. 4 - Establishment of an exclusion zone.	Assess further <i>(note: the assessment can be found in Section 9.0)</i>
17	Demolition of Reactor Hall: 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms	8.3.006	Reactor hall	Non-radiological and radiological hazard	Physical Radioactivity	Collapse of unstable structures	Release of radioactivity outside the structure	S1	F1	R0	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - Methods will be used during the demolition process to provide sufficient support to ensure that a structural failure does not occur. 3 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 4 - Demolition plan will be followed closely. 5- Exclusion zone will be established during demolition activities.	None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

Prior to any demolition, all power will be isolated to the facility including connection to the main power at the emergency generator. Access control to the site is transferred from the guard house to the temporary office trailers. The predominantly steel outer structure will be demolished and placed in the hole previously occupied by the steam condenser and cooling systems (turbine side). Above ground foundations, concrete walls of the control room, laundry and offices will be crushed and placed as fill prior to final grouting. Transit siding, an asbestos containing material will be placed in the hole if a conventional hazardous waste disposal site is unavailable. Water misting will be used to control dust.

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Table B.5 – Demolition of Guard House

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	Demolition of Guard House: 3.13 Remove recyclables from guard house 3.14 Demolish and emplace in furnace room & adjacent areas	8.3.006	Guard house	Non-radiological hazard	Combustible materials	Ignition of Combustibles	Smoke inhalation and workers injuries due to burning of combustibles (wooden shelving units and platforms, plastic conduits, paper, cardboard, wood, etc.)	S2	F1	R0	1 - Fire hazard analysis report shows low probability and impact of fire due to lack of large amount of combustible materials in the building. 2 - Housekeeping (reduction of combustible load), fire inspections, fire alarm system. Combustibles now stored in sea containers outside the Reactor Building. 3 - Small fires can be put out with hand-held fire extinguishers. 4 - Emergency response for larger fires local municipal Fire Department.	None
2	Demolition of Guard House: 3.13 Remove recyclables from guard house 3.14 Demolish and emplace in furnace room & adjacent areas	8.3.006	Guard house	Non-radiological hazard	Asbestos	Accidental exposure	Asbestos exposure during removal of insulation and old construction materials	S0	F1	R0	1 - These sources of asbestos are known and will be clearly identified prior to demolition activities. 2 - The resultant waste will be managed according to a demolition and waste management plan and applicable regulatory requirements. 3 - Personal protection equipment.	None
3	Demolition of Guard House: 3.13 Remove recyclables from guard house 3.14 Demolish and emplace in furnace room & adjacent areas	8.3.006	Guard house	Non-radiological hazard	Lead	Accidental exposure	Lead exposure during removal of lead-based paint	S0	F1	R0	1 - These sources of lead are known and will be clearly identified prior to demolition activities. 2 - The resultant waste will be managed according to a demolition and waste management plan and applicable regulatory requirements. 3 - Personal protection equipment.	None
4	Demolition of Guard House: 3.13 Remove recyclables from guard house	8.3.006	Guard house	Non-radiological hazard	Physical	Collapse of unstable structures	Personal injury	S2	F2	R1	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - Demolition plan will be followed closely. 3 - Establishment of an exclusion zone.	None
5	Demolition of Guard House: 3.13 Remove recyclables from guard house	8.3.006	Guard house	Non-radiological hazard	Physical	Collapse of unstable structures	Fatality	S4	F1	R2	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - Demolition plan will be followed closely. 3 - Establishment of an exclusion zone.	Assess further (note: the assessment can be found in Section 8.3.3) Result: The risk is as low as reasonably practicable. No additional action is required.
6	Demolition of Guard House	8.3.006	Guard house			See General Items No. 1 and 2						None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

Prior to any demolition, all power will be isolated to the facility including connection to the main power at the emergency generator. Access control to the site is transferred from the guard house to the temporary office trailers. The current one story building will be demolished. Walls, foundation and any underground services recovered and placed in the turbine side hole.

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Table B.6 – Removal of Emergency Generator

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	Removal of Emergency Generator	8.4.006	Emergency generator	Non-radiological hazard		See General Items No. 29, and 30						None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

Prior to any demolition, all power will be isolated to the facility including connection to the main power at the emergency generator. Access control to the site is transferred from the guard house to the temporary office trailers. The 80 MWe generator used for backup power will be disassembled and recycled or sold.

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Table B.7 – Demolition of Pressure Relief Pit

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	pressure relief pit	Radiological hazard	Radioactivity	Accidental exposure	Gamma, beta, and alpha exposure	S1	F2	R0	1 - Radiation protection plan. 2 - Work control documents will be used. 3 - Personal protection equipment.	None
2	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	pressure relief pit	Non-radiological hazard	Asbestos	Accidental exposure	Asbestos exposure during removal of insulation and old construction materials	S0	F2	R0	1 - These sources of asbestos are known and will be clearly identified prior to demolition activities. 2 - The resultant waste will be managed according to a demolition and waste management plan and applicable regulatory requirements. 3 - Personal protection equipment.	None
3	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	pressure relief pit	Radiological hazard	Radioactivity	Collapse of unstable structures	Release of radioactivity outside the pit due to loss of containment in case of major damage to the foundation and walls	S2	F1	R0	1 - Structural assessments will be performed to ensure that all demolition work is done in accordance with safe work practices and civil requirements. 2 - Methods will be used during the demolition process to provide sufficient support to ensure that a structural failure does not occur. 3 - If inclement weather does occur during the performance of project works and activities, the activities would be stopped, as deemed applicable, to minimize risks. 4 - Demolition plan will be followed closely.	None
4	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	pressure relief pit	Non-radiological hazard	Construction material	Spill of construction material	Site contamination	S0	F3	R0	1 - Response will be provided through contractors to rapidly respond to any accidental spills of construction material. 2 - Site supervision will be available to direct the movement of materials and batch mixing operation.	None
5	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	pressure relief pit	Non-radiological hazard	Construction material	Failure of drain seal	Release of construction materials into the drain system	S0	F2	R0	1 - Inspection before grouting. 2 - Engineered seal will be installed.	None
6	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	pressure relief pit			See General Items No. 1 and 2						None
7	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	pressure relief pit	Radiological hazard	Radioactivity	Drop of demolished structures into the pit	Release of radioactivity outside the structure	S1	F1	R0	Dust control measures in-place.	None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

Prior to any demolition, all power will be isolated to the facility including connection to the main power at the emergency generator. Access control to the site is transferred from the guard house to the temporary office trailers. Walls of the concrete pressure relief pit will be demolished and collapsed in place. The area will be filled with grout prior to final capping of the entire reactor area.

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Table B.8 – Installation of Concrete Cap & Engineered Barrier

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	Install Concrete Cap and Engineered Barrier: 4.1.3 Pour concrete, level & shape	8.4.005	Entire Site	Non-radiological hazard	Construction material	Spill of construction material	Site contamination	S0	F3	R0	1 - Response will be provided through contractors to rapidly respond to any accidental spills of construction material. 2 - Site supervision will be available to direct the movement of materials and batch mixing operation.	None
2	Install Concrete Cap and Engineered Barrier	8.4.005	Entire Site			See General Items No. 1 to No. 8 (excl. 3)						None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

After all below grade grouting has been completed, a final concrete cap is poured over the foot print of the previous reactor site. A mound designed to protect the grouted monolith from intrusion and water ingress is constructed. The area will be fenced.

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Table B.9 –Final Site Restoration

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	Demobilization & Final Site Restoration	8.4.006 8.4.003.24999	Entire site			See General Items No. 1 to No. 8 (excl. 3)						None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

Summary of Activity

After the final concrete has been poured, temporary facilities including the concrete batch plant, construction trailers, temporary fencing and barriers are removed. Parking areas for vehicles will be inspected and tested for any spills of oils or diesel. Tanks for water and diesel storage are removed. Pads and roads in areas previously occupied by training facilities and warehouses are rubblized using heavy equipment. This will allow natural reclamation of the land. Asphalt from parking areas may be removed for waste disposal. Roads required to access the dry hydrant and monitoring wells will remain. The temporary power upgrades installed to enable the work, transformers, panels, poles and overhead lines are removed back to the Hydro One junction at highway 17.

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Table B.10 – Long-Term Care & Maintenance

No.	Project Activity	WBS	Area	Hazard category	Hazardous Agent	Hazardous Event	Consequence (C)	S *	F **	R ***	Existing Safeguards	Action Required
1	Long Term care and Maintenance	N/A	Entire site			See General Items No. 1 and 2						None

Notes:

* Preliminary Severity Ranking – see Section 7.6. Assigned accounting for mitigative measures in place.

** Preliminary Frequency Ranking – see Section 7.6. The frequency evaluation of the accident scenarios in this table is the sum of the frequencies over the entire site and all project activities. Assigned accounting for preventative measures in place.

*** Preliminary Risk Ranking – see Section 7.6. Based on mitigated risk.

During the institutional controls phase, there is still the potential for external events (e.g. forest fires, floods, etc.) to occur. Consequences of these events would be bounded by those in the active operations phase. The safeguards would be different in the institutional control phase, and in the event that one of these events did occur, the follow-up action would be to perform an inspection, to ensure that the closed facility is still intact. (see Section 7.9.4.2)

Summary of Activity:

During the Institutional Controls phase, monitoring of the area around the mound will be carried out periodically, including air, soil, sediment and groundwater sampling, groundwater flow measurements, topographical inspections, surface drainage inspections, removal of deep-rooting vegetation, and visual inspections of the stack. In addition, moisture beneath the monolith will be monitored, and surface vegetative cover will be maintained.

APPENDIX C: ATMOSPHERIC DISPERSION MODELLING



Appendix C: Atmospheric Dispersion Modelling

C.1 Atmospheric Dispersion Modelling for Accidents Assessment

C.1.1 Introduction

Atmospheric dilution factors for the NPD facility, for use in assessing malfunctions and accident scenarios, were calculated by performing air dispersion modelling using CALPUFF (Scire *et al.* 1990, 2000) to simulate a unit release from the NPD facility for *fire* and *non-fire* events. The CALPUFF model has an option of using the area buoyancy source, which is applicable for simulations related to fire events.

C.1.2 Methodology & Parameters

For fire scenarios, the area buoyancy source was placed over the NPD facility and source characteristics used in modelling are given in Table C-1. For non-fire scenarios, a unit release from the NPD facility was modelled as a volume source located over the NPD building with the source characteristics presented in Table C-2. Both meteorological data configurations were used for comparison purposes

The CALPUFF model (version 6.42) was run in screening mode, using regional meteorological data for Ottawa (applicable for the Eastern region) along with forested land use, prepared by the Ontario Ministry of Environment and Climate Change (OMOECC) for the year 2000. Running CALPUFF in screening mode bypasses the need to generate a full three-dimensional wind field with CALMET. Instead, a single value for the land use category, surface roughness, and leaf area index is specified for the entire modelling domain. Meteorological conditions are assumed to vary from hour-to-hour, but are assumed to be uniform throughout the modeling domain *within* each given hour. Therefore, the ability to vary dispersion spatially according to local surface characteristics is lost. However, because this methodology is designed by the EPA and is meant to be a conservative screening technique, a number of assumptions made tend to result in the over prediction of impacts.

Terrain data was created from the Canadian Digital Elevation Data (CDED), with approximately 23 m horizontal resolution.

In addition to Ottawa meteorological data, CALPUFF was run in screening mode with meteorology combined from CNL wind and temperature data, and wind data from Chalk River with Ottawa surface and profile input files.

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Table C-1 CALPUFF Model Input Parameters – Fire Scenario Modelling

Parameter	Fire Scenario
Effective Release Height (m)	1
Source Area (m ²)	2,500
Effective Rise Velocity (m/s)	5
Effective Radius (m)	25
Initial Vertical Spread (m)	15
Temperature (°K)	523
Terrain Elevation	122

Table C-2 CALPUFF Model Input Parameters – Non-Fire Scenario Modelling

Parameter	Non-Fire Scenario
UTM Coordinates (m)	5118216 m N
Terrain Elevation	122
Source Area (m ²)	2,500
Effective Release Height (m)	1
Initial Lateral Dimensions (m)	11.6
Initial Vertical Dimensions (m)	1

Modelling was undertaken in the Universal Transverse Mercator (UTM) coordinate system. The coordinate system used for mapping was World Geodetic System (WGS84), Zone 18. A tiered grid was used for receptor placement, which ranged from 20 m to 500 m (based on recommendations provided by the OMOECC). In addition, discrete sensitive receptors that include residential and recreational locations in vicinity of the NPD facility, as well as the airborne human receptors from the NPD DRL Report (Chouhan & Scheier, 2011), were incorporated into the modelling.

C.1.3 Results

Fire Scenario Results

Results from CALPUFF modelling of the fire scenario are presented as air dilution factors (in g/m³ per g/s) and 1-hour concentrations (in µg/m³) at discrete receptors in Table C-3.

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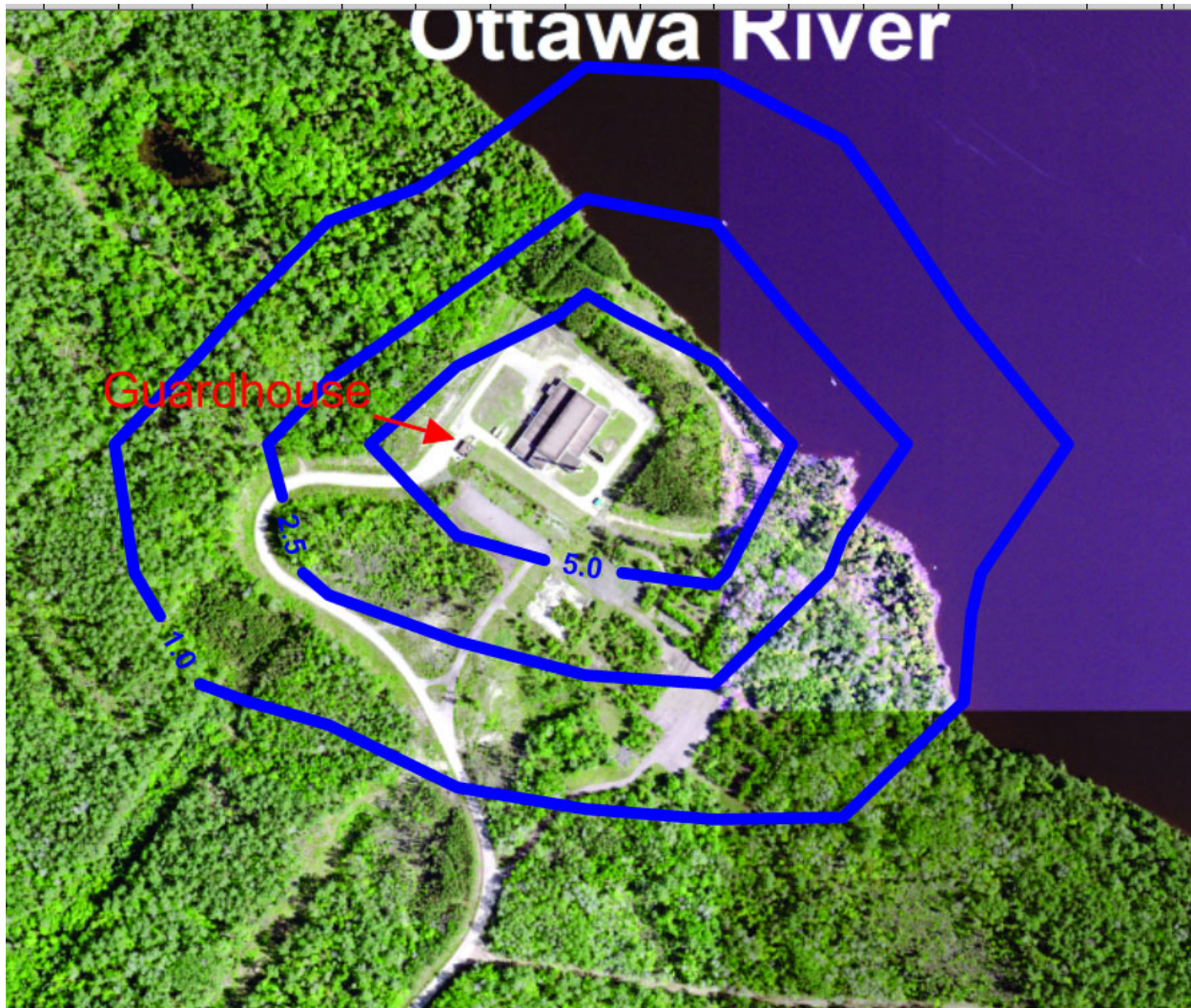
Table C-3 CALPUFF ADFs for Fire Scenarios

Discrete Receptors			Location relative to the NPD Facility			Fire Scenario			
			Distance from NPD (m)	Direction		CALPUFF-Ottawa Meteorology		CALPUFF-CNL Wind	
Easting (m)	Northing (m)	Receptor ID		Degrees from North	Sector	Dilution factor (g/m ³ per g/s)	Max 1-h Conc. (µg/m ³)	Dilution factor (g/m ³ per g/s)	Max 1-h Conc. (µg/m ³)
295485	5117153	Residential (R1)	1222	140	SE	3.6E-07	0.4	3.5E-07	0.3
294019	5117458	Residential (R2)	1149	230	SW	3.7E-07	0.4	3.5E-07	0.3
293941	5117474	Residential (R3)	1199	230	SW	3.6E-07	0.4	4.0E-07	0.4
296006	5117684	Recreational (R4)	1243	110	ESE	2.9E-07	0.3	3.2E-07	0.3
294800	5118207	Guardhouse	83	264	W	9.4E-06	9.4	5.2E-06	5.2
292899	5119449	Rapides des Joachims residential	2437	307	NW	2.5E-07	0.2	2.9E-07	0.3
296580	5117009	Point Stewart residential	1987	120	ESE	2.5E-07	0.3	2.6E-07	0.3
296334	5117317	Cottage	1627	115	ESE	2.5E-07	0.2	2.8E-07	0.3
292399	5116958	Rolphton residential	2665	247	WSW	3.7E-07	0.4	3.9E-07	0.4
283368	5116763	Mackey beef farm	11552	264	W	7.3E-08	0.07	1.2E-07	0.1
301240	5109238	Bass Lake beef farm	10838	144	SE	1.7E-07	0.2	2.1E-07	0.2

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The results of fire scenario modelling using *Ottawa meteorology* show that the maximum hourly concentration predicted at the guardhouse, from a 1 g/s release, is $9.4 \mu\text{g}/\text{m}^3$. Figure C-1 presents the 1-hour maximum concentration contour plot for this configuration.

Figure C-1 Predicted 1-hour Maximum Concentrations - Fire Scenario - Ottawa Meteorology [$\mu\text{g}/\text{m}^3$]



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The results of fire scenario modelling using *CNL wind data* show that the maximum hourly concentration predicted at the guardhouse, from a 1 g/s release, is $5.2 \mu\text{g}/\text{m}^3$. Figure C-2 presents the 1-hour maximum concentration contour plot for this configuration.

Figure C-2 Predicted 1-hour Maximum Concentrations - Fire Scenario – CNL Wind Data
[$\mu\text{g}/\text{m}^3$]



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Non-Fire Scenario Results

Table C-4 summarizes the ADF's and 1-hour maximum concentrations modelled by CALPUFF for non-fire accident scenario releases.

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Table C-4 CALPUFF ADFs for Non-Fire Scenarios

Discrete Receptors			Location relative to the NPD Facility			Non-Fire Scenario			
			Distance from NPD (m)	Direction		CALPUFF-Ottawa Meteorology		CALPUFF-CNL Wind	
Easting (m)	Northing (m)	Receptor ID		Degrees from North	Sector	Dilution factor (g/m ³ per g/s)	Max 1-h Conc. (µg/m ³)	Dilution factor (g/m ³ per g/s)	Max 1-h Conc. (µg/m ³)
295485	5117153	Residential (R1)	1222	140	SE	2.5E-04	254.8	3.5E-04	347.8
294019	5117458	Residential (R2)	1149	230	SW	4.1E-04	413.8	3.3E-04	328.9
293941	5117474	Residential (R3)	1199	230	SW	2.6E-04	258.0	2.9E-04	289.7
296006	5117684	Recreational (R4)	1243	110	ESE	2.5E-04	246.3	2.9E-04	292.1
294800	5118207	Guardhouse	83	264	W	1.5E-02	15317.0	1.5E-02	15291.0
292899	5119449	Rapides des Joachims residential	2437	307	NW	1.2E-04	120.1	1.1E-04	111.5
296580	5117009	Point Stewart residential	1987	120	ESE	1.2E-04	115.3	9.2E-05	92.4
296334	5117317	Cottage	1627	115	ESE	1.6E-04	155.5	2.0E-04	202.3
292399	5116958	Rolphon residential	2665	247	WSW	9.2E-05	92.1	8.4E-05	83.7
283368	5116763	Mackey beef farm	11552	264	W	9.9E-06	9.9	1.6E-04	163.2
301240	5109238	Bass Lake beef farm	10838	144	SE	9.9E-06	9.9	5.6E-06	5.6

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Modelling results based on *Ottawa meteorological data* for non-fire scenarios show that the maximum hourly concentration predicted at the guardhouse, from a 1 g/s release, is 15,317 $\mu\text{g}/\text{m}^3$. Figure C-3 presents the 1-hour maximum concentration contour plot for this configuration.

Figure C-3 Predicted 1-hour Maximum Concentrations – Non-Fire Scenario – Ottawa Meteorology [$\mu\text{g}/\text{m}^3$]



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Modelling results based on *CNL wind data* for non-fire scenarios show that the maximum hourly concentration predicted at the guardhouse, from a 1 g/s release, is 15,291 $\mu\text{g}/\text{m}^3$. Figure C-4 presents the 1-hour maximum concentration contour plot for this scenario.

Figure C-4 Predicted 1-hour Maximum Concentrations – Non-Fire Scenario – CNL Wind Data [$\mu\text{g}/\text{m}^3$]



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C.2 Atmospheric Dispersion Modelling for Normal Operations (AERMOD)

C.2.1 Introduction

Atmospheric dilution factors for normal operations at the NPD facility were derived by performing air dispersion modelling using AERMOD (U.S. EPA 2001) and CALPUFF (Scire *et al.* 1990, 2000) to simulate a unit release from the NPD facility.

The AERMOD model is the regulatory model currently recommended by the U.S.EPA and the OMOECC for simulating short-term air quality impacts from industrial complexes. The AERMOD Modelling System is an air quality modelling system developed by the AMS/EPA Regulatory Model Improvement Committee, (AERMIC). The AERMOD Modelling System consists of two pre-processors (AERMET and AERMAP) and the dispersion model AERMOD. In AERMOD, basic boundary layer parameters are calculated from the raw upper air data and are used to control the vertical travel of the pollutant plume. The stability is described by the Monin-Obukhov (M/O) length. The M/O length is a function of the surface roughness, the surface albedo (reflectivity) and surface soil moisture content as well as the upper air data. AERMET is used to combine and format the surface and upper air data. The AERMOD model is a steady-state Gaussian Plume model that provides options to model emissions from a wide range of sources. The model accepts hourly meteorological data records to define the conditions for plume rise, transport and dispersion. The model estimates the concentration or deposition value for each source-receptor combination, for each hour of input meteorology, and calculates short-term averages, such as 1 hour, 8 hour and 24 hour averages. The hourly averages can also be combined into longer averages (monthly, seasonal, annual or period).

C.2.2 Methodology & Parameters

A unit release from the NPD facility was modelled as a volume source located over the NPD building with the source characteristics presented in Table C-5.

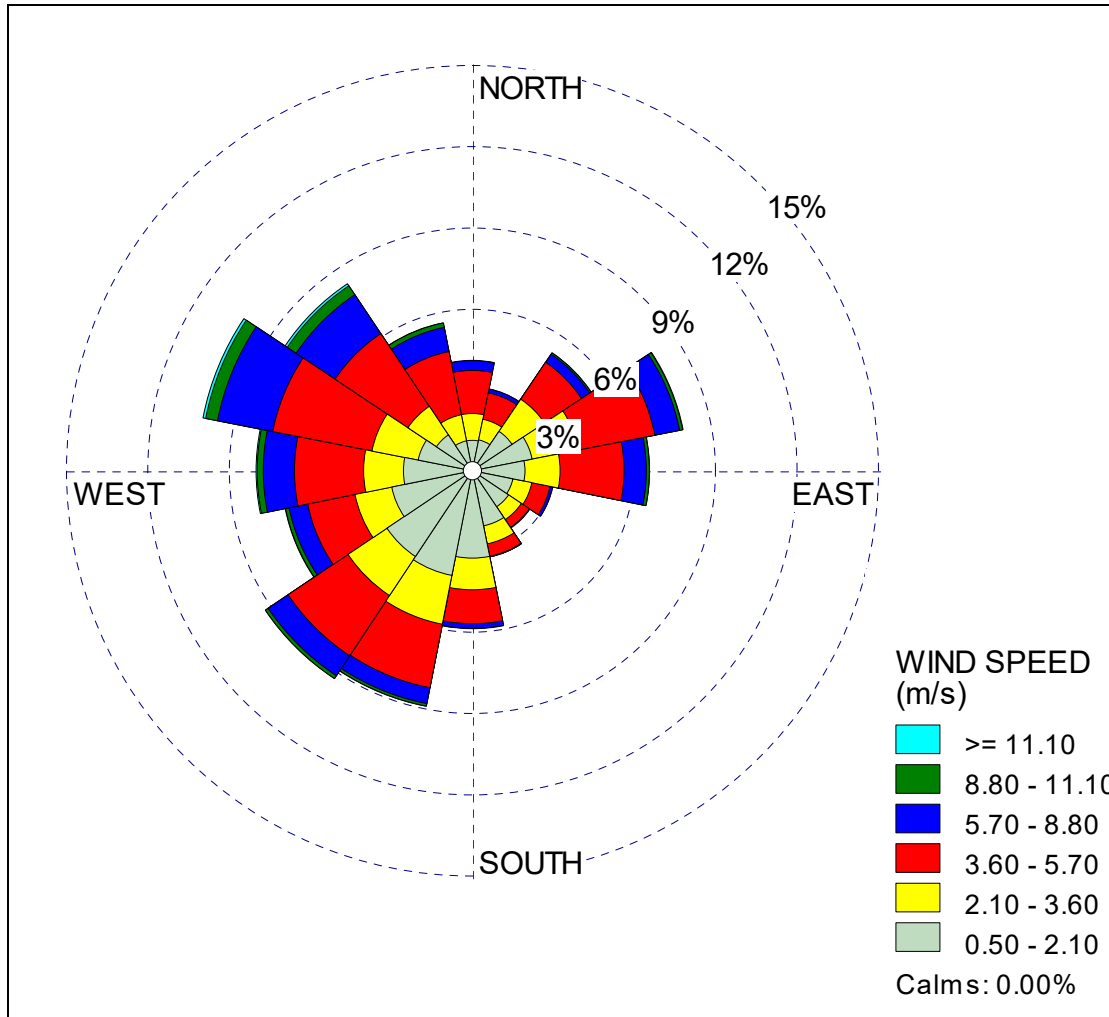
Table C-5 Air Dispersion Model Input Parameters – Normal Operations

Parameter	Non-Fire Scenario
UTM Coordinates (m)	294883 m E 5118216 m N
Terrain Elevation	122
Source Area (m ²)	2,500
Effective Release Height (m)	1
Initial Lateral Dimensions (m)	11.6
Initial Vertical Dimensions (m)	1

The meteorological data set used was the regional data for Ottawa (applicable for the Eastern region), prepared by the OMOECC, for forested land use, for the year 2000. Surface data (wind speed and direction, air temperature, ceiling, total opacity and total cloud amount) for the Ottawa airport were used. Upper air data from the Maniwaki upper air station was used. Figure C-5 shows wind rose plot of the Ottawa airport surface data for the period 1996 to 2000. The dominant wind direction is west-northwest (WNW) followed by southwest (SW). The average wind speed is 3.23 m/s.

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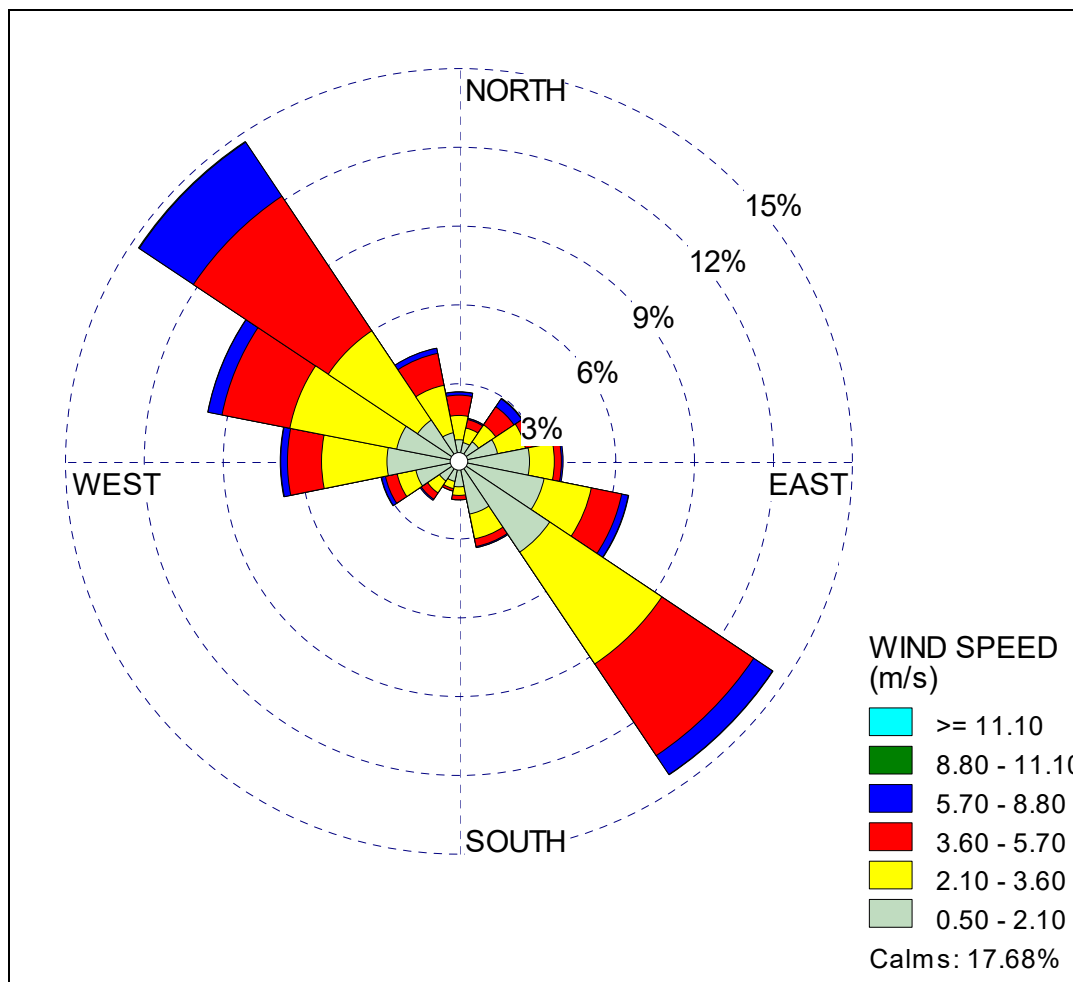
Figure C-5 Wind Rose Plot – Ottawa Airport (1996-2000)



In addition, select meteorological data were provided by CNL from the Chalk River Laboratories site for the period 2009 to 2015. These data consist of wind speed and wind direction measured at the top of the B456 tower; wind speed and direction and temperature at 30 m and 60 m height at the Perch Lake tower; and, ground temperature at Perch Lake (i.e. 50 m away from the Perch Lake tower). Since AERMOD requires surface measurements of ceiling and cloud cover in addition to wind speed and direction and ambient temperature, the CNL data set was combined with the Ottawa meteorological data to be used in air dispersion modelling. Wind and temperature from Ottawa input AERMOD files data was replaced with CNL wind and temperature and used by AERMOD and CALPUFF screening mode to simulate the unit release from the NPD facility (normal operations). Figure C-6 shows wind rose plot of the CNL wind data at CRL (for the period 2009 to 2013). The dominant wind directions are northwest (NW) and southeast (SE). The average wind speed for the CNL data set is 2.40 m/s and calm winds are recorded approximately 17% of the time.

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Figure C-6 Wind Rose Plot – CRL (2009-2013)



Modelling was undertaken in the Universal Transverse Mercator (UTM) coordinate system. The coordinate system used for mapping was World Geodetic System (WGS84), Zone 18. A tiered grid was used for receptor placement, which ranged from 20 m to 500 m (based on recommendations provided by OMOECC). In addition to the OMOECC grid, discrete sensitive receptors - including residential and recreational locations in vicinity of the NPD facility, as well as the airborne human receptors from the NPD DRL's Report (Chouhan & Scheier, 2011) - were also included.

C.2.3 Results

Results from the AERMOD modelling assessment are presented as air dilution factors (in g/m³ per g/s) and annual concentrations (in µg/m³) at discrete receptors in Table C-6, using two meteorological data sets. Table C-6 also includes the ADF's from the NPD DRL's Report (Chouhan 2016a), for comparison purposes. Figure C-7 and Figure C-8 show the annual concentration contours predicted by AERMOD with Ottawa meteorology and CNL wind data, respectively.

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Table C-6 AERMOD-Derived ADFs for Normal Operations

Discrete Receptors			Location relative to the NPD Facility			Atmospheric Dispersion Factors for Normal Operations				
			Distance from NPD (m)	Direction		NPD DRL (Chouhan 2016a) Dilution factor (Bq/m ³ per Bq/s)	AERMOD using Ottawa Meteorology		AERMOD using CNL Wind Data	
Easting (m)	Northing (m)	Receptor ID		Degrees from North	Sector		Dilution factor (g/m ³ per g/s)	Annual Conc. (µg/m ³)	Dilution factor (g/m ³ per g/s)	Annual Conc. (µg/m ³)
295485	5117153	Residential (R1)	1222	140	SE	n/a	5.4E-07	0.5	7.7E-07	0.8
294019	5117458	Residential (R2)	1149	230	SW	n/a	3.8E-07	0.4	2.9E-07	0.3
293941	5117474	Residential (R3)	1199	230	SW	n/a	3.8E-07	0.4	3.0E-07	0.3
296006	5117684	Recreational (R4)	1243	110	ESE	n/a	6.8E-07	0.7	1.2E-06	1.2
294800	5118207	Guardhouse	83	264	W	n/a	8.0E-05	80.3	6.8E-05	67.8
292899	5119449	Rapides des Joachims residential	2437	307	NW	3.0E-07	2.1E-07	0.21	3.3E-07	0.33
296580	5117009	Point Stewart residential	1987	120	ESE	2.4E-07	2.8E-07	0.28	5.6E-07	0.56
296334	5117317	Cottage	1627	115	ESE	2.5E-07	4.0E-07	0.40	8.3E-07	0.83
292399	5116958	Rolphon residential	2665	247	WSW	1.1E-07	9.0E-08	0.09	7.8E-08	0.08
283368	5116763	Mackey beef farm	11552	264	W	2.3E-08	1.5E-08	0.015	1.3E-08	0.013
301240	5109238	Bass Lake beef farm	10838	144	SE	2.2E-08	5.7E-09	0.006	1.2E-08	0.012

Notes:

n/a – Not Available (in the given reference document)

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Figure C-7 AERMOD-Predicted Annual Concentrations – Normal Operation – Ottawa
Meteorology [$\mu\text{g}/\text{m}^3$]



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Figure C-8 AERMOD-Predicted Annual Concentrations – Normal Operation – CNL Wind Data [$\mu\text{g}/\text{m}^3$]



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C.3 Atmospheric Dispersion Modelling for Normal Operations (CALPUFF re-derivation)

As discussed in Section C.2.1, ADFs for normal operation were also re-derived using CALPUFF. CALPUFF is a multi-layer, gridded non-steady-state puff dispersion model that can simulate the effects of temporally and spatially varying meteorological conditions on pollutant transport. In addition, CALPUFF can remove pollutants through dry and wet deposition processes and transform pollutant species through chemical reaction. CALPUFF can use the three-dimensional meteorological fields computed by the CALMET model, or can be used in a screening mode i.e. a simpler set of input data can be applied to the CALPUFF dispersion model and provide concentration estimates that are reasonably conservative when compared to a CALPUFF modeling effort with a fully-developed (i.e. 'refined') wind field.

CALPUFF model (version 6.42) was used in a screening mode, with the regional meteorological data for Ottawa (applicable for the Eastern region) and using forested land use, prepared by the OMOECC for the year 2000. Meteorological conditions were assumed to vary from hour-to-hour, but were assumed to be uniform throughout the modeling domain *within* each given hour. Terrain data was created from the Canadian Digital Elevation Data (CDED), with approximately 23 m horizontal resolution. Normal operations scenario was modelled by CALPUFF using a volume-source unit release from the NPD facility with the source characteristics presented in Table C-5. CALPUFF results, in the form of ADF's (in g/m^3 per g/s) at discrete receptors, are presented in Table C-7. In addition to Ottawa meteorological data, CALPUFF was also run with meteorology combined from CNL wind and temperature wind data from Chalk River with Ottawa surface and profile input files. These results are also included in Table C-7.

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Table C-7 CALPUFF-Derived ADFs for Normal Operations

Discrete Receptors			Location relative to the NPD Facility			Atmospheric Dispersion Factors for Normal Operations				
			Distance from NPD (m)	Direction		NPD DRL (Chouhan 2016a)	CALPUFF using Ottawa Meteorology		CALPUFF using CNL Wind Data	
Eastin g (m)	Northing (m)	Receptor ID		Degree s from North	Secto r		Dilution factor (Bq/m ³ per Bq/s)	Dilution factor (g/m ³ per g/s)	Annual Conc. (µg/m ³)	Dilution factor (g/m ³ per g/s)
295485	5117153	Residential (R1)	1222	140	SE	n/a	1.7E-06	1.7	4.8E-06	4.8
294019	5117458	Residential (R2)	1149	230	SW	n/a	2.3E-06	2.3	5.3E-06	5.3
293941	5117474	Residential (R3)	1199	230	SW	n/a	2.1E-06	2.1	4.9E-06	4.9
296006	5117684	Recreational (R4)	1243	110	ESE	n/a	2.3E-06	2.3	6.3E-06	6.3
294800	5118207	Guardhouse	83	264	W	n/a	6.1E-04	613.7	4.4E-04	444.5
292899	5119449	Rapides des Joachims residential	2437	307	NW	3.0E-07	4.4E-07	0.4	3.7E-06	3.7
296580	5117009	Point Stewart residential	1987	120	ESE	2.4E-07	7.7E-07	0.8	2.9E-06	2.9
296334	5117317	Cottage	1627	115	ESE	2.5E-07	1.2E-06	1.2	4.2E-06	4.2
292399	5116958	Rolphon residential	2665	247	WSW	1.1E-07	5.8E-07	0.6	1.6E-06	1.6
283368	5116763	Mackey beef farm	11552	264	W	2.3E-08	4.7E-08	0.05	9.1E-08	0.09
301240	5109238	Bass Lake beef farm	10838	144	SE	2.2E-08	3.8E-08	0.04	9.8E-08	0.10

Notes:

n/a – Not Available (in the given reference document)

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Figure C-9 and Figure C-10 show the annual concentrations contours predicted by CALPUFF with Ottawa meteorology and CNL wind data, respectively.

Figure C-9 CALPUFF-Predicted Annual Concentrations – Normal Operation – Ottawa Meteorology [$\mu\text{g}/\text{m}^3$]



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Figure C-10 CALPUFF-Predicted Annual Concentrations – Normal Operation – CNL Wind Data [$\mu\text{g}/\text{m}^3$]



The annual ADFs (for unit releases) under normal operations, modelled by the same model (either AERMOD or CALPUFF) using different wind data, are similar in general (i.e. are in the same range) and reflect the effects of dominant wind directions to the concentrations at discrete receptors. The results of annual concentrations and ADF's modelled by two models (with the same wind data) show that CALPUFF (in screening mode) results are higher comparing to the AERMOD results. As mentioned earlier, CALPUFF screening modelling results provide conservatively high impacts due to the model's design and intended use as a screening tool.

APPENDIX D: MCNP SIMULATION OF DRILLING



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Appendix D: MCNP Simulation of Drilling from the FM Room to the Reactor Vault

The following analysis assesses a bounding scenario where workers are drilling from the Fueling Machine (FM) room into the reactor vault. Other drilling activities would be bounded by this scenario because this scenario involves the highest drilling source term. This analysis will correspond to the estimated worker dose due to drilling, which is also provided in Section 8.4.4.6.

Drilling of Vent Holes into the Reactor Vault

Description

Three holes are anticipated to be drilled from the FM room, straight down into the reactor vault. This operation has the potential to expose workers to elevated levels of radiation, and as such this operation is simulated in order to estimate the dose rate and total dose that will be received.

Approach

MCNP was chosen to perform the dose calculations because it can account for possible streaming through the drill hole, and the possibility of skyshine off the roof of the FM room (both of which lead to an increase in the resulting dose).

In order to make the model of the system realistic, without requiring the modelling of every individual component, several simplifications were made. These simplifications are explained below.

The first component of the model is the reactor core. In reality this core is comprised of many different parts, each involving different material compositions, and each with varying levels of activity. In order to simplify this component for modelling, but not influence the results, the reactor was treated as a homogenous mixture. The outer diameter of the Calandria tank was used as the radius, and the length of the pressure tube assembly (including the end fittings) was used as a total length. This produces a Calandria with appropriate dimensions as shown in Table D-1. With the shape defined, the material of the reactor is needed. In order to maintain the shielding properties of the reactor, the material used to define the homogenous reactor must be a homogenized mix of the various materials, including air. This was accomplished by determining the ratio of each individual material to the total mass of all materials, and using this as a scaling factor for elemental composition and density. This produces a 'combined' material that includes all of the appropriate elements and a density that represents the mixture. Table D-5 presents the individual component compositions and the resulting homogenized composition. The source term for the reactor was evenly distributed throughout the entire volume of the cylinder in order to properly account for the variations in self-shielding. The isotopic source term is shown in Table D-6 and the energy binned source term is shown in Table D-7.

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Around the reactor core, the air that occupies the reactor vault was added. The elemental composition of this air is shown in Table D-3. The walls of the reactor vault were not included in this model, and instead, the boundary of the model was placed here. This means that any particles that hit the walls or floor of the reactor vault will stop being tracked by the simulation. This is a reasonable simplification because the probability of a photon scattering off the walls or floor of the reactor vault, and still having sufficient energy to reach the receptor is very low. This simplification improves the simulation time by focusing on the particles that are directed towards the receptor. Figure D-1 shows the structure of the model; the reactor core (yellow) and the air in the reactor vault (dark blue) can be seen.

Above the reactor vault is the FM room, and between these two rooms is a large section of shielding. The shielding, as seen in Figure D-1, consists of high-density concrete (light blue) around the edges, and special high-density concrete (green) in the central section. The elemental composition of both concretes was assumed to be the same, and only the density was varied. Table D-4 shows the elemental composition of the concrete, and Table D-2 shows the density of both concretes. In the center of the room there is a large open space which is closed with a hatch. This hatch consists of 3 plates of cast iron and three slabs of Masonite, which alternate (each 6.5" thick), followed by a section of special high density concrete (2' 6" thick). For modelling purposes, the Masonite was ignored, as the amount of shielding it provides relative to the concrete and iron is negligible. Therefore, the cast iron plates were considered a single piece (19.5" thick). The cast iron was modelled as pure iron, as trace contamination was expected to not affect the results. The walls of the FM room were included in this simulation to capture any skyshine effects that may occur, however the space beyond the walls was ignored and any particles that reached beyond the FM room walls were not further modelled. Similar to the reactor vault, the space inside of the FM room was filled with air. In reality, some of the walls in the FM room are actually made of standard density concrete; however, it was assumed that all of the walls were made of high density concrete for this simulation. This is a conservative assumption as it would provide an increased probability of skyshine. Table D-1 shows the dimensions used for the MCNP model.

To simulate the holes to be drilled between the FM room and the reactor vault, a corresponding set of holes was placed in the model. A 6" diameter hole was used, and three locations were modelled, based on the expected drilling locations. The first hole is in the center of the FM room, directly above the reactor, drilling through the hatch (Hole A). The other two holes are located on either side of the room, at X=675 cm, Y=250 cm (Hole B) and X=-675 cm, Y=-250 (Hole C) cm, relative to the model origin (0,0,0) located at the center of the reactor core. All three holes are shown in Figure D-2. The holes were modelled as being complete in the model. The workers were assumed to be standing directly above the open hole for the estimated drilling duration. These are both conservative assumptions, as the worker is not expected to be directly above the hole, and the worker would have some shielding material as the hole is being drilled.

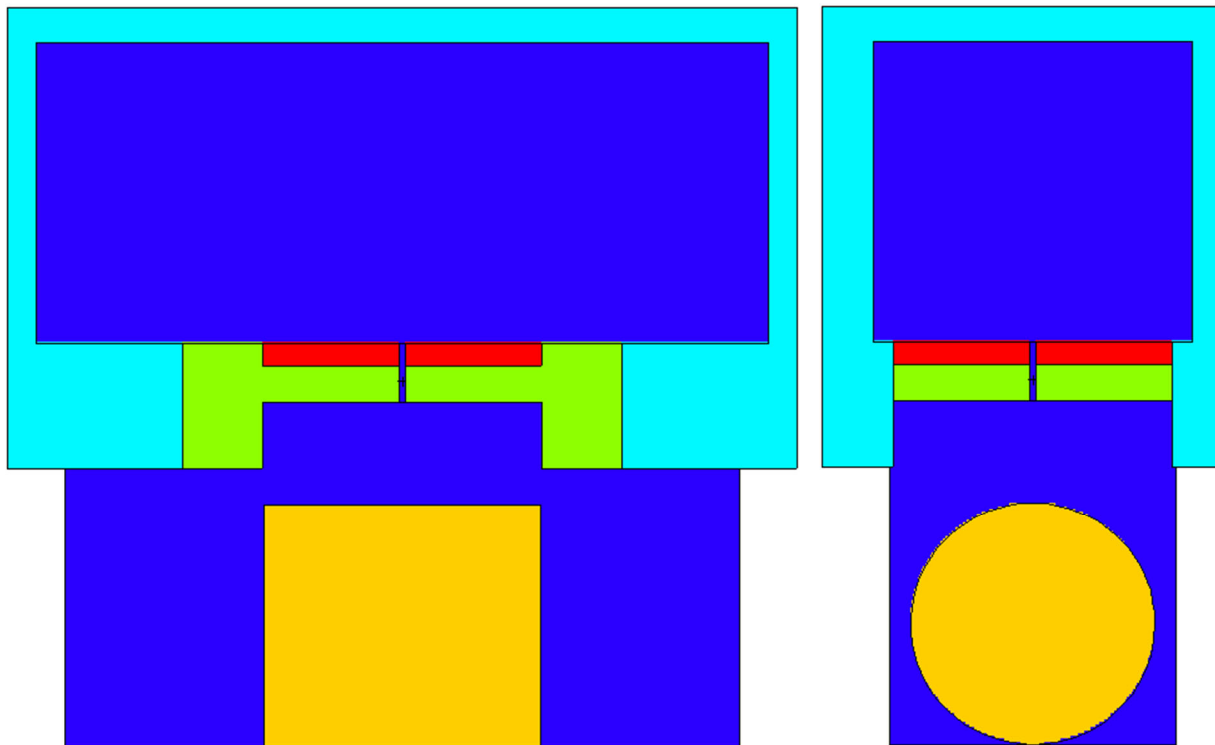
In MCNP tallies are used to create measurements. Therefore, point tallies were used to estimate the dose that the worker would receive. Three tally points were placed directly above the drill holes, where each point tally was placed 87.5 cm above the floor.

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The tallies are flux tallies, meaning that they estimate the flux at the location. In order to convert this into a dose rate the tallies were binned by energy, and a response function was applied. The response function allows for the direct conversion of a flux into a dose rate. For this model, an ambient photon dose equivalent ($H^*(10)$) response function was applied (Shultis and Faw 2000). This response function was used for calculating a conservative dose rate from external radiation, using the ICRU sphere, which calculates the dose rate at a depth of 10 mm from the tally point. This dose rate will provide an acceptable estimate of the dose rates that a worker will encounter.

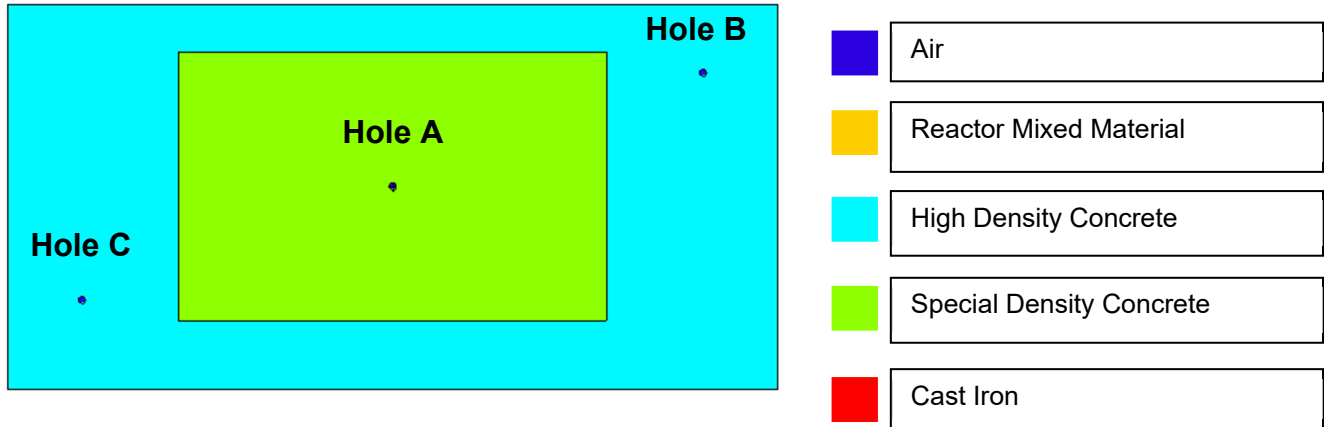
**Figure D-1 XZ and YZ Section Views of MCNP Model
(though X=0 plane and Y=0 plane respectively)**

(for dimensions, see Table D-1 below)



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Figure D-2 XY Section View of MCNP Model Showing Drill Hole Locations
(for dimensions, see Table D-1 below)



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Table D-1 Dimensions used in the MCNP Model

Room / Component	Length (X)	Width (Y)	Height (Z) / Thickness	Material	Reference (unless otherwise noted)
Reactor Vessel	585 cm	259 cm (radius)	N/A	Homogenised Reactor Materials	(CNL 2016b)
Reactor Vault Interior	1432 cm	610 cm	596 cm	Air	(CNL 2016b)
FM Floor/RV Roof (not including Hatch)	1676 cm	846 cm	269 cm ¹	High Density Concrete	(CNL 2016b)
Special Density Concrete Component	932 cm	594 cm	269 cm (at edge) 76.2 cm (at hatch)	Special Density Concrete	(Harris 1958)
Cast Iron Hatch Component	594 cm	594 cm	49.5 cm	Cast Iron	(Harris 1960)
FM Room Interior	1554 cm	678 cm	644 cm ¹	Air	(CNL 2016b)
FM Room Walls	N/A	N/A	61 cm 107 cm (next to BR (-Y) wall)	High Density Concrete	(CNL 2016b)
FM Room Roof	N/A	N/A	76 cm	High Density Concrete	(Harris 1958)

Notes: ¹ – (Harris 1958)

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Table D-2 Densities of Materials Used

Material	Density (g/cm ³)	Reference
Air	0.001205	McConn <i>et al.</i> 2011
High Density Concrete	3.692	Krasznai 1991
Special Density Concrete	4.8055	Harris 1960
Homogenised Reactor Material	5.9259	Calculated
Cast Iron	7.86	MicroShield

Table D-3 Elemental Composition of Air Used (Source: McConn *et al.* 2011)

Air (Dry, Near Sea Level)	
Element	wt%
Carbon	0.0124
Nitrogen	75.5268
Oxygen	23.1781
Argon	1.2827

Table D-4 Elemental Composition of Concrete Used (Source: Krasznai 1991)

Concrete	
Element	wt%
Hydrogen	0.24
Oxygen	34
Iron	36
Titanium	19
Silicon	2.4
Aluminium	1.9
Calcium	4.6
Magnesium	1.8

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Table D-5 Elemental Composition of Homogenized Reactor Material

Element	Zircaloy ^{2,1}	Aluminum ¹	SS410 ¹	SS17-4 ¹	CS ¹	Concrete ¹	Air ²	wt% (scaled)
Calculated Mass % ³	14%	21%	7%	13%	29%	15%	1%	
Hydrogen	0.002					0.23		0.0343
Boron	0.00005							0.0000
Carbon	0.05		0.15	0.07	0.32		0.000124	0.1202
Nitrogen	0.009	0.009					0.755268	0.0072
Oxygen	0.14					35	0.231781	5.1988
Magnesium	0.002	2.8				1.8		0.8444
Aluminum	0.008	96				1.9		20.0955
Silicon	0.01	0.45	0.5	1	0.3	2.5		0.7219
Phosphorus			0.04		0.04			0.0145
Sulphur			0.03		0.05			0.0167
Chlorine	0.002					4.7		0.6956
Calcium						19		2.8106
Titanium	0.005							0.0007
Vanadium	0.005							0.0007
Chromium			12	16.5				3.0901
Manganese	0.005	0.1	1	1	0.9			0.4893
Iron	0.2	0.45	86.18	73.03	98.29	35		49.8656
Cobalt	0.002	0.002	0.05	0.05	0.05	0.0023		0.0259
Nickel	0.08			4				0.5496
Copper	0.005	0.1		4				0.5594
Zinc		0.1						0.0206
Zirconium	98							14.0566
Niobium			0.01	0.01	0.01			0.0050
Molybdenum	0.005							0.0007

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Element	Zircaloy ^{2,1}	Aluminum ¹	SS410 ¹	SS17-4 ¹	CS ¹	Concrete ¹	Air ²	wt% (scaled)
Calculated Mass % ³	14%	21%	7%	13%	29%	15%	1%	
Silver			0.04	0.04	0.04			0.0199
Cadmium	0.00005							0.0000
Tin	1.7							0.2438
Hafnium	0.02							0.0029
Tantalum				0.3				0.0404
Tungsten	0.01							0.0014
Lead	0.01							0.0014
Thorium						0.0012		0.0002
Uranium	0.0004	0.05				0.0004		0.0104

Notes:

- 1 – Obtained from (Smith 1988)
- 2 – Obtained from (McConn *et al.* 2011)
- 3 – Calculated from the ratios of the component mass over the total mass

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Table D-6 Radioactive Source Term by Isotope (Bq)

Isotope	Material						Total
	Zircaloy	Aluminum	S Steel	C Steel	Concrete	Surface	
Ac-225	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-	1.25E+06
Ac-228	3.28E+04	3.14E+05	9.15E+06	1.98E+06	0.00E+00	-	1.15E+07
Ag-108	2.98E+07	3.44E+02	7.34E+07	6.73E+09	1.08E+09	-	7.91E+09
Ag-108m	3.42E+08	3.96E+03	8.63E+08	7.74E+10	2.16E+10	-	1.00E+11
Ag-109m	3.00E+03	2.61E-07	1.01E+02	3.08E+04	3.06E+05	-	3.40E+05
Al-26	4.18E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	4.18E+06
Am-241	1.36E+08	0.00E+00	0.00E+00	1.88E+09	1.80E+09	1.49E+09	5.31E+09
Am-242	3.35E+05	0.00E+00	0.00E+00	7.87E+06	3.37E+06	-	1.16E+07
Am-242m	3.37E+05	0.00E+00	0.00E+00	7.91E+06	3.39E+06	-	1.16E+07
Am-243	9.67E+06	0.00E+00	0.00E+00	3.48E+05	1.64E+08	-	1.74E+08
Ar-39	2.73E+07	3.28E+04	6.97E+04	5.85E+05	1.80E+08	-	2.08E+08
At-217	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-	1.25E+06
Ba-133	1.02E+09	1.57E+06	0.00E+00	1.37E+03	1.19E+04	-	1.02E+09
Ba-137m	5.86E+09	1.01E+06	8.50E+07	4.55E+10	7.37E+10	-	1.25E+11
Be-10	1.26E+05	0.00E+00	0.00E+00	5.14E+04	5.62E+04	-	2.34E+05
Bi-210	4.02E+01	3.67E+01	0.00E+00	0.00E+00	4.86E+02	-	5.63E+02
Bi-211	0.00E+00	2.96E+01	7.68E+03	1.97E+05	0.00E+00	-	2.05E+05
Bi-212	9.11E+05	3.14E+05	9.69E+06	1.38E+07	1.90E+03	-	2.47E+07
Bi-213	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-	1.25E+06
C-14	1.00E+11	2.40E+10	1.25E+09	1.05E+11	1.36E+12	2.97E+09	1.59E+12
Ca-41	9.21E+08	7.62E+09	5.80E+06	3.28E+08	1.25E+09	-	1.01E+10
Cd-109	3.00E+03	2.61E-07	1.01E+02	3.08E+04	3.06E+05	-	3.40E+05
Cd-113m	4.13E+07	2.15E+01	6.28E+08	2.21E+09	2.71E+07	-	2.91E+09
Cl-36	4.58E+09	1.74E+08	1.09E+07	2.64E+05	2.50E+10	2.79E+07	2.98E+10
Cm-242	2.77E+05	0.00E+00	0.00E+00	6.51E+06	2.79E+06	-	9.58E+06
Cm-243	5.45E+05	-	-	3.10E+05	9.27E+06	-	1.01E+07
Cm-244	9.95E+08	0.00E+00	0.00E+00	1.19E+06	1.58E+10	-	1.68E+10
Cm-245	1.14E+05	0.00E+00	0.00E+00	0.00E+00	1.83E+06	-	1.94E+06
Cm-246	3.64E+05	0.00E+00	0.00E+00	0.00E+00	5.25E+06	-	5.61E+06
Co-60	5.28E+11	3.18E+11	1.61E+11	1.34E+13	2.63E+12	2.52E+08	1.70E+13
Co-60m	7.25E+04	0.00E+00	0.00E+00	1.80E+05	1.74E+05	-	4.27E+05
Cs-134	5.57E+05	2.89E-03	4.33E+00	3.60E+05	6.70E+06	-	7.62E+06
Cs-135	6.68E+04	3.86E+01	1.79E+03	1.34E+06	7.45E+05	-	2.15E+06
Cs-137	6.91E+09	1.07E+06	1.87E+08	4.82E+10	7.79E+10	4.11E+10	1.74E+11
Eu-152	7.78E+09	1.23E+11	5.92E+07	1.26E+08	3.48E+09	-	1.34E+11
Eu-154	2.51E+10	1.38E+06	8.78E+05	6.75E+08	1.16E+09	1.60E+08	2.71E+10
Eu-155	1.90E+09	1.25E+04	6.57E+04	3.18E+07	8.38E+07	-	2.02E+09
Fe-55	8.77E+10	7.84E+10	1.73E+10	3.15E+12	1.79E+11	1.53E+08	3.51E+12

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Isotope	Material						Total
Fe-60	7.25E+04	0.00E+00	0.00E+00	1.80E+05	1.74E+05	-	4.27E+05
Fr-221	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-	1.25E+06
H-3	9.13E+09	1.41E+12	2.35E+08	2.04E+09	7.36E+11	7.62E+08	2.16E+12
Hf-182	0.00E+00	0.00E+00	0.00E+00	2.69E+03	4.44E+06	-	4.44E+06
Ho-166m	3.73E+07	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	3.73E+07
I-129	3.76E+03	0.00E+00	0.00E+00	3.94E+04	5.25E+04	-	9.57E+04
Kr-85	1.08E+08	2.82E+04	5.41E+06	1.35E+09	7.82E+08	-	2.25E+09
La-137	2.92E+05	1.18E+01	2.38E+05	1.41E+07	0.00E+00	-	1.46E+07
Mo-93	3.71E+06	0.00E+00	3.50E+07	1.93E+09	6.84E+08	-	2.65E+09
Nb-91	2.91E+04	0.00E+00	4.07E+05	1.39E+07	7.84E+06	-	2.22E+07
Nb-93m	4.97E+06	2.25E+03	2.55E+07	1.41E+09	1.94E+11	-	1.95E+11
Nb-94	0.00E+00	1.62E+05	5.84E+07	4.40E+09	1.13E+10	-	1.58E+10
Ni-59	2.17E+09	1.68E+06	8.37E+08	1.54E+11	2.16E+11	-	3.73E+11
Ni-63	5.22E+11	6.83E+10	3.96E+10	1.44E+13	3.36E+13	1.05E+09	4.86E+13
Np-237	0.00E+00	0.00E+00	0.00E+00	2.97E+04	3.09E+04	-	6.06E+04
Np-239	9.67E+06	0.00E+00	6.93E-06	3.48E+05	1.64E+08	-	1.74E+08
P-32	3.20E+04	1.47E-01	4.80E+01	2.06E+03	4.80E+05	-	5.14E+05
Pa-234	0.00E+00	7.03E+02	4.33E+04	9.66E+03	0.00E+00	-	5.37E+04
Pa-234m	4.68E+05	4.40E+05	2.79E+07	6.04E+06	9.24E+04	-	3.49E+07
Pb-205	2.79E+04	0.00E+00	0.00E+00	1.26E+04	2.53E+05	-	2.94E+05
Pb-209	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-	1.25E+06
Pb-210	0.00E+00	3.67E+01	0.00E+00	0.00E+00	0.00E+00	-	3.67E+01
Pb-212	9.11E+05	3.14E+05	9.69E+06	1.38E+07	1.90E+03	-	2.47E+07
Pd-107	2.78E+04	0.00E+00	0.00E+00	1.07E+05	4.74E+05	-	6.09E+05
Pm-145	2.47E+08	4.60E+03	0.00E+00	0.00E+00	0.00E+00	-	2.47E+08
Pm-146	1.83E+05	0.00E+00	0.00E+00	2.16E+02	0.00E+00	-	1.83E+05
Pm-147	7.80E+06	9.03E+02	1.44E+06	1.60E+08	2.44E+07	-	1.94E+08
Po-210	4.02E+01	3.67E+01	0.00E+00	1.02E+00	4.86E+02	-	5.64E+02
Po-212	5.84E+05	2.01E+05	5.81E+06	8.87E+06	0.00E+00	-	1.55E+07
Po-213	0.00E+00	2.20E+02	1.29E+04	1.21E+06	0.00E+00	-	1.22E+06
Po-215	0.00E+00	2.96E+01	7.68E+03	1.97E+05	0.00E+00	-	2.05E+05
Po-216	9.11E+05	3.14E+05	9.41E+06	1.38E+07	1.90E+03	-	2.44E+07
Pt-193	2.24E+06	0.00E+00	0.00E+00	0.00E+00	7.92E+08	-	7.94E+08
Pu-238	8.96E+07	8.30E+08	7.26E+02	3.27E+08	1.05E+09	1.47E+08	2.44E+09
Pu-239	6.44E+07	2.06E+07	1.08E+08	1.49E+09	4.22E+08	9.98E+08	3.10E+09
Pu-240	4.24E+07	2.29E+01	1.39E+05	9.71E+08	4.80E+08	-	1.49E+09
Pu-241	1.12E+09	0.00E+00	1.50E+04	1.30E+10	1.56E+10	-	2.97E+10
Pu-242	6.73E+05	0.00E+00	0.00E+00	3.57E+05	1.11E+07	-	1.21E+07
Ra-224	9.11E+05	3.14E+05	9.32E+06	1.38E+07	1.90E+03	-	2.43E+07
Ra-225	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-	1.25E+06

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Isotope	Material						Total
Ra-228	3.28E+04	3.14E+05	9.17E+06	1.98E+06	0.00E+00	-	1.15E+07
Rb-87	0.00E+00	3.29E+04	0.00E+00	0.00E+00	0.00E+00	-	3.29E+04
Re-186	2.33E+03	0.00E+00	6.63E-01	8.64E+03	1.20E+06	-	1.21E+06
Re-186m	2.06E+03	0.00E+00	0.00E+00	7.91E+03	1.20E+06	-	1.21E+06
Rn-220	9.11E+05	3.14E+05	9.33E+06	1.38E+07	1.90E+03	-	2.44E+07
Ru-106	2.27E+01	4.62E-04	9.79E-02	1.22E+02	3.46E+02	-	4.91E+02
Sb-125	2.67E+07	1.55E+01	1.15E+06	2.52E+07	9.05E+10	-	9.06E+10
Sb-126m	5.66E+04	3.32E+00	0.00E+00	3.71E+05	6.86E+05	-	1.11E+06
Se-79	1.06E+04	2.06E+00	6.08E+05	1.77E+07	1.04E+05	-	1.84E+07
Si-32	3.15E+04	0.00E+00	0.00E+00	1.76E+03	4.80E+05	-	5.13E+05
Sm-151	4.71E+08	5.51E+05	3.07E+08	2.25E+09	7.60E+07	-	3.10E+09
Sn-121	4.80E+07	1.24E+02	1.53E+06	5.87E+07	1.61E+11	-	1.61E+11
Sn-121m	6.19E+07	1.60E+02	1.94E+06	7.56E+07	2.08E+11	-	2.08E+11
Sn-126	5.66E+04	3.32E+00	0.00E+00	3.71E+05	6.86E+05	-	1.11E+06
Sr-90	3.11E+09	1.01E+06	1.68E+08	3.55E+10	2.55E+10	2.68E+10	9.11E+10
Ta-182	3.17E+02	0.00E+00	1.36E-01	2.93E+03	4.44E+06	-	4.44E+06
Tb-157	4.24E+07	1.46E+03	0.00E+00	0.00E+00	0.00E+00	-	4.24E+07
Tb-158	8.26E+06	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-	8.26E+06
Tc-99	2.17E+06	3.94E+02	7.53E+06	4.12E+08	1.45E+08	1.76E+07	5.84E+08
Te-125m	6.53E+06	3.79E+00	2.62E+05	6.14E+06	2.22E+10	-	2.22E+10
Th-228	9.11E+05	3.14E+05	9.21E+06	1.38E+07	1.90E+03	-	2.42E+07
Th-229	0.00E+00	2.25E+02	1.32E+04	1.24E+06	0.00E+00	-	1.25E+06
Th-230	0.00E+00	3.15E+03	9.66E+04	2.59E+04	0.00E+00	-	1.26E+05
Th-231	2.08E+04	2.02E+04	1.26E+06	2.45E+05	0.00E+00	-	1.55E+06
Th-232	3.28E+04	3.14E+05	9.19E+06	1.98E+06	0.00E+00	-	1.15E+07
Th-234	4.68E+05	4.40E+05	2.79E+07	6.04E+06	9.24E+04	-	3.49E+07
Tl-208	3.13E+05	1.13E+05	3.26E+06	4.98E+06	0.00E+00	-	8.67E+06
U-232	8.52E+05	0.00E+00	1.33E+03	1.15E+07	1.84E+03	-	1.24E+07
U-233	1.52E+06	5.72E+04	8.26E+06	3.13E+08	0.00E+00	-	3.23E+08
U-234	7.04E+05	4.35E+05	2.76E+07	1.18E+07	1.35E+05	-	4.07E+07
U-235	2.08E+04	2.02E+04	1.26E+06	2.45E+05	0.00E+00	-	1.55E+06
U-236	0.00E+00	1.02E+01	0.00E+00	1.51E+05	1.85E+04	-	1.70E+05
U-237	2.75E+04	1.84E-06	3.69E-01	3.18E+05	3.82E+05	-	7.28E+05
U-238	4.68E+05	4.40E+05	2.79E+07	6.04E+06	9.24E+04	-	3.49E+07
Y-90	2.97E+09	1.01E+06	1.73E+08	7.09E+10	2.55E+10	-	9.95E+10
Zr-93	2.76E+06	2.80E+03	3.67E+03	2.06E+06	2.40E+11	-	2.40E+11

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Table D-7 Radioactive Source Term by Energy Bins
(Derived using radionuclide quantities and associated energies)

Energy (MeV)	Source Strength (γ/s)
0.015	3.26E+13
0.02	7.12E+10
0.03	1.12E+11
0.04	9.80E+10
0.05	2.10E+10
0.06	1.96E+09
0.08	7.77E+09
0.1	5.03E+10
0.15	2.89E+08
0.2	1.93E+10
0.3	3.89E+10
0.4	1.29E+11
0.5	1.09E+10
0.6	2.41E+11
0.8	1.59E+11
1	1.70E+13
1.5	1.70E+13
2	2.24E+08
3	8.96E+06
4	4.46E+03
5	1.25E+03
6	3.20E+02
8	3.59E+01
10	3.10E+00
Total	6.76E+13

Dose Rate Results

Table D-8 shows the dose rate estimates for the drilling scenario. The simulation was run for 1×10^{10} histories (simulated particles), in order to achieve an acceptable error level. It is important to note that the error associated with these dose rates is the statistical error from MCNPs generation of random numbers in Monte Carlo calculations, and is not the error associated with the model or its assumptions.

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Table D-8 Dose Rates from Drilling into the Reactor Vault

Location	Dose Rate (mSv/hr)	Error (%)
Hole A	1.19E-02	1.13%
Hole B	9.36E-06	6.48%
Hole C	9.86E-06	5.81%
Ambient Dose Rate in FM room	2.1 E-02	From (Primeau 2016)

Table D-9 shows the total dose the workers are estimated to receive over the duration of drilling.

Table D-9 Total Dose from Drilling into the Reactor Vault

Location	Total Dose (mSv)	Dose Limit (mSv) (Max Per Year)	Dose Limit (mSv) (Max for 5 Years)
4 Hours			
Hole A	0.132	50	100
Hole B ¹	0.084	50	100
Hole C ¹	0.084	50	100
8 Hours			
Hole A	0.263	50	100
Hole B ¹	0.168	50	100
Hole C ¹	0.168	50	100
16 Hours²			
Hole A	0.527	50	100
Hole B ¹	0.336	50	100
Hole C ¹	0.336	50	100

Note:

¹ – the ambient dose rate dominates this total dose.

² – assuming two 8-hour work days.

APPENDIX E: DETAILED RESULTS – RADIOLOGICAL & NON-RADIOLOGICAL



Appendix E: Detailed Dose Results

A Scenario 1 – Forest Fire, Release of Radioactivity

Table E-1 Bounding Scenario 1 – Forest Fire – Soil Screening Indices

Parameter	Soil Screening Index <i>[unitless; comparison of estimated soil concentrations to Unconditional Clearance Levels]</i>												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3 (Soil)	Not Applicable	Not Applicable	5.76E-04	5.76E-04	6.58E-04	5.26E-04	8.56E-03	4.77E-04	4.28E-04	4.61E-04	6.42E-04	1.97E-04	3.45E-04
C-14 (Soil)	Not Applicable	Not Applicable	1.90E-04	1.90E-04	2.18E-04	1.74E-04	2.83E-03	1.58E-04	1.41E-04	1.52E-04	2.12E-04	6.53E-05	1.14E-04
Sum of Fractions	Not Applicable	Not Applicable	7.66E-04	7.66E-04	8.76E-04	7.01E-04	1.14E-02	6.35E-04	5.69E-04	6.13E-04	8.54E-04	2.63E-04	4.60E-04

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

Table E-2 Inhalation Dose for Various Receptor Locations, Scenario 1.

Radionuclides	Inhalation Dose [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3	1.41E-05	1.41E-05	6.15E-07	6.15E-07	7.03E-07	5.62E-07	9.14E-06	5.10E-07	4.57E-07	4.92E-07	6.86E-07	2.11E-07	3.69E-07
C-14	6.57E-07	6.57E-07	1.67E-07	1.67E-07	1.91E-07	1.53E-07	2.49E-06	1.39E-07	1.24E-07	1.34E-07	1.86E-07	5.74E-08	1.00E-07

Table E-3 Air Immersion Dose for Various Receptors, Scenario 1

Radionuclides	Air Immersion Dose [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C-14	8.84E-12	8.84E-12	2.48E-13	2.48E-13	2.83E-13	2.27E-13	3.68E-12	2.05E-13	1.84E-13	1.98E-13	2.76E-13	8.50E-14	1.49E-13

Table E-4 Total Dose (Inhalation + Immersion) for Various Receptors, Scenario 1.

Radionuclides	Total Dose (Inhalation + Immersion) [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3	1.41E-05	1.41E-05	6.15E-07	6.15E-07	7.03E-07	5.62E-07	9.14E-06	5.10E-07	4.57E-07	4.92E-07	6.86E-07	2.11E-07	3.69E-07
C-14	6.57E-07	6.57E-07	1.67E-07	1.67E-07	1.91E-07	1.53E-07	2.49E-06	1.39E-07	1.24E-07	1.34E-07	1.86E-07	5.74E-08	1.00E-07
Total:	1.48E-05	1.48E-05	7.83E-07	7.83E-07	8.94E-07	7.15E-07	1.16E-05	6.48E-07	5.81E-07	6.26E-07	8.72E-07	2.68E-07	4.70E-07

B Scenario 2 – Forest Fire, Release of Hazardous Chemicals

Table E-5 (a) Inhalation Screening Indexes for Various Receptors, Scenario 2

Hazardous Chemicals	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
Asbestos	6.00E-01	6.00E-01	4.20E-03	4.20E-03	4.80E-03	3.84E-03	6.24E-02	3.48E-03	3.12E-03	3.36E-03	4.68E-03	1.44E-03	2.52E-03
Lead	2.33E-05	2.33E-05	1.09E-04	1.09E-04	1.24E-04	9.93E-05	1.61E-03	9.00E-05	8.06E-05	8.69E-05	1.21E-04	3.72E-05	6.51E-05
Mercury	Not Applicable												
PCBs	Not Applicable												
Dioxins & Furans	Not Applicable												

Table E-5(b) Soil Screening Indexes for Various Receptors, Scenario 2

Hazardous Chemicals	Soil Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
Lead	Not Applicable	Not Applicable	9.77E-10	9.77E-10	1.12E-09	8.93E-10	1.45E-08	8.09E-10	7.26E-10	7.82E-10	1.09E-09	3.35E-10	5.86E-10

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

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C Scenario 3 – Tornado, Release of Radioactivity

Table E-6 Bounding Scenario 3 – Tornado (EF-2) – Soil Screening Indices

Parameter	Soil Screening Index [unitless; comparison of estimated soil concentrations to Unconditional Clearance Levels]												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3 (Soil)	Not Applicable	Not Applicable	3.76E-11	3.76E-11	3.76E-11	3.76E-11	3.76E-11	1.69E-03	3.76E-11	3.76E-11	1.69E-03	5.64E-05	5.64E-05
C-14 (Soil)	Not Applicable	Not Applicable	5.44E-14	5.44E-14	5.44E-14	5.44E-14	5.44E-14	2.45E-06	5.44E-14	5.44E-14	2.45E-06	8.16E-08	8.16E-08
Sum of Fraction	Not Applicable	Not Applicable	3.76E-11	3.76E-11	3.76E-11	3.76E-11	3.76E-11	1.69E-03	3.76E-11	3.76E-11	1.69E-03	5.64E-05	5.64E-05

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus, they are not applicable for soil pathways.

Table E-7 Inhalation Dose for Various Receptors, Scenario 3

Radionuclides	Inhalation Dose [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3	6.44E-15	6.44E-15	4.01E-14	4.01E-14	4.01E-14	4.01E-14	4.01E-14	1.81E-06	4.01E-14	4.01E-14	1.81E-06	6.02E-08	6.02E-08
C-14	1.31E-18	1.31E-18	4.78E-17	4.78E-17	4.78E-17	4.78E-17	4.78E-17	2.15E-09	4.78E-17	4.78E-17	2.15E-09	7.17E-11	7.17E-11

Table E-8 Air Immersion Dose for Various Receptors, Scenario 3

Radionuclides	Air Immersion Dose [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C-14	1.77E-23	1.77E-23	7.08E-23	7.08E-23	7.08E-23	7.08E-23	7.08E-23	3.19E-15	7.08E-23	7.08E-23	3.19E-15	1.06E-16	1.06E-16

Table E-9 Total Dose for Various Receptors, Scenario 3

Radionuclides	Total Dose (Inhalation + Immersion) [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3	6.44E-15	6.44E-15	4.01E-14	4.01E-14	4.01E-14	4.01E-14	4.01E-14	1.81E-06	4.01E-14	4.01E-14	1.81E-06	6.02E-08	6.02E-08
C-14	1.31E-18	1.31E-18	4.78E-17	4.78E-17	4.78E-17	4.78E-17	4.78E-17	2.15E-09	4.78E-17	4.78E-17	2.15E-09	7.17E-11	7.17E-11
Total:	6.43E-15	6.43E-15	4.02E-14	4.02E-14	4.02E-14	4.02E-14	4.02E-14	1.81E-06	4.02E-14	4.02E-14	1.81E-06	6.02E-08	6.02E-08

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D Scenario 4 – Tornado, Release of Hazardous Chemicals

Table E-10 (a) Inhalation Screening Indexes for Various Receptors, Scenario 4

Hazardous Chemicals	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
Asbestos	1.47E-08	1.47E-08	1.47E-08	1.47E-08	1.47E-08	1.47E-08	1.47E-08	6.60E-01	1.47E-08	1.47E-08	6.60E-01	2.93E-02	2.93E-02
Lead	9.31E-14	9.31E-14	6.20E-11	6.20E-11	6.20E-11	6.20E-11	6.20E-11	2.79E-03	6.20E-11	6.20E-11	2.79E-03	9.31E-05	9.31E-05
Mercury	Not Applicable												
PCBs	Not Applicable												

Table E-10 (b) Soil Screening Indexes for Various Receptors, Scenario 4

Hazardous Chemicals	Soil Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
Lead	Not Applicable	Not Applicable	5.58E-16	5.58E-16	5.58E-16	5.58E-16	2.51E-08	2.51E-08	5.58E-16	5.58E-16	2.51E-08	8.37E-10	8.37E-10

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

E Scenario 6 – Accidental Exposure to Radioactivity

Table E-11 Dust Dose for Workers, Scenario 6

Radionuclides	Inhalation Dose [in mSv]		Air Immersion Dose [in mSv]		Total Dose (Inhalation + Immersion) [in mSv]	
	Worker (Near-Field)	Worker (Far-Field)	Worker (Near-Field)	Worker (Far-Field)	Worker (Near-Field)	Worker (Far-Field)
H-3	1.29E-03	1.26E-03	0.00E+00	0.00E+00	1.29E-03	1.26E-03
C-14	3.10E-04	3.03E-04	4.16E-09	4.08E-09	3.10E-04	3.03E-04
Ag-108m	3.08E-09	3.02E-09	1.91E-11	1.87E-11	3.10E-09	3.04E-09
Ba-133	6.28E-08	6.16E-08	1.70E-09	1.66E-09	6.45E-08	6.32E-08
Ca-41	3.22E-05	3.15E-05	0.00E+00	0.00E+00	3.22E-05	3.15E-05
Cd-113m	6.21E-11	6.09E-11	1.30E-16	1.27E-16	6.21E-11	6.09E-11
Cl-36	2.67E-05	2.62E-05	1.93E-09	1.89E-09	2.67E-05	2.62E-05
Co-60	2.05E-01	2.01E-01	2.52E-03	2.47E-03	2.08E-01	2.03E-01
Cs-135	8.50E-13	8.33E-13	2.45E-17	2.40E-17	8.50E-13	8.33E-13
Cs-137	1.20E-05	1.17E-05	4.97E-10	4.87E-10	1.20E-05	1.17E-05
Eu-152	1.07E-01	1.05E-01	4.33E-04	4.24E-04	1.07E-01	1.05E-01
Eu-154	2.73E-05	2.68E-05	9.43E-08	9.24E-08	2.74E-05	2.69E-05
La-137	2.62E-12	2.57E-12	2.36E-16	2.31E-16	2.62E-12	2.57E-12
Nb-93m	8.00E-11	7.84E-11	4.58E-16	4.49E-16	8.01E-11	7.84E-11
Nb-94	1.62E-07	1.59E-07	7.78E-10	7.62E-10	1.63E-07	1.60E-07
Ni-59	8.22E-09	8.05E-09	0.00E+00	0.00E+00	8.22E-09	8.05E-09
Ni-63	7.90E-04	7.74E-04	0.00E+00	0.00E+00	7.90E-04	7.74E-04
Pu-238	7.94E-01	7.78E-01	1.94E-10	1.90E-10	7.94E-01	7.78E-01
Pu-239	2.15E-02	2.11E-02	4.78E-12	4.69E-12	2.15E-02	2.11E-02
Pu-240	2.39E-08	2.34E-08	5.22E-18	5.12E-18	2.39E-08	2.34E-08
Sb-125	1.55E-12	1.52E-12	1.93E-14	1.89E-14	1.57E-12	1.54E-12
Se-79	1.42E-13	1.39E-13	5.41E-19	5.30E-19	1.42E-13	1.39E-13
Sm-151	4.53E-08	4.44E-08	9.04E-16	8.86E-16	4.53E-08	4.44E-08
Sn-121m	1.49E-11	1.46E-11	5.59E-16	5.48E-16	1.49E-11	1.46E-11
Sn-126	1.99E-12	1.95E-12	4.08E-16	3.99E-16	1.99E-12	1.95E-12
Sr-90	3.37E-06	3.30E-06	6.62E-12	6.49E-12	3.37E-06	3.30E-06
Tc-99	3.42E-11	3.35E-11	7.54E-16	7.39E-16	3.42E-11	3.35E-11
Th-229	4.95E-07	4.85E-07	5.04E-14	4.94E-14	4.95E-07	4.85E-07
Th-230	2.80E-06	2.75E-06	3.11E-15	3.05E-15	2.80E-06	2.75E-06
Th-232	2.93E-04	2.87E-04	1.52E-13	1.49E-13	2.93E-04	2.87E-04
U-233	1.11E-05	1.08E-05	5.42E-14	5.31E-14	1.11E-05	1.08E-05
U-234	8.22E-05	8.06E-05	1.77E-13	1.74E-13	8.22E-05	8.06E-05
U-235	3.46E-06	3.39E-06	8.70E-12	8.53E-12	3.46E-06	3.39E-06
U-236	1.79E-09	1.76E-09	2.63E-18	2.57E-18	1.79E-09	1.76E-09
U-238	7.14E-05	7.00E-05	7.34E-14	7.19E-14	7.14E-05	7.00E-05
Zr-93	1.81E-09	1.77E-09	0.00E+00	0.00E+00	1.81E-09	1.77E-09
Total dose: Inhalation & Immersion [mSv]					1.13E+00	1.11E+00
External Dose Rate – Drilling in FM Room [mSv/hr]					3.29E-02	
Total Dose (for 32-hr drilling) [mSv]					2.19E+00	2.16E+00

Note: external gamma dose contribution is based on the dose rate from Hole A, because it is the highest (more conservative) among Hole A, B, and C locations.

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F Scenario 8 – Indoor Fire, Release of Radioactivity

Table E-12 Bounding Scenario 8 – Underground (Indoor) Fire – Soil Screening Indices

Parameter	Soil Screening Index [unitless; comparison of estimated soil concentrations to Unconditional Clearance Levels]												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
Cs-137 (Soil)	Not Applicable	Not Applicable	5.47E-07	5.47E-07	6.25E-07	5.00E-07	8.12E-06	4.53E-07	4.06E-07	4.37E-07	6.09E-07	1.87E-07	3.28E-07
Co-60 (Soil)	Not Applicable	Not Applicable	8.61E-08	8.61E-08	9.84E-08	7.87E-08	1.28E-06	7.13E-08	6.39E-08	6.89E-08	9.59E-08	2.95E-08	5.16E-08
Sum of Fractions	Not Applicable	Not Applicable	6.33E-07	6.33E-07	7.23E-07	5.78E-07	9.40E-06	5.24E-07	4.70E-07	5.06E-07	7.05E-07	2.17E-07	3.80E-07

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

Table E-13 Inhalation Dose for Various Receptors, Scenario 8

Radionuclides	Inhalation Dose [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
Cs-137	6.62E-04	6.48E-04	3.93E-11	3.93E-11	4.49E-11	3.59E-11	5.84E-10	3.26E-11	2.92E-11	3.14E-11	4.38E-11	1.35E-11	2.36E-11
Co-60	4.51E-04	4.42E-04	3.90E-11	3.90E-11	4.46E-11	3.56E-11	5.79E-10	3.23E-11	2.90E-11	3.12E-11	4.34E-11	1.34E-11	2.34E-11

Table E-14 Air Immersion Dose for Various Receptors, Scenario 8

Radionuclides	Air Immersion Dose [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
Cs-137	2.75E-08	2.69E-08	9.10E-13	9.10E-13	1.04E-12	8.32E-13	1.35E-11	7.54E-13	6.76E-13	7.28E-13	1.01E-12	3.12E-13	5.46E-13
Co-60	5.55E-06	5.44E-06	6.68E-13	6.68E-13	7.63E-13	6.10E-13	9.92E-12	5.53E-13	4.96E-13	5.34E-13	7.44E-13	2.29E-13	4.01E-13

Table E-15 Total Dose for Various Receptors, Scenario 8

Radionuclides	Total Dose (Inhalation + Immersion) [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
Cs-137	6.62E-04	6.48E-04	4.02E-11	4.02E-11	4.60E-11	3.68E-11	5.98E-10	3.33E-11	2.99E-11	3.22E-11	4.48E-11	1.38E-11	2.41E-11
Co-60	4.57E-04	4.47E-04	3.97E-11	3.97E-11	4.53E-11	3.63E-11	5.89E-10	3.29E-11	2.95E-11	3.17E-11	4.42E-11	1.36E-11	2.38E-11
Total:	1.12E-03	1.10E-03	7.99E-11	7.99E-11	9.13E-11	7.30E-11	1.19E-09	6.62E-11	5.93E-11	6.39E-11	8.90E-11	2.74E-11	4.79E-11

G Scenario 9 – Indoor Fire, Release of Hazardous Chemicals

Table E-16(a) Inhalation Screening for Various Receptors, Scenario 9a (FM Room)

Hazardous Chemicals	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
Asbestos	Not Applicable												
Lead	7.95E-01	7.79E-01	4.07E-06	4.07E-06	4.66E-06	3.72E-06	6.05E-05	3.38E-06	3.03E-06	3.26E-06	4.54E-06	1.40E-06	2.44E-06
PCBs	Not Applicable												
Dioxins & Furans	Not Applicable												

Table E-16 (b) Soil Screening Indexes for Various Receptors, Scenario 9a (FM Room)

Hazardous Chemicals	Soil Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
Lead	Not Applicable	Not Applicable	3.67E-11	3.67E-11	4.19E-11	3.35E-11	5.45E-10	3.04E-11	2.72E-11	2.93E-11	4.08E-11	1.26E-11	2.20E-11

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

Table E-17 Inhalation Screening for Various Receptors, Scenario 9b (Boiler Room)

Hazardous Chemicals	Inhalation Screening Index <i>[unitless; comparison of estimated concentration to benchmark value]</i>												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
Asbestos	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Mercury	2.39E-01	2.38E-01	6.48E-07	6.48E-07	7.41E-07	5.93E-07	9.63E-06	5.37E-07	4.81E-07	5.19E-07	7.22E-07	2.22E-07	3.89E-07

H Scenario 10 – Stack Collapse, Release of Radioactivity

Table E-18 Bounding Scenario 10 – Stack Collapse – Soil Screening Indices

Radionuclide	Soil Screening Index <i>[unitless; comparison of estimated soil concentrations to Unconditional Clearance Levels]</i>												
	Worker* (Near-Field)	Worker* (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3 (Soil)	Not Applicable	Not Applicable	4.54E-04	4.28E-04	3.76E-04	3.76E-04	1.56E-02	1.43E-04	1.19E-04	2.59E-04	1.09E-04	2.07E-04	7.26E-06
C-14 (Soil)	Not Applicable	Not Applicable	2.80E-02	2.64E-02	2.32E-02	2.32E-02	9.60E-01	8.80E-03	7.36E-03	1.60E-02	6.72E-03	1.28E-02	4.48E-04
Sum of Fractions	Not Applicable	Not Applicable	2.28E-02	2.15E-02	1.89E-02	1.89E-02	9.75E-01	7.15E-03	5.98E-03	1.30E-02	5.46E-03	1.04E-02	3.64E-04

Notes:

*Worker Receptor Locations represent indoor exposure locations within the main building. Thus they are not applicable for soil pathways.

Table E-19 Inhalation Dose for Various Receptors, Scenario 10

Radionuclides	Inhalation Dose [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3	6.66E-07	6.66E-07	2.91E-05	2.74E-05	2.41E-05	2.41E-05	1.25E-03	9.14E-06	7.64E-06	1.66E-05	6.98E-06	1.33E-05	4.65E-07
C-14	5.80E-06	5.80E-06	1.48E-03	1.39E-03	1.22E-03	1.22E-03	6.33E-02	4.64E-04	3.88E-04	8.44E-04	3.54E-04	6.75E-04	2.36E-05

Table E-20 Air Immersion Dose for Various Receptors, Scenario 10

Radionuclides	Air Immersion Dose [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphton Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
C-14	7.80E-11	7.80E-11	2.19E-09	2.06E-09	1.81E-09	1.81E-09	9.37E-08	6.87E-10	5.75E-10	1.25E-09	5.25E-10	1.00E-09	3.50E-11

Table E-21 Water Immersion Dose for Workers, Scenario 10

Radionuclides	Water Immersion Dose [in mSv]
	Worker
H-3	3.69E-04
Co-60	1.17E-10
Cs-137	4.90E-15
Total:	3.69E-04

Table E-22 Total Dose for Various Receptors, Scenario 10

Radionuclides	Total Dose (Inhalation + Water Immersion) [in mSv]												
	Worker (Near-Field)	Worker (Far-Field)	Res. 1	Res. 2	Res. 3	Rec. (Res. 4)	Guardhouse	Rapides Des Joachims	Pt. Stewart Res.	Cottage	Rolphon Res.	Mackey Beef Farm	Bass Lake Beef Farm
H-3 (inhalation)	6.66E-07	6.66E-07	2.91E-05	2.74E-05	2.41E-05	2.41E-05	1.25E-03	9.14E-06	7.64E-06	1.66E-05	6.98E-06	1.33E-05	4.65E-07
H3 (Water immersion)	3.69E-04	3.69E-04	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
C-14 (inhalation)	5.80E-06	5.80E-06	1.48E-03	1.39E-03	1.22E-03	1.22E-03	6.33E-02	4.64E-04	3.88E-04	8.44E-04	3.54E-04	6.75E-04	2.36E-05
Total:	3.75E-04	3.75E-04	1.51E-03	1.42E-03	1.25E-03	1.25E-03	6.45E-02	4.73E-04	3.96E-04	8.60E-04	3.61E-04	6.88E-04	2.41E-05

APPENDIX F: AIR QUALITY ASSESSMENT FOR THE NPD PROJECT



Appendix F: Air Quality Assessment for the NPD Project

F.1 Introduction

In support of the NPD decommissioning, air dispersion modelling of emissions from the activities related to the batch mixing plant operation which may interact with air quality, was undertaken using the AERMOD dispersion model. A general description of the inputs used in the dispersion model is provided below, followed by the results of the dispersion modelling.

F.2 Air Quality Regulations

The Ontario Ministry of Environment (MOE; now called the Ministry of Environment, Conservation and Parks - MECP) specifies ambient air quality criteria (AAQC – 24 hour and annual average) for a large number of chemical parameters as does Ministère de l'Environnement et de la Lutte contre les changements climatiques (MELCC). As the activities that will be undertaken as part of the NPD Project are of a construction / demolition nature, the conventional contaminants that are relevant to this undertaking are related to particulate emissions (TSP, PM₁₀, PM_{2.5}) and the products of fossil fuel combustion related to the diesel generators and heavy equipment operation (NO₂ and SO₂). The NPD Closure Project will comply with the standards or screening criteria that are in effect at the time of the project. The applicable Federal and Provincial criteria and objectives for this assessment are provided in Table F-1. The recently endorsed new Canadian Ambient Air Quality Standards (CAAQS) are also presented; the year when the CAAQS come into effect is shown in brackets. Table F-1 includes the new air standard for SO₂ that will come into effect on July 1, 2023.

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Table F-1 Applicable Air Quality Criteria

Parameter	MOE AAQC (µg/m ³)			CAAQS (µg/m ³)			MELCC (µg/m ³)		
	1 Hour Average	24 Hour Average	Annual Average	1 Hour Average	24 Hour Average	Annual Average	1 Hour Average	24 Hour Average	Annual Average
NO ₂	400	200	-	119 ^a (2020), 83 ^a (2025)	-	34 ^b (2020), 24 ^b (2025)	414	207	103
SO ₂	690, 100 ^j	275	55, 10 ^j	193 ^c (2020), 179 ^c (2025)	125 ^e , 300 ^f	14 ^d (2020), 11 ^d (2025)	-	288	52
TSP	-	120	60	-	-	-	-	120	-
PM ₁₀	-	50 ^g	-	-	-	-	-	-	-
PM _{2.5}	-	30 ^h	-	-	28 ^h (2015), 27 ^h (2020)	10.0 ⁱ (2015), 8.8 ⁱ (2020)	-	30	-

Note: The conversion from ppb to µg/m³ assumes an ambient pressure of 1 atmosphere and a temperature of 10 degrees Celsius

^a The 3-year average of the annual 98th percentile of the NO₂ daily maximum 1-hour average concentrations

^b The average over a single calendar year of all the 1-hour average NO₂ concentrations

^c The 3-year average of the annual 99th percentile of the SO₂ daily maximum 1-hour average concentrations

^d The average over a single calendar year of all the 1-hour average SO₂ concentrations

^e Maximum desirable level

^f Maximum acceptable level

^g Interim value

^h The 3-year average of the annual 98th percentile of the daily 24-hour average PM_{2.5} concentrations

ⁱ The 3-year average of the annual average concentrations

^j March 20, 2018 MECP new air standard for 1-hour and annual average SO₂ concentrations, will take effect on July 1, 2023

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F.3 Air Dispersion Model Configuration

F.3.1 Overview of Atmospheric Dispersion Modelling

F.3.1.1 AERMOD Model

To calculate the concentration at a given location near an emissions source, an atmospheric dispersion model is used. These models take the emissions from a source and disperse them into the surrounding area, typically using historical hourly meteorological data from a local weather station. The preferred regulatory model in Ontario is AERMOD (U.S. EPA 1998, 2001). The AERMOD Modelling System is a steady state air quality modelling system developed by the AMS/EPA Regulatory Model Improvement Committee, (AERMIC). AERMOD is a steady state Gaussian plume dispersion model that can be used to assess pollutant concentrations from a wide variety of complex industrial settings including multiple stacks, fugitive emissions, and building wake effects. The AERMOD Modelling System consists of two pre-processors (AERMET and AERMAP) and the dispersion model AERMOD. The AERMOD model is the regulatory model currently recommended by the U.S.EPA and the MECP for simulating short-term air quality impacts from industrial complexes.

In AERMOD, basic boundary layer parameters are calculated from the raw upper air data and are used to control the vertical travel of the pollutant plume. The stability is described by the Monin-Obukhov (M/O) length. The M/O length is a function of the surface roughness, the surface albedo (reflectivity) and surface soil moisture content as well as the upper air data. AERMET was used to combine and format the surface and upper air data. AERMOD then processes the meteorological data directly without the need of a pre-processor.

The AERMOD model is a steady-state Gaussian Plume model that provides options to model emissions from a wide range of sources. The model accepts hourly meteorological data records to define the conditions for plume rise, transport and dispersion. The model estimates the concentration or deposition value for each source-receptor combination, for each hour of input meteorology, and calculates short-term averages, such as 1 hour, 8 hour and 24 hour averages. The hourly averages can also be combined into longer averages (monthly, seasonal, annual or period).

F.3.1.2 Uncertainties in Air Dispersion Modelling

Uncertainty in air dispersion modelling in general is affected by the quality of the information input to the modelling (such as emissions data and meteorology) and the capabilities of the modelling program with regard to physics and formulation (EPA, 2005). In short, an increase in accuracy in the input parameters and model physics is likely to result in a reduction to the uncertainty in the results. There are parameters for which even the most advanced models may not be able to account for, such as complex meteorological conditions. In instances where actual meteorological conditions are unknown to the modelling program, the difference between

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observed concentrations and modelled concentrations may be in the order of $\pm 50\%$. In general, dispersion modelling programs are more accurate (in the range of $\pm 10\%$ to 40%) when modelling a highest concentration for a given area; however, less reliable when attempting to predict a highest concentration at a specific time and place. For example, uncertainty in meteorological data may cause a modelled plume to touch down in a slightly different location than in actual conditions – so while the highest concentration predicted by the model may be accurate, there is increased uncertainty in the exact location.

In general, to account for uncertainty in emissions estimation, maximum emission scenarios were used to estimate the potential effect of the different Project activities. Additionally, background concentrations were added to account for upwind sources which were not included in the dispersion model. Furthermore, to compare against regulatory criteria, the maximum predicted concentration for each time frame (e.g., 24 hour average) over a five year meteorological period was used. All of these factors are included to reduce the potential of underestimating a potential effect.

The following model-specific sensitive input factors are expected to contribute to uncertainty in results. The U.S. EPA emission factor for paved roads is included, as there are inputs to this equation that may affect the model uncertainty. A summary of how uncertainty was addressed accompanies each input parameter identified below in Table F-2.

Table F-2 Measures to Address Uncertainty in Atmospheric Dispersion Modelling

Input	Measures to Address Uncertainty
Emission Rates	<ul style="list-style-type: none"> Based on conservative maximum operating scenarios in which equipment is operating at capacity Modelled a conservative maximum bounding scenario which considered the maximum amount of equipment that may operate simultaneously
Meteorology	<ul style="list-style-type: none"> Used a validated 5-year data set from a representative meteorological station, which is expected to capture all meteorological conditions that are likely to occur in the site and local study areas. The use of these data will typically result in predicted maximum concentrations based on these conditions

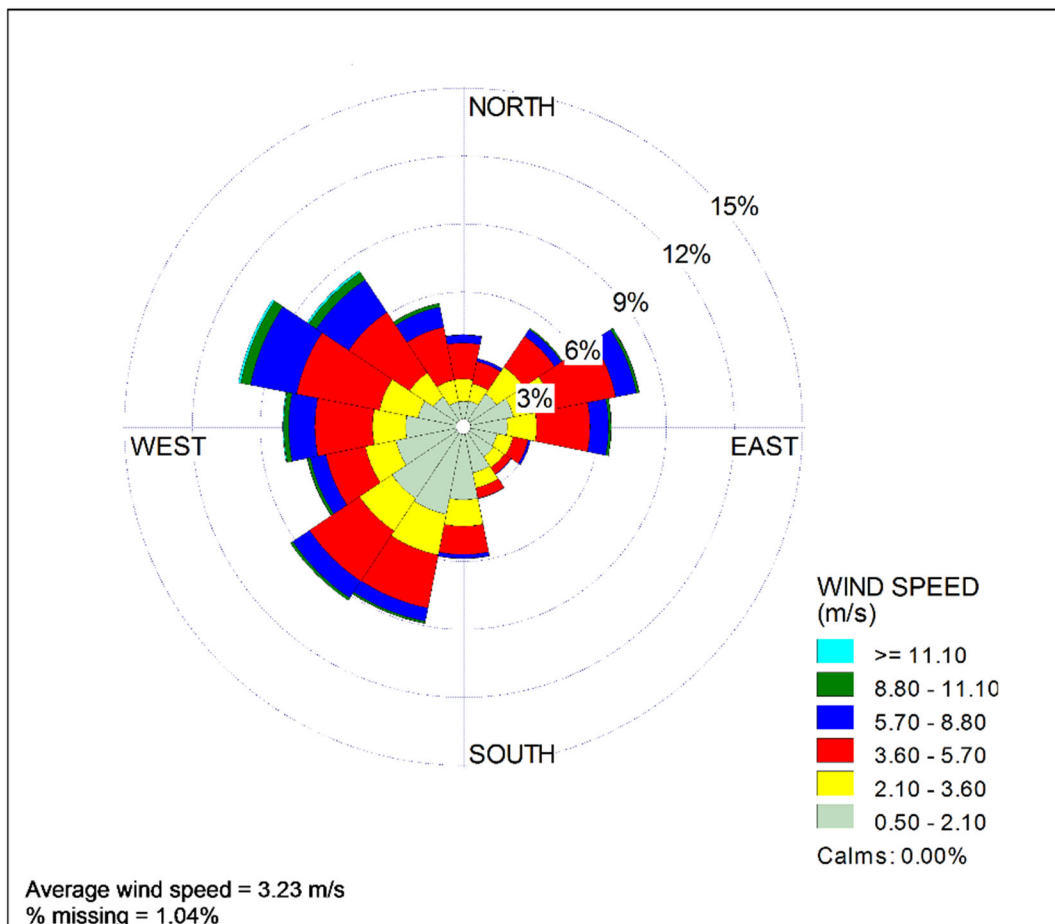
F.3.2 Meteorological Data

The meteorological data set provided by CNL, collected over 5-year period from 2011 to 2015, consists of hourly observations of wind speed and wind direction measured at the roof of the 456 tower at Chalk River Laboratories (no actual height was provided). In addition, wind speed, wind direction and temperature at 30 m and 60 m height at the Perch Lake tower were provided, as well as ground temperature at Perch Lake (i.e. 50 m away from the Perch Lake tower). AERMOD requires surface measurements of wind speed and direction (generally, at a height of 10 meters) and ambient temperature (generally, at a height of 2 meters) and observed ceiling and cloud cover. The available meteorological data set had data gaps for some of the above

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meteorological parameters, and thus, was not used for air dispersion modelling for the air quality assessment for the NPD project. The meteorological data set applied in this assessment was the AERMOD regional data for Ottawa (applicable for the Eastern region), prepared by the MOE, with forest type of land use, for the 5-year period from 1996 to 2000. Surface data (wind speed and direction, air temperature, ceiling, total opacity and total cloud amount) was from the Ottawa airport (approximately 180 km SE from the NPD site). Upper air data was taken from the Maniwaki upper air station (approximately 134 km E from the NPD site). Figure F-1 shows wind rose plot of the Ottawa airport surface data for the period 1996 to 2000. The dominant wind direction in the MOE regional data set is west-northwest (WNW) followed by southwest (SW). The average wind speed for the Ottawa MOE data set is 3.23 m/s.

Figure F-1 Wind Rose plot at Ottawa Airport (1996-2000)



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F.3.3 Modelling Grid and Discrete Receptors

All modelling was undertaken in the Universal Transverse Mercator (UTM) coordinate system. The coordinate system used for mapping was World Geodetic System (WGS84), Zone 18.

The model was based on a nested receptor grid centered on the emission sources. A tiered grid was used which encompasses receptor locations, ranging from 20 m to 500 m, based on recommendations provided in Section 7.1 of the MOE document “Air Dispersion Modelling Guideline for Ontario (ADMGO), Version 2.0” dated March 2009 (MOE 2009). *Specific* grid points were also added along the fence line at a spacing of 20 m, as well as along the property line. Figure F-2 shows the modelling grid used in the air dispersion modelling. The calculated concentrations at all of these points were used to prepare concentration isopleths. *In addition* to the MOE grid shown in Figure F-2 below, the grid points along the fence line, and the gridpoints along the property line, discrete sensitive receptors that represent residential and recreational locations were also included in the model to estimate human impacts at specific locations (see Figure F-3).

Figure F-2 Air Dispersion Modelling Receptor Grid



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Figure F-3 Air Dispersion Discrete Receptor Locations



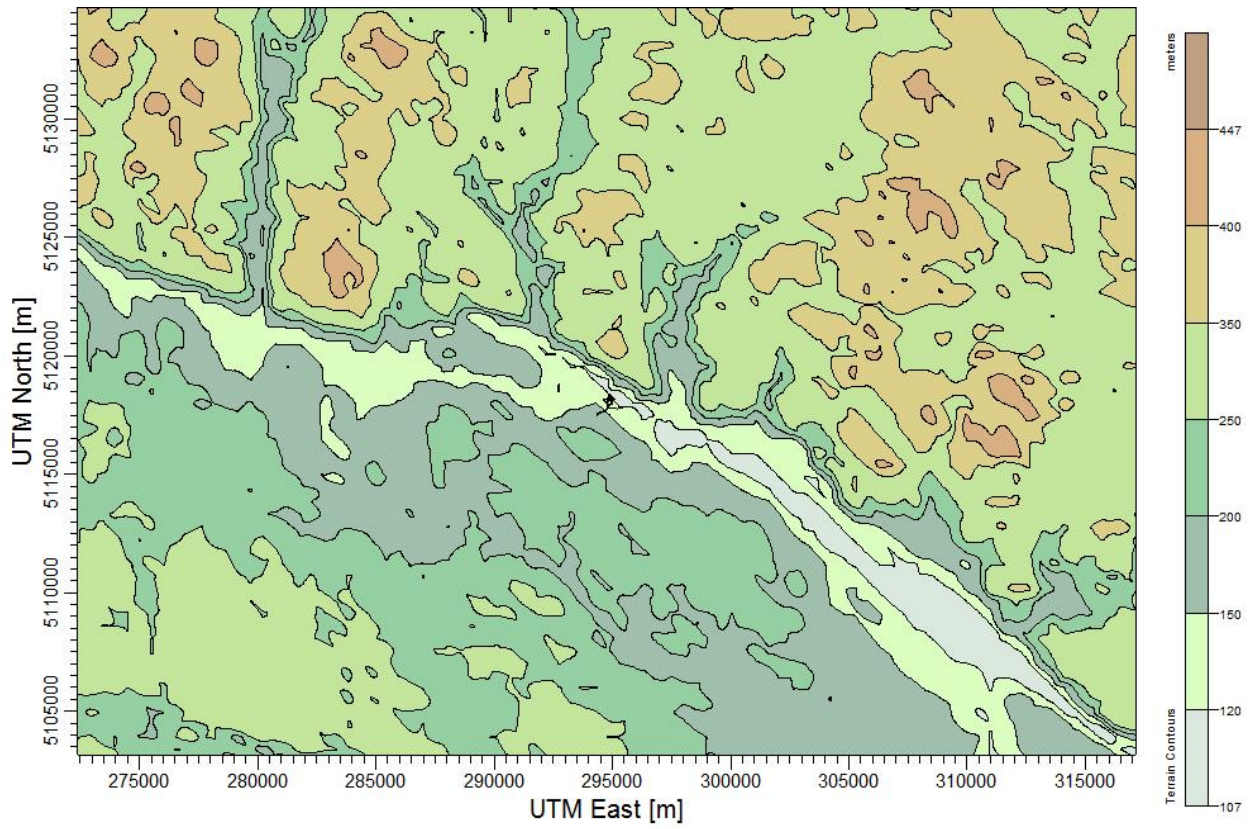
Note: R1, R2 and R3 are residential discrete receptors; R4 is recreational

F.3.4 Terrain

Due to the change in elevations in the area surrounding the NPD site, terrain data was included in the dispersion modelling (Figure F-4). AERMAP is the terrain pre-processor used to calculate a representative terrain-influence height associated with each receptor within the modelling domain. The terrain data input into AERMAP were Canadian Digital Elevation Data (CDED), with approximately 23 m horizontal resolution. As can be seen in Figure F-4 the terrain data realistically depicts the Ottawa Valley.

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Figure F-4 Terrain Used in Air Dispersion Modelling



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F.3.5 Source Characterization

F.3.5.1 Development of Scenarios

During the NPD Project, activities which may interact with air quality include:

- Batch mixing plant (raw material delivery, material handling, batch mixing, diesel generator, transport to placement site);
- Grouting of below grade structure (transport of concrete from batch plant to placement site);
- Removal of above grade structure (demolition activities including concrete cutting, crane activity, material handling, heavy equipment activity, crushing and screening);
- Install concrete cap and engineered barrier (transport of concrete from batch plant to placement site);
- Final site restoration (heavy equipment activity).

A list of equipment that will be required during the above activities is based on past experience with similar projects. A reasonable maximum scenario of the predominant operating equipment was developed considering each of the above project activities. For the purposes of assessing the maximum conditions, the following activities were assumed to occur simultaneously:

- Batch mixing plant (raw material delivery, material handling, batch mixing, diesel generator, transport to placement site);
- Grouting of below grade structure (transport of concrete from batch plant to placement site);
- Removal of above grade structure (demolition activities including concrete cutting, crane activity, material handling, heavy equipment activity, crushing and screening).

Installation of the concrete cap and engineered barrier and final site restoration are both activities which will be bounded by the scenario described above and are not considered independently.

Table F-3 contains a list of the equipment that was assumed to be operating simultaneously for 12 hours per day.

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Table F-3 Summary of Equipment and Assumptions Used to Estimate Emissions

Equipment Assumed Operating Simultaneously	Concrete Batch	Grouting / Demolition
Haul Trucks	35 T Haul Trucks– raw material delivery (1 vehicle/hr) – Travel from Hwy 17 to concrete batch plant (970 m) Same delivery rate (1 vehicle/hr) assumed for trucks delivering raw material for the cap (very conservative)	35 T Haul Truck – mixed concrete delivery to placement area (3 vehicles/hr) – Travel from concrete batch plant to placement area (460 m)
Stationary Equipment Tailpipe	Diesel generator (45 hp)	Diesel generator (100 hp)
Material Handling Emissions	Sand (14 tonnes/hr), aggregate (18 tonnes/h), cement (5 tonnes/h), slag (1 tonne/h) handling and storage	Excavator drop to storage stockpile, and drop from storage pile to crusher / screener
Non-Road Vehicle Tailpipe Emissions	-	One (1) 100 T Crane for Demolition (Lieberr LR1100)
		Two (2) 10 T Excavator (CAT 330D L) with various attachments
		Two (2) Backhoe (CAT 430E)
Concrete Saw	-	Two (2) Concrete saws (25 hp)
Crushing / Screening	-	Primary crusher / screener to resize material for placement (150 tonnes/h)
Dozer	-	One (1) Dozer- Operating 6 hours per day

F.3.5.2 Emissions Estimates

The above activities are expected to result in combustion emissions from mobile equipment (primarily NO_x, with minor SO₂) and particulate matter (TSP, PM₁₀ and PM_{2.5}) from concrete batching and grouting / demolition activities.

Emission calculation, assumptions made, and references used to calculate emissions are presented below for each activity modelled in the air quality assessment (see Tables F-4 to F-6).

Unpaved roads

For vehicle traveling on unpaved surfaces at industrial sites, emissions are estimating from the following equations (AP-42 13.2.2-4):

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$$E = k \times (s/12)^a \times (W/3)^b$$

Where:

E = size specific emission factor (lb/VMT);
s = surface material silt content (%);
W = mean vehicle weight (tons); and,
k, a and b are empirical constants given below:

Constant	Industrial Roads		
	TSP	PM ₁₀	PM _{2.5}
k (lb/VMT)	4.9	1.5	0.15
a	0.7	0.9	0.9
b	0.45	0.45	0.45

Assumptions used in the emission calculations are:

- Average silt content of 4.8% was used in calculation, as given below.
- Control Efficiency of 50%

Crushing and Screening

Emission factors (EF's) for crushing and screening activities are based on AP-42 Table 11.19.2-1. Tertiary EF's were used as upper limits as no data was available for primary or secondary crushing.

Assumption: Crushing frequency of 3h/day

TSP emissions sample calculation for controlled screening is based on the following equation:

$$\frac{g(PM_{30})}{\text{sec}} = \frac{\text{tonnes loaded}}{\text{per hour}} \times \frac{0.0011 \text{ kg } PM_{30}}{\text{tonne loaded}} \times \frac{1 \text{ hour}}{3600 \text{ seconds}} \times \frac{1000 \text{ grams}}{1 \text{ kg}}$$

Concrete Batch Plant

Emission factors (EF's) for concrete batch plant activities are based on AP-42 Table 11.12-1.

Uncontrolled emissions from aggregate material drops are calculated from AP-42 Section 13.2.4 based on following equation:

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$$E = k(0.0016) \frac{\left(\frac{U}{2.2}\right)^{1.3}}{\left(\frac{M}{2}\right)^{1.4}} \text{ (kg/megagram [Mg])}$$

where

E = emission factor

k = particle size multiplier (dimensionless)

U = mean wind speed, meters per second (m/s)

M = material moisture content (%).

The particle size multiplier used in the equation k is shown below for all particulates.

k		
TSP	PM ₁₀	PM _{2.5}
0.74	0.35	0.05

Assumptions used in the emission calculations are:

- U= 5 m/s
- M= 4.17%
- Control Efficiency of 50%

Sample calculations of emissions from all sources modelled in air quality assessment for the NPD project are given under the “Calculation Details” section, at the end of this Appendix.

A summary of NO_x, SO₂, TSP, PM₁₀ and PM_{2.5} emission rates used in the air dispersion modelling is provided in Tables F-4 through F-6.

The different activities described for this project, will take place for, at most, a few months. The 24-hour average emission rates presented in the following tables were used to develop annual average emission rates assuming six months of activity would take place within a one-year period.

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Table F-4 Summary of NOx Emissions used in Air Dispersion Model

Constituent	Activity	Model Source				
		Demolition Area	Concrete Batching	Stockpile	Road from Hwy-17	Road from Concrete Batch to Demolition Area
1 Hour NOx Emissions (g/s)	Material Handling					
	Unpaved roads					
	Haul Truck Tailpipe				4.3E-03	5.1E-03
	Stationary Equipment Tailpipe	2.9E-01	1.2E-01			
	Non-Road Tailpipe	2.4E-01				
	Dozer					
	Concrete Saw	5.1E-02				
	Crushing and Screening					
	Concrete Batch Plant					
Total		5.85E-01	1.16E-01	0.00E+00	4.28E-03	5.05E-03
24 Hour NOx Emissions (g/s)	Material Handling					
	Unpaved roads					
	Haul Truck Tailpipe				2.1E-03	2.5E-03
	Stationary Equipment Tailpipe	1.2E-02	5.8E-02			
	Non-Road Tailpipe	1.2E-01				
	Dozer					
	Concrete Saw	2.6E-02				
	Crushing and Screening					
	Concrete Batch Plant					
Total		1.60E-01	5.79E-02	0.00E+00	2.14E-03	2.53E-03

Table F-5 Summary of SO₂ Emissions used in Air Dispersion Model

Constituent	Activity	Model Source				
		Demolition Area	Concrete Batching	Stockpile	Road from Hwy-17	Road from Concrete Batch to Demolition Area
1 Hour SO ₂ Emissions (g/s)	Material Handling					
	Unpaved roads					
	Haul Truck Tailpipe				3.0E-06	7.2E-06
	Stationary Equipment Tailpipe	1.9E-02	7.7E-03			
	Non-Road Tailpipe	6.8E-02				
	Dozer					
	Concrete Saw	6.7E-04				
	Crushing and Screening					
	Concrete Batch Plant					
Total		8.80E-02	7.66E-03	0.00E+00	3.04E-06	7.19E-06
24 Hour SO ₂ Emissions (g/s)	Material Handling					
	Unpaved roads					
	Haul Truck Tailpipe				1.5E-06	3.6E-06
	Stationary Equipment Tailpipe	8.0E-04	3.8E-03			
	Non-Road Tailpipe	3.4E-02				
	Dozer					
	Concrete Saw	3.3E-04				
	Crushing and Screening					
	Concrete Batch Plant					
Total		3.52E-02	3.83E-03	0.00E+00	1.52E-06	3.59E-06

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Table F-6 Summary of TSP, PM₁₀ and PM_{2.5} Emissions used in Air Dispersion Model

Constituent	Activity	Model Source				
		Demolition Area	Concrete Batching	Stockpile	Road from Hwy-17 to Batch Plant	Road from Batch Plant to Demolition Area
24 Hour TSP Emissions (g/s)	Material Handling	1.5E-02				
	Unpaved roads				6.7E-02	7.9E-02
	Haul Truck Tailpipe				5.7E-05	6.8E-05
	Stationary Equipment Tailpipe	8.6E-04	4.1E-03			
	Non-Road Tailpipe	6.7E-03				
	Dozer	8.7E-02				
	Concrete Saw	1.6E-03				
	Crushing and Screening	8.9E-03				
	Concrete Batch Plant		4.3E-02	2.3E-03		
Total	1.20E-01	4.72E-02	2.34E-03	6.74E-02	7.96E-02	
24 Hour PM ₁₀ Emissions (g/s)	Material Handling	7.1E-03				
	Unpaved roads				1.7E-02	2.0E-02
	Haul Truck Tailpipe				5.7E-05	6.8E-05
	Stationary Equipment Tailpipe	8.6E-04	4.1E-03			
	Non-Road Tailpipe	6.7E-03				
	Dozer	1.6E-02				
	Concrete Saw	1.6E-03				
	Crushing and Screening	3.3E-03				
	Concrete Batch Plant		4.1E-02	1.1E-03		
Total	3.56E-02	4.53E-02	1.11E-03	1.72E-02	2.03E-02	
24 Hour PM _{2.5} Emissions (g/s)	Material Handling	1.1E-03				
	Unpaved roads				1.7E-03	2.0E-03
	Haul Truck Tailpipe				4.7E-05	5.6E-05
	Stationary Equipment Tailpipe	8.6E-04	4.1E-03			
	Non-Road Tailpipe	6.7E-03				
	Dozer	9.2E-03				
	Concrete Saw	1.6E-03				
	Crushing and Screening	3.9E-04				
	Concrete Batch Plant		4.1E-02	1.7E-04		
Total	1.98E-02	4.53E-02	1.68E-04	1.76E-03	2.08E-03	

F.3.5.3 Source Characteristics

Concrete batching activities were represented by a volume source of dimensions 10 m by 10 m by 4.4 m tall, placed at approximately 100 m distance south from the existing NPD building. The demolition activities were represented by a volume source of dimensions 50 m by 50 m and with release height of 25 m, at the location of the existing NPD building (Figure F-5). Additional sources were a stock pile volume source and a series of volume sources to represent the road from Highway 17 to the batch plant and from the batch plant to the demolition area. Sources were also separated into source groups in an effort to estimate combined effects from each activity area.

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Employee traffic and non-truck traffic, to and from the NPD site, was not included in the air dispersion model because it is a minor source of emissions. The number of employees today is approximately 20 people, and this employee traffic is included in the background levels. During decommissioning, only an additional 20 contractors are anticipated to be arriving at/leaving from the NPD site, which is minor compared to Hwy 17 traffic.

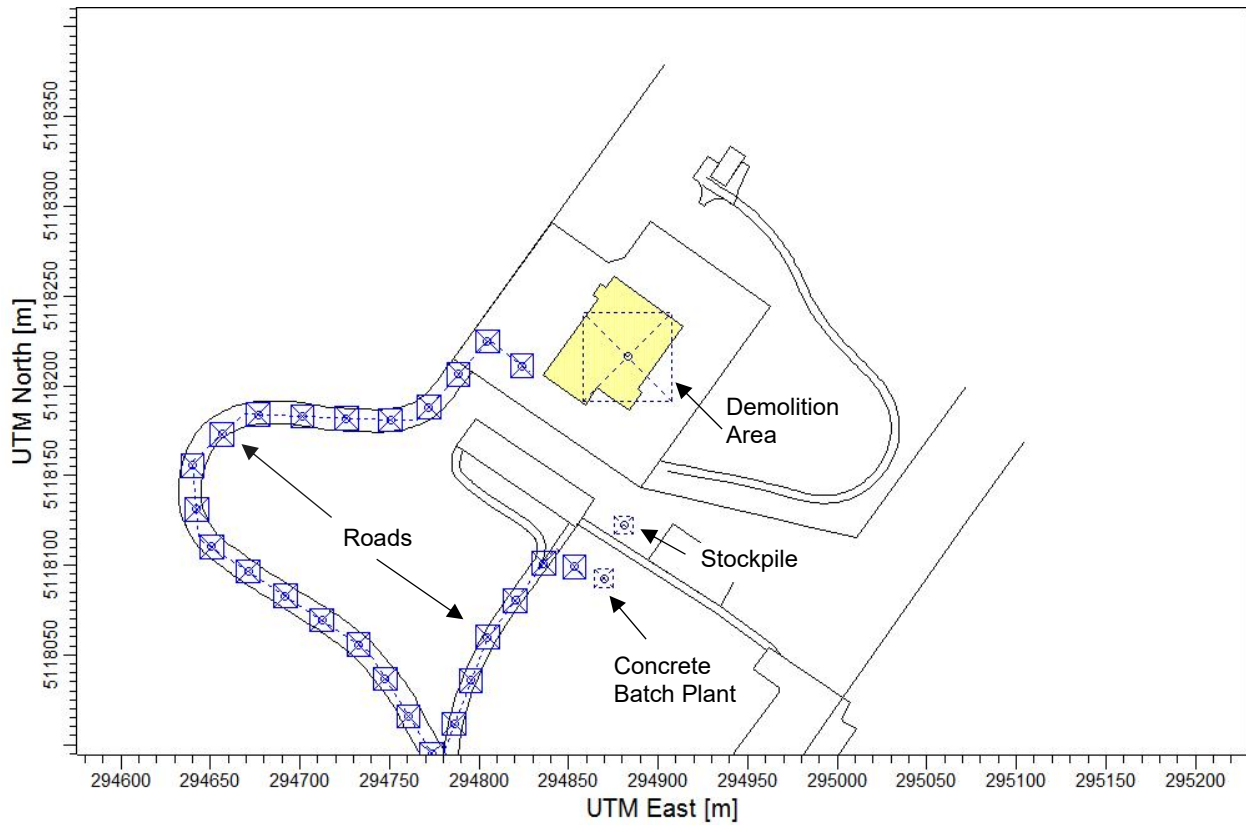
In fact, for NPRI reporting in 2017, a year where employee and contractor traffic would be considered comparable to the volume predicted for the project, the total estimated vehicle-kilometres travelled of 8042 kVt (17 employees, 249 working days, 2 trips a day and 0.95 km one way trip) for the NPD site were below reporting thresholds. Additionally, an assessment was done to calculate the contribution of employee vehicles to the project emissions. The predicted emissions from the employee vehicles were calculated for each contaminant (NO₂, SO₂, TSP, PM₁₀ and PM_{2.5}).

The additional contribution of employee vehicles emissions to total emissions from the NPD closure project is estimated to be less than 5% for NO_x and SO₂ and can be considered insignificant. For particulates, the additional contribution ranges from 4% for PM_{2.5} to 18% for TSP.

The facility ventilation system will be deactivated as part of the planned decommissioning activities and air emissions from it were not considered in these assessments. CNL may use local supplementary ventilation equipment, equipped with HEPA filters, if such a need is identified during the preparation of work control and radiation protection plans (which are prepared before decommissioning tasks are undertaken). There are only a few areas of concern within the facility where local supplementary ventilation may be required (i.e. boiler room). Additionally, local supplementary ventilation would only be required for relatively short periods of time (i.e. grouting activities) thus unlikely to have a significant contribution on the overall air quality.

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Figure F-5 Sources Used in Air Dispersion Modelling



Note: The location of the concrete batch plant as shown is illustrative.

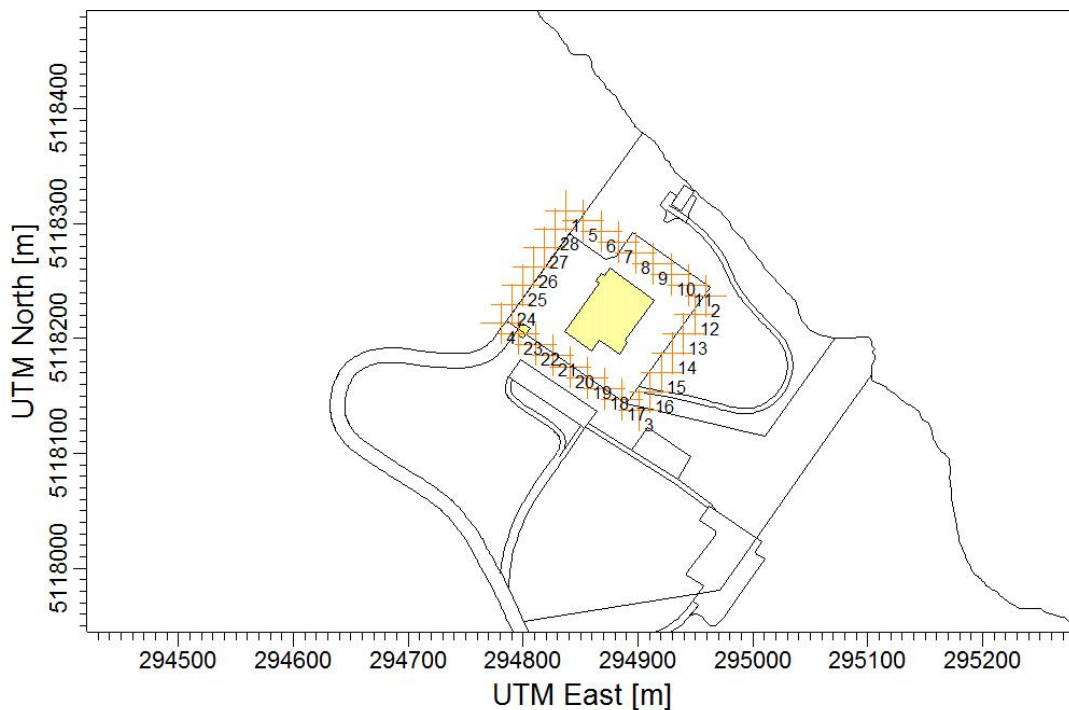
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F.4 Air Modelling Results

Based on the analysis completed in Section F-3, NO₂, SO₂, TSP, PM₁₀ and PM_{2.5} were evaluated for air quality effects associated with Project activities. Air dispersion modelling results are presented for each of these contaminants.

While a large number of grid points were used in the model calculations, the following discussion presents the tabulated model results for the discrete sensitive receptor locations (i.e. those residential and recreational receptor locations shown earlier in Figure F-3). In addition, maximum predicted concentrations along the property line are presented in the tables, as well as for fenceline locations at 20 m distance around the NPD facility (fenceline locations shown in Figure F-6 below). Concentrations predicted at the fenceline receptor locations include the contribution of all modelled sources of emissions presented in Figure F-5 (e.g. batch plant, stock pile, internal roads and demolition area).

Figure F-6 Fenceline Locations along the NPD Facility



Results for all receptor locations included in the modelling, for all monitoring constituents, are shown on subsequent figures in the form of concentration isopleths (see following subsections).

For further clarity, the fenceline locations shown in Figure F-6 above are not the limits of the modelling domain. These are simply additional ‘receptor’ locations for which modelling results are reported. Emissions sources such as the batch plant and those along the internal roadway

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(i.e. those shown in Figure F-5) that are located outside of these fence line locations *are* included in modelling (see also Tables F-4 to F-6 which outline emission details).

F.4.1 Effects Assessment

The following sub-sections provide a summary of the cumulative maximum predicted 1-hour, 24-hour and annual NO₂ and SO₂ concentrations, and the 24-hour and annual TSP, PM₁₀ and PM_{2.5} concentrations at the discrete receptor locations in a tabular form. In addition, the cumulative maximum concentrations along the property line for 1-hour, 24-hour and annual averaging period are also provided in the tables below. Annual contour plots of these constituents are presented in the figures following the tables.

F.4.1.1 NO₂

Emissions estimates for Nitrogen Oxides are provided in terms of NO_x. However, emissions from combustion sources are almost entirely in the form of NO. This converts to NO₂ in the atmosphere in the presence of ozone (O₃). The AAQC are for NO_x as NO₂ consequently, using NO_x emissions to predict concentrations in air is an overly conservative approach. To approximate NO₂ concentrations, the predicted NO_x concentrations were multiplied by the ratio of NO_x to NO₂ measured at the air quality stations (see Section 3.3.4.1 in the EIS Report). This ratio is 0.79 for the 1-hour, 24-hour and annual average time frames. All subsequent discussion of Nitrogen Oxides refers only to NO₂. Table F-7 provides a summary of the cumulative maximum NO₂ concentrations at discrete sensitive receptor locations, as well as at the property line. For the 1-hour averaging period the 3-year average of the annual 98th percentile of the NO₂ daily maximum 1-hour average concentrations are presented for the purpose of comparison to the new CAAQs.

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Table F-7 Maximum Predicted NO₂ (µg/m³) Concentrations at Discrete Receptors and along the Property Line (Including Background)

Constituent	Averaging Period	CAAQS/AAQS (µg/m ³)	Upwind Background (µg/m ³)	Receptor Type				Maximum Concentrations along the property line (µg/m ³)
				Residential	Residential	Residential	Recreational	
				R1 (µg/m ³)	R2 (µg/m ³)	R3 (µg/m ³)	R4 (µg/m ³)	
NO ₂	1 hour ^a	119 (2020), 83 (2025)	26	27.6	28.8	28.9	29.1	64
	24 hour	200	24	25.3	25.3	24.9	25.2	33
	Annual	34 (2020), 24 (2025)	12	12.1	12.1	12.1	12.1	14

Note: NO_x/NO₂ ratio of 0.79 was used for conversion of the maximum 1-hr, 24-hr and annual NO_x concentrations.

^a The 3-year average of the annual 98th percentile of the NO₂ daily maximum 1-hour average concentrations.

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During the activities related to the concrete batch plant operation and grouting / demolition activities, the maximum predicted 1-hour, 24-hour and annual average NO₂ concentration at all residential and recreational receptors will be well below their respective AAQCs and AQOs. The predicted incremental 24-hour and average annual NO₂ concentrations are also less than the baseline concentrations. Table F-7 shows that the incremental change in the maximum predicted 24-hour and average annual concentration of NO₂ at discrete sensitive receptors is less than 2 µg/m³ and 1 µg/m³ respectively. Given the typical variation in measured concentrations (see Section 3.3.4.1 in the EIS Report), these incremental levels are considered to be not measurable, and will not be advanced to the Significance Assessment for further consideration. The maximum predicted 1-hour NO₂ concentration at discrete sensitive receptors under the worst meteorological conditions, is in the range of baseline concentrations.

Table F-8 provides the *cumulative maximum* predicted concentrations (i.e. the predicted incremental concentration *plus* background) for NO₂ at fence line locations around the NPD facility.

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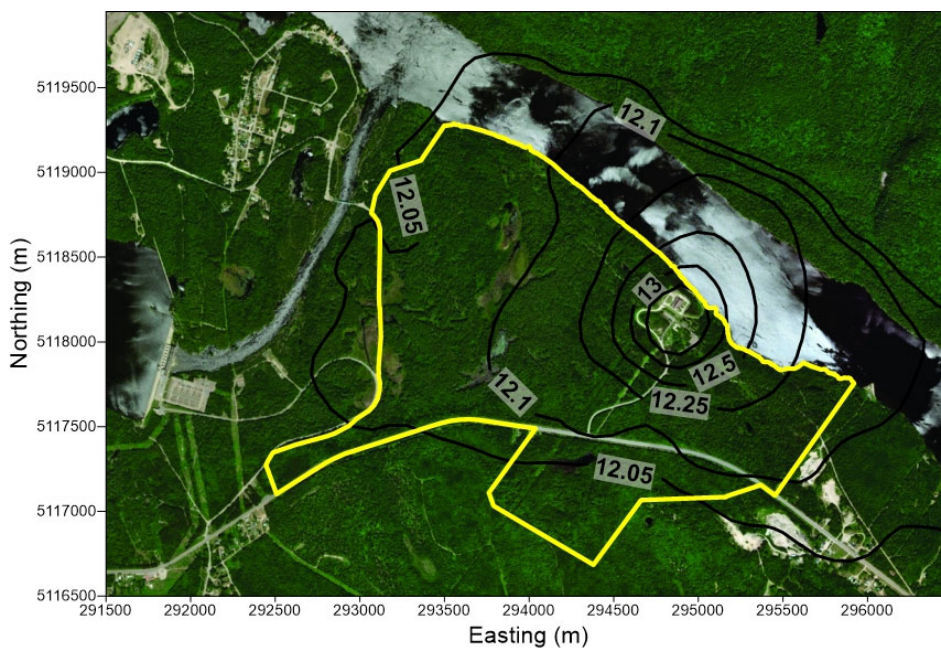
Table F-8 – Predicted Annual NO₂ Concentrations (µg/m³) at Fence Line Locations along the NPD Facility (Including Background)

Receptor ID	Receptor	Easting (m)	Northing (m)	Annual NO ₂ Concentration (µg/m ³)
1	Fenceline	294837.33	5118311.2	13.8
2	Fenceline	294959.37	5118237.1	15.1
3	Fenceline	294900.86	5118137.1	24.4
4	Fenceline	294780.66	5118213.4	15.1
5	Fenceline	294852.59	5118301.9	14.1
6	Fenceline	294867.84	5118292.7	14.5
7	Fenceline	294883.1	5118283.4	15
8	Fenceline	294898.35	5118274.2	15.4
9	Fenceline	294913.6	5118264.9	15.7
10	Fenceline	294928.86	5118255.7	15.6
11	Fenceline	294944.11	5118246.4	15.3
12	Fenceline	294949.62	5118220.5	15.7
13	Fenceline	294939.87	5118203.8	16.4
14	Fenceline	294930.11	5118187.1	17.1
15	Fenceline	294920.36	5118170.4	18.1
16	Fenceline	294910.61	5118153.7	20
17	Fenceline	294885.83	5118146.6	23.7
18	Fenceline	294870.81	5118156.1	21.6
19	Fenceline	294855.78	5118165.7	19.6
20	Fenceline	294840.76	5118175.2	18.3
21	Fenceline	294825.73	5118184.8	17.3
22	Fenceline	294810.71	5118194.3	16.3
23	Fenceline	294795.68	5118203.8	15.6
24	Fenceline	294790.1	5118229.7	14.8
25	Fenceline	294799.55	5118246	14.6
26	Fenceline	294808.99	5118262.3	14.3
27	Fenceline	294818.44	5118278.6	14.1
28	Fenceline	294827.89	5118294.9	14

Figure F-7 shows the contour plot of cumulative annual NO₂ concentrations (i.e. the predicted incremental concentration *plus* background) at the NPD site.

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Figure F-7 Predicted Annual NO₂ Concentrations Including Background(µg/m³)



Note: Included background concentrations

F.4.1.2 SO₂

Table F-9 provides a summary of the cumulative maximum predicted SO₂ concentrations for 1-hour, 24-hour and annual average time period at discrete sensitive receptor locations and along the property line. For the 1-hour averaging period the 3-year average of the annual 99th percentile of the SO₂ daily maximum 1-hour average concentrations are presented for the purpose of comparison to the new CAAQs.

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Table F-9 Maximum Predicted SO₂ (µg/m³) Concentrations at Discrete Receptors and along the Property Line (Including Background)

Constituent	Averaging Period	CAAQS/AAQS (µg/m ³)	Upwind Background (µg/m ³)	Receptor Type				Maximum Concentrations along the property line (µg/m ³)
				Residential	Residential	Residential	Recreational	
				R1 (µg/m ³)	R2 (µg/m ³)	R3 (µg/m ³)	R4 (µg/m ³)	
SO ₂	1 hour ^a	193 (2020), 179 (2025)	20	20.7	21.0	21.0	21.3	28
	24 hour	275	3	3.3	3.3	3.2	3.3	5
	Annual	14 (2020), 11 (2025)	0	0.02	0.02	0.02	0.02	0.4

^a The 3-year average of the annual 99th percentile of the SO₂ daily maximum 1-hour average concentrations.

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The predicted SO₂ concentrations are well below applicable criteria at sensitive receptors and beyond the property boundary for all time frames. Table F-10 provides the *cumulative maximum* predicted concentrations (i.e. the predicted incremental concentration *plus* background) for SO₂ at fenceline locations around the NPD facility.

Table F-10 – Predicted Annual SO₂ Concentrations (µg/m³) at Fence Line Locations along the NPD Facility (Including Background)

Receptor ID	Receptor	Easting (m)	Northing (m)	Annual SO ₂ Concentration (µg/m ³)
1	Fenceline	294837.33	5118311.2	0.3
2	Fenceline	294959.37	5118237.1	0.6
3	Fenceline	294900.86	5118137.1	1.3
4	Fenceline	294780.66	5118213.4	0.4
5	Fenceline	294852.59	5118301.9	0.4
6	Fenceline	294867.84	5118292.7	0.5
7	Fenceline	294883.1	5118283.4	0.6
8	Fenceline	294898.35	5118274.2	0.7
9	Fenceline	294913.6	5118264.9	0.7
10	Fenceline	294928.86	5118255.7	0.7
11	Fenceline	294944.11	5118246.4	0.6
12	Fenceline	294949.62	5118220.5	0.7
13	Fenceline	294939.87	5118203.8	0.8
14	Fenceline	294930.11	5118187.1	0.8
15	Fenceline	294920.36	5118170.4	0.8
16	Fenceline	294910.61	5118153.7	0.9
17	Fenceline	294885.83	5118146.6	1.2
18	Fenceline	294870.81	5118156.1	1
19	Fenceline	294855.78	5118165.7	0.9
20	Fenceline	294840.76	5118175.2	0.8
21	Fenceline	294825.73	5118184.8	0.8
22	Fenceline	294810.71	5118194.3	0.6
23	Fenceline	294795.68	5118203.8	0.5
24	Fenceline	294790.1	5118229.7	0.4
25	Fenceline	294799.55	5118246	0.4
26	Fenceline	294808.99	5118262.3	0.4
27	Fenceline	294818.44	5118278.6	0.4
28	Fenceline	294827.89	5118294.9	0.3

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Figure F-8 shows the predicted annual SO₂ concentrations around NPD site (i.e. the predicted incremental concentration *plus* background). Similar to NO₂, the predicted incremental SO₂ concentrations are well within normal measured variability and are not considered to be measurable (thus, do not warrant further assessment).

Figure F-8 Predicted Annual SO₂ Concentrations Including Background (µg/m³)



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F.4.1.3 Total Suspended Particulate Matter (TSP, PM₁₀ and PM_{2.5})

Tables F-11 and F-12 provide summaries of the maximum predicted 24-hour and annual TSP, PM₁₀ and PM_{2.5} concentrations at discrete sensitive receptor locations. The maximum predicted 24-hour TSP, PM₁₀ and PM_{2.5} concentrations at the maximum residential receptor are 40 µg/m³, 19 µg/m³ and 9 µg/m³, respectively, which are all well below their respective AAQCs.

In order to assess the possible effects of the particulate emissions from employee vehicles, the estimated TSP emissions from the employee traffic to and from NPD site have been added to the road sources and re-modelled. The predicted 24-hour TSP concentrations with included background at discrete receptors are shown in Table F-11. The contribution of emissions from employee vehicles to overall 24-hour TSP concentrations at discrete receptors ranges from 0% to 4% and does not change the conclusions of the NPD air quality assessment.

The predicted incremental 24 hour average TSP concentrations at the maximum residential receptors and beyond the property boundary are less than 4 µg/m³, and the predicted incremental annual average TSP concentrations are < 1 µg/m³, which are well within the normal variability of measured concentrations (see Section 3.3.4.1 in the EIS Report). Therefore, incremental TSP associated with the Project is not considered measurable, and will not be advanced to the Significance Assessment for further consideration. Similarly, for PM₁₀ and PM_{2.5}, the incremental concentrations associated with the Project are not considered measurable, and will not be advanced to the Significance Assessment for further consideration.

The annual average predicted TSP, PM₁₀ and PM_{2.5} concentrations are well below applicable criteria at all sensitive receptors (see Table F-11 and Table F-12). Figures F-9, F-10 and F-11 show the isopleths of *cumulative annual* concentrations (i.e. the predicted incremental concentrations plus background) of TSP, PM₁₀ and PM_{2.5} respectively, around the NPD site.

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Table F-11 Predicted TSP at Discrete Receptors Concentrations and along the Property Line (Including Background)

Modelled Scenario	Constituent	Averaging Period	Criterion (µg/m³)	Upwind Background (µg/m³)	Receptor Type				Maximum Concentrations along the property line (µg/m³)
					Residential	Residential	Residential	Recreational	
					R1 (µg/m³)	R2 (µg/m³)	R3 (µg/m³)	R4 (µg/m³)	
Employee traffic not included	TSP	24 hour	120	36	38	40	39	38	50
Employee traffic included					39	42	40	38	nr
Employee traffic contribution (%)					1%	4%	4%	0%	nr
Employee traffic not included	TSP	Annual	60	20	20	20	20	20	23

Note: nr - not relevant

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Table F-12 Predicted PM₁₀ and PM_{2.5} Concentrations at Discrete Receptors and along the Property Line (Including Background)

Constituent	Averaging Period	CAAQS / AAQC Criteria (µg/m ³)	AZM "Lowest Threshold Value" (µg/m ³) ^c	Upwind Background (µg/m ³)	Receptor Type				Maximum Concentrations along the property line (µg/m ³)
					Residential	Residential	Residential	Recreational	
					R1 (µg/m ³)	R2 (µg/m ³)	R3 (µg/m ³)	R4 (µg/m ³)	
PM ₁₀	24 hour	50	Not Available	18	19	19	19	19	25
PM _{2.5}	24 hour	27 ^a	10	9	9	9	9	9	12
	Annual	8.8 ^b	4	5	5	5	5	5	6

Note: ^a The 3-year average of the annual 98th percentile of the daily 24-hour average concentrations (CCME, 2012).

^b The 3-year average of the annual average concentrations (CCME, 2012).

^c AZM "Lowest Threshold Value"(s) from CCME (2012).

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Table F-13 provides the *cumulative annual* concentrations (i.e. the predicted incremental concentrations plus background) for TSP, PM₁₀, and PM_{2.5}, at fenceline locations around the NPD facility.

Table F-13 Predicted Annual Concentrations of TSP, PM₁₀ and PM_{2.5} (µg/m³) at Fence Line Locations along the NPD Facility (Including Background)

Receptor ID	Receptor	Easting (m)	Northing (m)	Annual Concentrations (ug/m ³)		
				TSP	PM ₁₀	PM ₂₅
1	Fenceline	294837.33	5118311.2	24.5	19.8	6.2
2	Fenceline	294959.37	5118237.1	25	20.4	6.9
3	Fenceline	294900.86	5118137.1	38.8	31.5	17.4
4	Fenceline	294780.66	5118213.4	35.4	23.1	7.3
5	Fenceline	294852.59	5118301.9	24.8	20	6.3
6	Fenceline	294867.84	5118292.7	25.2	20.2	6.4
7	Fenceline	294883.1	5118283.4	25.5	20.3	6.6
8	Fenceline	294898.35	5118274.2	25.9	20.5	6.8
9	Fenceline	294913.6	5118264.9	26	20.6	6.9
10	Fenceline	294928.86	5118255.7	25.7	20.6	6.9
11	Fenceline	294944.11	5118246.4	25.3	20.5	6.9
12	Fenceline	294949.62	5118220.5	25.8	20.9	7.3
13	Fenceline	294939.87	5118203.8	26.8	21.5	7.9
14	Fenceline	294930.11	5118187.1	27.9	22.4	8.7
15	Fenceline	294920.36	5118170.4	29.4	23.7	10
16	Fenceline	294910.61	5118153.7	32.2	26.1	12.4
17	Fenceline	294885.83	5118146.6	38.4	30.8	16.5
18	Fenceline	294870.81	5118156.1	35.6	28.3	14.2
19	Fenceline	294855.78	5118165.7	33.7	26.1	11.9
20	Fenceline	294840.76	5118175.2	33.5	24.8	10.3
21	Fenceline	294825.73	5118184.8	35.4	24.4	9.2
22	Fenceline	294810.71	5118194.3	32.2	23	8.3
23	Fenceline	294795.68	5118203.8	33.3	22.9	7.7
24	Fenceline	294790.1	5118229.7	29.3	21.5	7
25	Fenceline	294799.55	5118246	28.9	21.3	6.8
26	Fenceline	294808.99	5118262.3	28.6	21.1	6.7
27	Fenceline	294818.44	5118278.6	26.5	20.5	6.5
28	Fenceline	294827.89	5118294.9	25.3	20.1	6.3

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Figure F-9 Predicted Annual TSP Concentrations Including Background ($\mu\text{g}/\text{m}^3$)

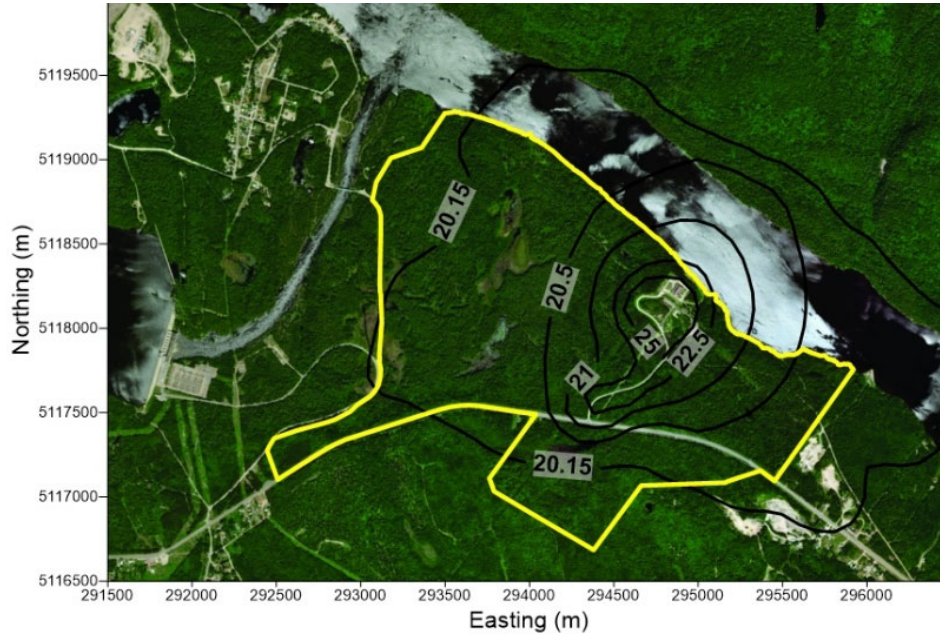
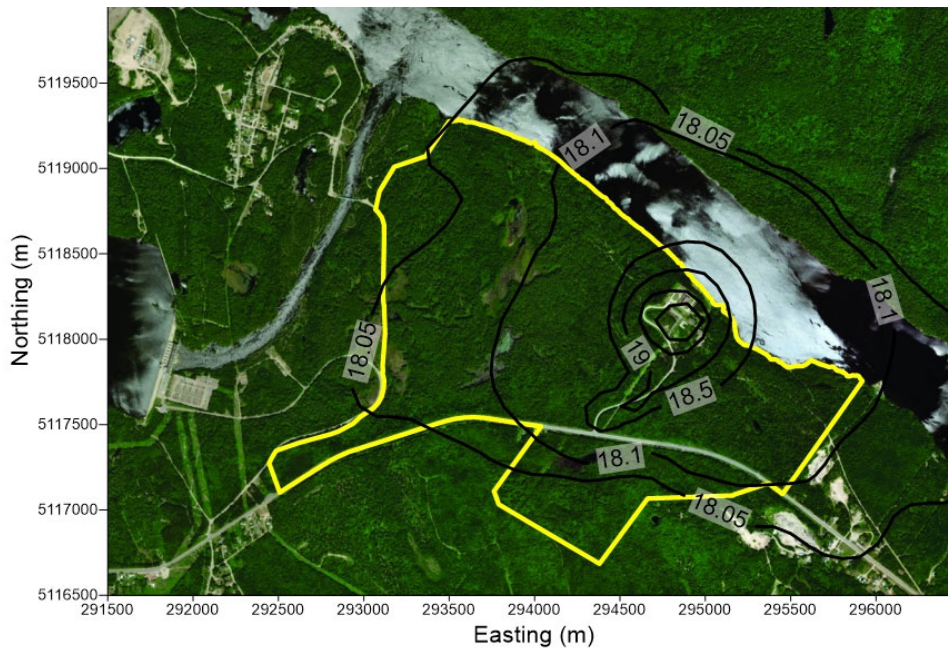
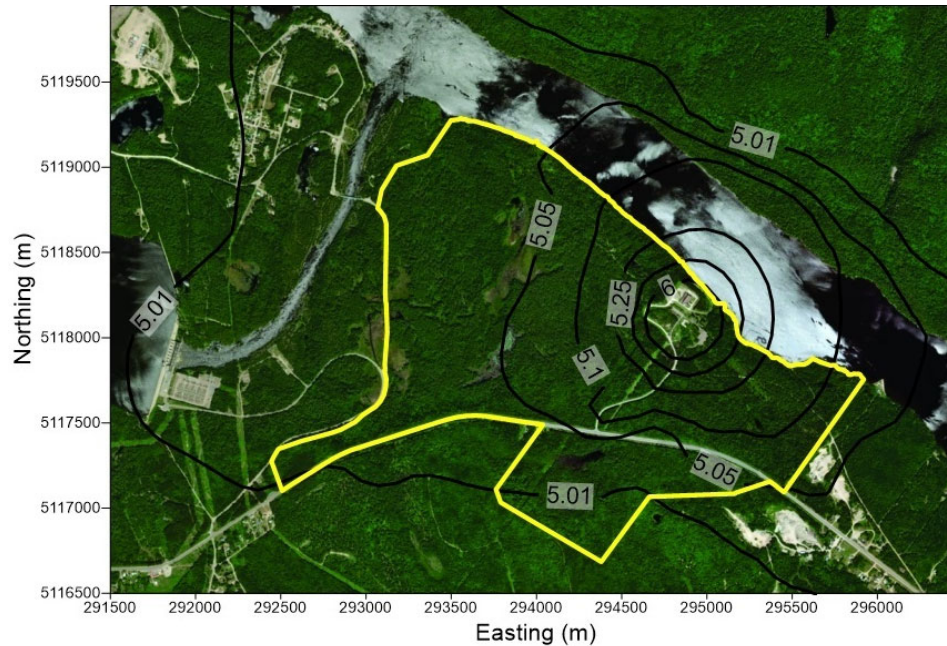


Figure F-10 Predicted Annual PM_{10} Concentrations Including Background ($\mu\text{g}/\text{m}^3$)



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Figure F-11 Predicted Annual PM_{2.5} Concentrations Including Background (µg/m³)



F.4.1.4 Mitigation Measures

The project plans to implement appropriate mitigation measures to reduce exposures associated with the project. Mitigation measures include (but are not limited to) the following:

- Post speed limits on-site to minimize dust emissions,
- Limit idling of vehicles and equipment on-site to minimize emissions,
- Standard forms of dust mitigation (e.g. water spray misting) will be utilized during demolition and material sizing activities,
- Roads and areas will be wetted/misted as needed in dry conditions to minimize dust generation, and,
- Regular maintenance of machinery to efficiently reduce emission.

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Appendix F - Calculation Details

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Summary of Variables Used for Emission Estimates on Worksheets

"Daily" or "Annual" Multiplier Used? **Daily**

Material Handling				
Calculation Method: Drop Equation AP-42 13.2.4, November 2006				
Variable	Assumed Value	Units	Comments	
Construction Weeks per year	40	weeks per year	Not Used in Calculations 52 weeks per year minimum 12 weeks during winter = 40 weeks	
Construction Days per week	5	days per week	Not Used in Calculations	
Construction Hours per day	12	hours per day		
Capacity per Haul Truck	35	tonnes		
Moisture Content of clean fill	10%	%	ARCADIS Experience	
Wind Speed	5	m/s	MOE Outdoor default wind speed	
Control Efficiency	0%	%	No Control Efficiencies for drops to haul trucks and clean fill drops to excavation	
24 hour average Adjustment Factor		0.5		

Truck Idling Tailpipe Emissions

Calculation Method: Mobile 6C (Haul Trucks and Pick-Up Trucks)

Variable	Assumed Value	Units	Comments
Haul trucks - g/VKT	various	g PM/VKT	Based on Mobile 6C EF's for Haul Trucks and Light Duty Trucks - HDDV8b and ALLVEH Emission factors were used
Assumption: Site haul roads are short, therefore road dust and tailpipe emissions during truck travel on site is considered negligible.			

Stationary Equipment Tailpipe Emissions

Calculation Method: AP-42 Section 3.3 Small Diesel Generators (<600 hp)

Variable	Assumed Value	Units	Comments
Assumption from URBEMIS2007 Model Appendix G Air Compressors and Generator Sets			
Equipment hp ratings	various	hp	Actual hp ratings from assumed diesel fired generator equipment

NonRoad Equipment Tailpipe Emissions

Calculation Method: US EPA Nonroad (Excavators & Loaders)

Variable	Assumed Value	Units	Comments
Assumption from URBEMIS2007 Model Appendix G for each piece of Equipment (equipment not listed in Appendix G assumed to be "Other General Industrial Equipment")			
Equipment hp ratings	various	hp	Actual hp ratings from assumed equipment
Excavators and Loaders - g/hp-hr	various	g/hp-hr	US EPA Nonroad (EPA420-P-04-009) April 2004

Concrete Saw Cutting Emissions

Calculation Method: Emission Factors from URBEMIS2007

Variable	Assumed Value	Units	Comments
Assumption: Concrete Saw cutting activities are controlled with water			

Welder with Power from a Diesel Generator

Calculation Method: Emission Factors from URBEMIS2007

Variable	Assumed Value	Units	Comments
Assumption: Welders are 15 hp each			

Model Source	Calculation	Activity
1 - Demolition	NonRoad -	One 100T Crane for demolition One Excavator with Shears One Backhoe for loading and movement of debris Concrete Saw - Two concrete saws to cut building materials

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Material Handling Particulate Matter Emissions

Material Handling Emissions	k			M (%)	U (m/s)	Emission Factor in kg/tonne			Tonnes Handled per Hour*	Uncontrolled (g/s)			Assumed Control Efficiency (%)	Hourly Controlled (g/s)		
	SPM	PM ₁₀	PM _{2.5}			SPM	PM ₁₀	PM _{2.5}		SPM	PM ₁₀	PM _{2.5}		SPM	PM ₁₀	PM _{2.5}
Excavator - drop to Storage Stockpile	0.74	0.35	0.053	10%	5.00	0.00036	0.00017	0.00003	150	0.0151	0.0071	0.0011	0%	0.0151	0.0071	0.0011
Excavator - drop to final storage	0.74	0.35	0.053	10%	5.00	0.00036	0.00017	0.00003	150	0.0151	0.0071	0.0011	0%	0.0151	0.0071	0.0011

* Tonnes handled per hour for typical 12hour construction day (assumed)

Emission Factor Equation	Reference
$E = k \times (0.0016) \times (U/2.2)^{1.3} / (M/2)^{1.4}$	AP-42 13.2.4 November 2006

Parameter	SPM	PM ₁₀	PM _{2.5}
k	0.74	0.35	0.053

E = emission factor in kg/megagram
 k = particle size multiplier for particulate size range and units of interest
 U = mean wind speed (m/s)
 M = material moisture content (%)

On-Site Unpaved Haul Roads Particulate Matter Emissions NOTE: calculated g/s emission rates are over a 12 hour construction day

Unpaved Road Emissions (see description on Soil & Truck Volumes worksheet)	k (lb/VMT)			s (%)	W (tonnes)	Emission Factor in g/VKT			Annual EF	Total # vehicle passes per day (in and out)	One way length (km)	Construction Hours per day	AERMOD Calibration Factor for Roads	Uncontrolled (g/s)			Assumed Control Efficiency (%)	Controlled (g/s)					
	SPM	PM ₁₀	PM _{2.5}			SPM	PM ₁₀	PM _{2.5}						SPM	PM ₁₀	PM _{2.5}		Annual SPM	SPM	PM ₁₀	PM _{2.5}	Annual SPM	
Construction																							
From Hwy 17 to Concrete Batch	4.9	1.5	0.15	4.8	37.5	2266	578	58	1335	26	0.97	12.0	4.8	0.27	0.07	0.01	0.16	50 %	0.135	0.034	0.003	0.08	
Concrete Batch to Demolition Area	4.9	1.5	0.15	4.8	37.5	2266	578	58	1335	64	0.46	12.0	4.8	0.32	0.08	0.01	0.19	50 %	0.159	0.041	0.004	0.09	

Emission Factor Equation	Reference
$E_{unpaved} = k \times (s/12)^a \times (W/3)^b$	AP-42 13.2.2-4, November 2006 industrial sites

Constant	Industrial Roads		
	SPM	PM ₁₀	PM _{2.5}
k (lb/VMT)	4.9	1.5	0.15
a	0.7	0.9	0.9
b	0.45	0.45	0.45

SILT CONTENT (%)	Location	Low	High	Average
sand and gravel processing	plant road	4.1	6.0	4.8

E = size specific emission factor (lb/VMT)
 s = surface material silt content (%)
 W = mean vehicle weight (tons)
 1 lb/VMT = 281.9 g/VKT
 $E_{ext} = E \times [(365-P)/365]$
 E_{ext} = annual size-specific emission factor for natural mitigation, lb/VMT
 P = number of days in a year with at least 0.254 mm of precipitation

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Haul Truck Tailpipe Emissions

Vehicle Type	One Way Road Length	Number of 35T Vehicles per hour	SPM	PM ₁₀	PM _{2.5}	NOx	SO ₂	CO	Acrolein	CO ₂	CH ₄
			(g/s)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)
From Hwy 17 to Concrete Batch	0.97	1	1.14E-04	1.14E-04	9.44E-05	4.28E-03	1.16E-04	2.05E-03	9.54E-07	5.82E-01	1.21E-05
Concrete Batch to Demolition Area	0.46	3	1.35E-04	1.35E-04	1.12E-04	5.05E-03	1.37E-04	2.42E-03	1.13E-06	6.87E-01	1.43E-05

Mobile 6C Emission Factors - Year 2007	
Vehicle Type	
Off-Site Haul Trucks - 35T Capacity (Values in g/km) (4 km/hr HDDV8b)	
Pick-up Trucks - Approx 3T (4 km/hr ALLVEH)	

SPM	PM ₁₀	PM _{2.5}	NOx	SO _x	CO	Acrolein	CO ₂	CH ₄
0.199	0.199	0.164	7.440	0.201	3.565	0.00166	1012	0.021
0.0296	0.0296	0.0194	1.1881	0.0189	11.712	0.0004039	339	0.040

Emission Rate Calculation

$E = F \times 4 \text{ km/hr} \times 1 \text{ hr} / 3600 \text{ sec} \times \text{Number of Vehicles}$

E = emission rate in g/s

EF = Mobile 6C Emission Factors in g/km

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Stationary Diesel Equipment Tailpipe Emissions

Vehicle Use	Power Rating (hp)	% of Maximum Operating Capacity ¹	Uncontrolled (g/s) - Emitted During Operating Hours								
			TSP	PM ₁₀	PM _{2.5}	NO _x	SO _x	CO	Acrolein	CO ₂	CH ₄
Diesel Generator for Back-up power	100	74	0.0206	0.0206	0.0206	0.2896	0.0192	0.0624	0.000864	10.7449	0.000588
Diesel Generator for Concrete batch	40	74	0.0082	0.0082	0.0082	0.1159	0.0077	0.0250	0.000346	4.2980	0.000235

(1) Assumption from URBEMIS2007 Model Appendix G Air Compressors and Generator

AP-42 Emission Factors for Diesel Generators (lb/hp-hr)									
Vehicle Type	SPM	PM ₁₀	PM _{2.5}	NO _x	SO _x	CO	Acrolein	CO ₂	CH ₄
Small Diesel Generators (less than 600 hp) Table 3.3-1 and Table 3.3-2	0.0022	0.0022	0.0022	0.031	0.00205	0.00668	0.0000925	1.15	6.29E-05

NO_x Emissions Sample Calculation for generator less than 600 hp:

$$\text{NO}_x \text{ Emission} = \text{power}(hp) \times \frac{0.031 lb}{hp-hr} \times \left(\frac{1 hr}{3,600 sec} \right) \times \left(\frac{1 kg}{2.2 lb} \right) \times \left(\frac{1000 g}{kg} \right) \times \% \text{ operating time}$$

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Tailpipe Emissions - Working Face Excavators and Loaders

Vehicle Use	Number of Units	Power Rating (hp)	Emission Factor in g/hp-hr				Transient Adjustment Factor (TAF)				BSFC	PM Adj g/hp.hr	Emission Factor per Unit in g/hp-hr								% of Maximum Operating Capacity ¹	Uncontrolled (g/s) during Operating Hours									
			PM EF _{ss}	NOx EF _{ss}	CO EF _{ss}	HC EF _{ss}	PM TAF	NOx TAF	CO TAF	HC TAF			SPM	PM ₁₀	PM _{2.5}	NOx	SO _x	CO	Acrolein*	CO ₂		CH ₄ *	TSP	PM ₁₀	PM _{2.5}	NOx	SO _x	CO	Acrolein*	CO ₂	CH ₄ *
100T Crane for Demolition (Liebherr LR1100)	1	362	0.402	8.38	2.70	0.68	1.23	0.95	1.53	1.05	1.01	0.0584	0.436	0.436	0.436	7.961	2.227	4.131	0.000402	1459	0.437	10%	0.0044	0.0044	0.0044	0.0801	0.0224	0.0415	0.000004	14.7	0.0044
10T Excavator (CAT 330D L) with various attachments	2	268	0.402	8.38	2.70	0.68	1.23	0.95	1.53	1.05	1.01	0.0584	0.436	0.436	0.436	7.961	2.227	4.131	0.000402	1459	0.437	10%	0.0065	0.0065	0.0065	0.1185	0.0332	0.0615	0.000006	21.7	0.0065
Backhoe (CAT 430E)	2	102	0.402	8.38	2.70	0.68	1.23	0.95	1.53	1.05	1.01	0.0584	0.436	0.436	0.436	7.961	2.227	4.131	0.000402	1459	0.437	10%	0.0025	0.0025	0.0025	0.0451	0.0126	0.0234	0.000002	8.3	0.0025

Assumption from URBEMIS2007 Model Appendix G for each piece of Equipment (equipment not listed in Appendix G assumed to be "Other General Industrial Equipment")

EF_{ss} values are from US EPA Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling—Compression-Ignition, April 2004 (EPA420-P-04-009), Pages 9 to 12. TAF and BSFC values are from EPA420-P-04-009, Page A9, based on SCC 2270002069, Tier 0.

Emission Factors are calculated based on calculation outlined on EPA420-P-04-009 page 6, except for Acrolein and CH₄ (Methane).

*Acrolein Emission Factor is calculated based on the ratio of CO emission factor in AP-42 Table 3.3-1 (0.95 lb/MMBtu) to the CO emission factor above (4.131 g/hp-hr), and the Acrolein emission factor in AP-42 Table 3.3-2 (9.25E-05 lb/MMBtu).

*CH₄ Emission Factor is calculated based on the ratio of CO emission factor in AP-42 Table 3.4-1 (0.85 lb/MMBtu) to the CO emission factor above (4.131 g/hp-hr), and the CH₄ emission factors in AP-42 Table 3.4-1 (0.09 lb/MMBtu).

Concrete Saw Cutting Emissions

Concrete Saw Use	Power Rating (hp)	SPM	PM ₁₀	PM _{2.5}	NOx	SO ₂	CO	Acrolein	CO ₂	CH ₄
		(g/s)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)	(g/s)
Demolition	25	1.64E-03	1.64E-03	1.64E-03	2.57E-02	3.33E-04	1.23E-02	1.20E-06	2.88E+00	1.31E-03
Demolition	25	1.64E-03	1.64E-03	1.64E-03	2.57E-02	3.33E-04	1.23E-02	1.20E-06	2.88E+00	1.31E-03

Assumption: Concrete Saw cutting activities are controlled with water

Emission Factors - URBEMIS2007 Model Appendix I

	SPM	PM ₁₀ ¹	PM _{2.5} ¹	NOx	SO _x	CO	Acrolein ²	CO ₂	CH ₄ ³
Concrete/Industrial Saw - 25hp Emission Factors in g/hp/hr	0.236	0.236	0.236	3.699	0.048	1.776	0.00017	415	0.188

Note: EF's include dust generated by saw and tailpipe emissions

(1) EF provided is for SPM, it is assumed all particulate matter generated is less than 2.5 microns

(2) Acrolein Emission Factor is calculated based on the ratio of CO emission factor in AP-42 Table 3.3-1 (0.95 lb/MMBtu) to the CO emission factor above (1.776 g/hp-hr), and the Acrolein emission factor in AP-42 Table 3.3-2 (9.25E-05 lb/MMBtu).

(3) CH₄ Emission Factor is calculated based on the ratio of CO emission factor in AP-42 Table 3.4-1 (0.85 lb/MMBtu) to the CO emission factor above (1.776 g/hp-hr), and the CH₄ emission factors in AP-42 Table 3.4-1 (0.09 lb/MMBtu).

Emission Rate Calculation

$$E = EF \text{ (g/hp-hr)} \times \text{hp} \times 1 \text{ hr} / 3600 \text{ sec}$$

E = emission rate in g/s

EF = URBEMIS2007 Appendix I Emission Factors in g/hp-hr

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Grading and Dozing Particulate Matter Emissions

Description	Silt (%)	Moisture (%)	Emission Factor in kg/hr			Operating Hours per Day	Uncontrolled Emission Rate (g/s)			Control Based on Watering (%)	Controlled Emission Rate (g/s)		
			SPM	PM ₁₀	PM _{2.5}		SPM	PM ₁₀	PM _{2.5}		SPM	PM ₁₀	PM _{2.5}
Construction Year 1													
Bulldozing -Site Area	6.9	10.4	1.257	0.231	0.132	50%	0.1746	0.0320	0.0183	50%	0.0873	0.0160	0.0092

Size Fraction	Emission Factor Equation	Reference
TSP <30 µm	$E = 2.6 \times (s)^{1.2} \times (M)^{-1.3}$	AP-42 Table 11.9-2, October 1998
TSP <10 µm	$E = 0.75 \times 0.45 \times (s)^{1.5} \times (M)^{-1.4}$	AP-42 Table 11.9-2, October 1998
TSP <2.5 µm	$E = 0.105 \times 2.6 \times (s)^{1.2} \times (M)^{-1.3}$	AP-42 Table 11.9-2, October 1998

E = emission factor in kg/hour
s = silt content (%)
M = material moisture content (%)

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Crushing and Screening Particulate Matter Emissions

Description	Emission Factor in kg/tonne			Tonnes Loaded per Hour	Emission Rate (g/s)			Crushing Frequency (hours/day) ¹	Emission Rate Over a 12-hr Work Day (g/s)		
	SPM	PM ₁₀	PM _{2.5}		SPM	PM ₁₀	PM _{2.5}		SPM	PM ₁₀	PM _{2.5}
Construction											
Primary Crushing (Controlled)	0.00060	0.00027	0.00005	150	0.0250	0.0113	0.0021	3	0.0063	0.0028	0.0005
Screening (Controlled)	0.0011	0.00037	0.000025	150	0.0458	0.0154	0.0010	3	0.0115	0.0039	0.0003

(1) Calculation: Rock blasted per day divided by tonnes of rock loaded per hour into the primary crusher

Assumption - 80% of material from primary crusher requires secondary crushing

EMISSION FACTORS (kg/Mg of material throughput) ¹			
Source	SPM	PM ₁₀	PM _{2.5}
Primary Crushing	ND	0.0012	0.00005
Primary Crushing (controlled)	0.0006	0.00027	0.00005
Secondary Crushing	0.0012	0.0012	0.00005
Secondary Crushing (controlled)	0.0006	0.00027	0.00005
Tertiary Crushing	0.0027	0.0012	0.00005
Tertiary Crushing (controlled)	0.0006	0.00027	0.00005
Screening	0.0125	0.0043	ND
Screening (controlled)	0.0011	0.00037	0.000025
Conveyor Transfer Point	0.0015	0.00055	ND
Conveyor Transfer Point (controlled)	0.00007	0.000023	0.0000065

(1) All emission factors from AP-42 Table 11.19.2-1

uses tertiary EF's as upper limits as No Data was available for Primary or Secondary Crushing

SPM Emissions Sample Calculation for Controlled Screening Emissions:

$$\frac{g(PM_{30})}{sec} = \frac{tonnes\ loaded}{per\ hour} \times \frac{0.0011\ kg\ PM_{30}}{tonne\ loaded} \times \frac{1\ hour}{3600\ seconds} \times \frac{1000\ grams}{1\ kg}$$

Note: AP-42 Section 11.19.2 describes the stages of the crushing process as follows:

Type of Crushing Activity	Crusher Output Sizing
Primary Crushing - Jaw, Impact or Gyratory Crusher	7.5 to 30 cm (3 to 12 inches) diameter
Secondary Crushing - Cone Crusher	2.5 to 10 cm (1 to 4 inches) diameter
Tertiary Crushing - Cone or Impact Crusher	0.5 to 2.5 cm (3/16th to 1 inch) diameter

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Concrete Batching Plant - Emissions

ACTIVITY	k			M-Moisture Content %	U-Wind Speed (m/s)	Loading Rate ⁽¹⁾ (t/h)	Emission Factor ⁽²⁾		Uncontrolled Emissions ⁽³⁾			Control Efficiency (%)	Controlled Emissions		
	SPM	PM ₁₀	PM _{2.5}				SPM	PM ₁₀ & PM _{2.5}	SPM	PM ₁₀	PM _{2.5}		SPM	PM ₁₀	PM _{2.5}
							(kg/T)	(kg/T)	(g/s)	(g/s)	(g/s)		(g/s)	(g/s)	(g/s)
For Construction Years 3 to 5															
Delivery truck to stockpile (sand)	0.74	0.35	0.05	4.17	5.0	13.7			0.0047	0.0022	0.0003	0%	0.0047	0.0022	0.0003
Front-end-Loader to Hopper (sand)	0.74	0.35	0.05	4.17	5.0	13.7			0.0047	0.0022	0.0003	50%	0.0023	0.0011	0.0002
Conveyor drop to hopper (sand)	0.74	0.35	0.05	4.17	5.0	13.7			0.0047	0.0022	0.0003	0%	0.0047	0.0022	0.0003
Delivery tanker to Cement Silo (controlled by dust collector)				n/a	n/a	26.7	0.0005	0.00017					0.0037	0.0037	0.0013
Delivery tanker to Slag Silo (controlled by dust collector)				n/a	n/a	26.7	0.0045	0.0024					0.0333	0.0333	0.0178
Collection hopper to Ready-Mix truck (cement and Slag)				n/a	n/a	5.4	0.028	0.008					0.0421	0.0421	0.0120

(1) Emission factors are from AP-42 Table 11.12-1, June 2006

(2) Uncontrolled emissions from aggregate material drops are calculated from AP-42 Section 13.2.4: $k(0.0016)(U/2.2)^{1.3}/(M/2)^{1.4}$ kg/t, where k=0.74 for TSP (particles less than 30 microns).

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APPENDIX G: SCENARIOS COMPARISON: SAR vs. DECOMSA



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Appendix G: Scenarios Comparison – SAR vs. DecomSA

The following concordance table compares the scenarios assessed as bounding scenarios in the DecomSA to the scenarios assessed in the facility SAR (Athauda-Arachchige, 2015), to highlight the complete range of events assessed among these two studies, and, to note key differences.

Table G-1 Scenario Comparison – SAR vs. DecomSA

DecomSA			Facility SAR		
Scenario	Description	Conclusion	Scenario	Description	Conclusion (SAR Table 10-8)
<p><i>Bounded by SAR.</i> <i>See also this report, Section 9.0.</i></p>			Earthquake (Design-Basis Accident)	An earthquake occurs, which could result in structural damage, falling objects, damage to the ventilation system, fires from electrical short circuits and flammable materials in the facility, physical injury to personnel, and resuspension of contamination.	The calculated dose is 2.38E-03 Sv.
Forest Fire and Release of Radioactivity	A large forest fire engulfs the facility. The entire facility is affected and all radioactive contaminants within the walls become airborne.	The maximum calculated total dose received is 2.84E-04 mSv.	External Fire (Design-Basis Accident)	External fire from a i) forest fire, ii) aircraft/missile strike, or iii) lightning could release contamination, resulting in increased doses.	i) "No discernible effect" ii) "catastrophic effect" iii) "minor effect".
<p>For Aircraft/Missile, and Lightning: Bounded by SAR.</p>					
Forest Fire and Release of Chemical Contaminants	A large forest fire engulfs the facility. The entire facility is affected and all chemical contaminants within the walls become airborne.	The maximum calculated screening indices are: 6.2E-02 (public) and 6.0E-01 (worker) for asbestos, 1.7E-03 (public) and 2.4E-05 (worker) for lead, 0 for mercury (none available), 0 for PCBs (none available), 0 for dioxins & furans (based on PCBs).	Not in scope of SAR.		
Tornado and Release of Radioactivity	A tornado (EF-2) strikes the facility. Only above ground structures are affected, releasing radioactive contaminants. Based on a realistic inventory	The maximum calculated dose is 2.8E-16 mSv for workers and 8.0E-08 mSv for public (Rapides Des Joachims and Rolphton locations).	Extreme Weather Conditions (Design-Basis Accidents)	Extreme weather conditions are considered, including: i) high/low temperatures, excessive humidity ii) heavy rain, snow, ice or hail iii) rain entering building iv) strong winds v) EF-2 tornado (for conservative inventory) vi) extended loss of Class IV or III power	i) "No discernible effect" ii) calculated dose is 2.38E-03 Sv. iii) "minor effect" iv) "no dose" v) The calculated dose is <2.38 E-03 Sv vi) "no dose".
Tornado and Release of Chemical Contaminants	A tornado (EF-2) strikes the facility. Only above ground structures are affected, releasing chemical contaminants.	The maximum calculated screening indices are: 6.6E-01 (public) and 1.5E-08 (worker) for asbestos, 2.9E-03 (public) and 9.8E-14 (worker) for lead, 0 for mercury (none available), 0 for PCBs (none available).	Not in scope of SAR.		

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DecomSA			Facility SAR		
Scenario	Description	Conclusion	Scenario	Description	Conclusion (SAR Table 10-8)
SAR assessment is specific to sump pump failure; not applicable to decommissioning (sump will be decommissioned & grouted). Also, consequences are bounded by external flooding.			Internal Flooding (Design-Basis Accident)	Internal flooding from failure of sump pumps (and associated valves and piping), building condensation, and/or roof leakage. Flooding could occur in i) the Non-Nuclear Area, or ii) the Nuclear Area. The main hazard associated with this is localized contamination and resulting exposure. Flooding from dam failure is considered elsewhere.	i) No discernible effect ii) The calculated dose is <1.49E-07 Sv.
Major Flood and Release of Radioactivity	A large precipitation flood occurs, resulting in a large volume of water entering the facility. The floodwater mobilizes all contamination within the above ground walls of the facility and releasing it outside of the facility.	Based on the findings of the facility SAR, with brief discussion of circumstances specific to decommissioning. No discernable effect.	<u>External Flooding:</u> Precipitation, River Level (Design-Basis Accident) 3-Dam Failure (Beyond-Design-Basis Accident)	External flooding from: i) heavy precipitation, ii) high river levels, or iii) failure of dams, resulting in the release of contamination from the facility to the river.	i) No discernible effect ii) No discernible effect iii) the dose is likely to be <1mSv due to significant dilution in floodwaters.
Not Applicable: No general facility ventilation is used during decommissioning. Based on chronic tritium measurements in the facility, ventilation is not expected to have an effect on tritium levels (McVeigh 2016b).			Ventilation Fan Failure (AOO)	A loss of ventilation has the potential to increase airborne contamination, resulting in an increased dose to workers.	The calculated dose is 8.04E-05 Sv.
Hydrogen Generation from Grout Reactions	Alkaline grout is used to fill the boiler room (including the dump tank) and the reactor vault (including the calandria). The resulting chemical reaction between the grout and aluminum produces hydrogen.	Based on the findings of Hongqiang (2017), and assuming that the measures to address hydrogen safety are implemented, adverse effects on workers are not anticipated.	Not applicable to SwS state.		
Accidental Exposure to Radioactivity	Personnel working underground are exposed to unanticipated levels of radioactivity. Two scenario variants are considered: i) a worker spends additional time drilling, thereby increasing exposure time; ii) the source is stronger than originally estimated, thereby increasing dose.	i) 8.71E-01 mSv ii) 5.33E-01 mSv	New activity - not SwS.		
Accidental Exposure to Chemicals	Personnel working underground receive unanticipated exposure to hazardous chemicals.	No exposure to hazardous chemical is expected.	New activity - not SwS.		

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DecomSA			Facility SAR		
Scenario	Description	Conclusion	Scenario	Description	Conclusion (SAR Table 10-8)
Underground (Indoor) Fire and Release of Radioactivity	A small underground fire occurs, releasing volatile radionuclides, and radioactive contamination embedded in any combustible materials, and loose surface contamination, becoming partially airborne.	The maximum calculated dose is 1.12E-03 mSv for workers and 1.19E-09 mSv for public (guard house location).	Internal Fire (Internal Fire)	An internal fire (ignited from electrical or mechanical service equipment) may result in doses and environmental releases and injury to personnel.	minor effect.
Bounded by SAR. Gas cylinders used as part of decommissioning will be stored in an external location.			Internal Explosions (Design-Basis Accident)	An explosion from i) high-pressure gas cylinders, or ii) chemicals could occur, resulting in structural damage, personnel injury	i) Minor effect ii) No dose.
Underground (Indoor) Fire and Release of Chemicals	An underground fire occurs, releasing volatile radionuclides and radioactive contamination embedded in combustible materials and loose surface contamination become partially airborne.	The maximum calculated screening indices are: 0 for asbestos (not affected by small fire), 0 for lead (not affected by small fire), 2.39E-01 (worker) and 9.63E-06 (public) for mercury, 0 for PCBs (not available to a small fire), 0 for dioxins and furans (based on PCBs).	Not in scope of SAR.		
Stack Collapse and Release of Radioactivity	The ventilation stack accidentally fails and falls. This results in potential personal injuries and fatality, as well as loose surface contamination and a portion of the fixed contamination becoming partially airborne. A worker could also be splashed with the radioactive water contained within the base of the stack.	The maximum calculated dose is 9.76E-04 mSv for workers and 1.15E-02 mSv for public (guard house location).	New activity - not SwS.		
SAR is bounding while current safety related systems are in place. Power will be disconnected from the facility as part of planned decommissioning.			Loss of Class IV power (AOO)	All electrical systems in the facility will lose power, and battery-operated emergency lights will come on. Class III emergency power will start within approx. five seconds for the entire facility.	"No discernible effect."
			Class III Power Failure (Design-Basis Accident)	Class III power failure will result in all electrical systems in the facility losing power (except for units on UPS). Emergency lights remain for 30 minutes.	No dose.
SAR is bounding while current safety related systems are in place. Sump pump and fire detection systems will be offline and decommissioned			Equipment Failure (Design-Basis Accident)	Equipment failure of i) sump pump, and ii) fire detection system is considered.	i) No discernible effect ii) Public: 5E-03 Sv Worker: is 5E-02 Sv.
SAR is bounding while current safety related systems are in place.			Effects of Flora and Fauna (Design-Basis Accident)	Flora and fauna could reduce structural integrity of shielding structures, degrade electrical wiring, and destroy functional equipment. A loss of safety-related systems could occur.	Minor effect.

APPENDIX H: BOUNDING SCENARIO PROCESS



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Appendix H: Bounding Scenario Process

The following table presents details of the bounding scenario selection process, e.g. the screening and groupings performed as per the process described in Section 7.9.

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Table H.1 - General

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence (C)	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Resulting Consequence Group	Bounding Scenario
1	General	N/A	Physical	Conventional construction accident	Personnel injury due to typical project activities such as working at heights, working with heavy equipment. Potential injuries include falls, trips, strains, crushing, pinching, etc.	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
2	General	N/A	Physical	Conventional construction accident	Work place fatality due to typical project activities such as working at heights, working with heavy equipment. Potential injuries include falls, trips, crushing, etc.	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
3	General	N/A	Physical	Physical situation – difficult access to below-grade areas	Restricted emergency response & departure	F3	Y	S1	Y	R1	Conventional Injury (Restricted Response)	Conventional Health & Safety
4	General	N/A	Physical	Presence of a construction zone on site	Restricted emergency response	F3	Y	S1	Y	R1	Conventional Injury (Restricted Response)	Conventional Health & Safety
5	General	N/A	Hydrocarbons	Transportation accident on-site	Potential release of oil or hydrocarbons to the environment causing contamination, fire, personal injury, road access restriction	F2	Y	S0	N	R0	Screened Out	Screened Out

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence (C)	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Resulting Consequence Group	Bounding Scenario
6	General	N/A	Physical	Transportation accident, offsite	Injuries	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
7	General	N/A	Physical	Transportation accident, offsite	Fatalities	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
8	General	N/A	Hydrocarbons	Fuel spill from mobile storage tank or during fueling activities	Site contamination	F3	Y	S0	N	R0	Screened Out	Screened Out
9	General	N/A	Physical	Road access block due to forest fire, flood, traffic accident, winter storm, etc.	Restricted emergency response, limited site access	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
10	General	N/A	Radionuclides	Forest fire	Release of radioactivity (from aboveground portion only) due to fire spreading to the building and mobilizing the radionuclides	F1	Y	S3(conservative)	Y	R1	Release of Radioactivity; Exposure	Yes: Bounds Above-Ground/Outdoor Airborne (Fire) Releases of Radioactivity & Subsequent Exposure Bounding Scenario #1
11	General	N/A	Hazardous chemicals	Forest fire	Smoke inhalation, chemical exposure (chemicals in the above ground portion only), and worker injuries due to burning of combustibles.	F1	Y	S3(conservative)	Y	R1	Release of Haz. Chemicals; Exposure	Yes: Bounds Above-Ground/Outdoor Airborne (Fire) Releases of Haz. Chemicals & Subsequent Exposure Bounding Scenario #2
12	General	N/A	Physical	Forest fire	Injury	F1	Y	S2	Y	R0	Conventional Injury	Conventional Health & Safety
13	General	N/A	Physical	Forest fire	Fatality	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
14	General	N/A	Radionuclides	Tornado	Release of radioactivity (from aboveground portion only) due to damage to the building and mobilizing the radionuclides	F2	Y	S3(conservative)	Y	R2	Release of Radioactivity; Exposure	Yes: Bounds Above-Ground/Outdoor Airborne (Non-Fire) Releases of Radioactivity & Subsequent Exposure Bounding Scenario #3

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence (C)	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Resulting Consequence Group	Bounding Scenario
15	General	N/A	Hazardous chemicals	Tornado	Exposure to chemicals (chemicals in the aboveground portion only) released due to damage to the building and mobilizing the radionuclides	F2	Y	S3(conservative)	Y	R2	Release of Haz. Chemicals; Exposure	Yes: Bounds Above-Ground/Outdoor Airborne (Non-Fire) Releases of Haz. Chemicals Bounding Scenario #4
16	General	N/A	Physical	Tornado	Injury	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
17	General	N/A	Physical	Tornado	Fatality	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
18	General	N/A	Hazardous \Chemicals	Heavy precipitation, Flood	Release of chemicals due to water ingress and mobilization (incl. release from their stored material forms)	F2	Y	S2	Y	R1	Release of Haz. Chemicals; Exposure	No:Due to waste forms. Water ingress from precipitation would not release the chemicals from their waste forms.
19	General	N/A	Radionuclides	Heavy precipitation, Flood	Release of radioactivity due to water ingress and mobilization of radionuclides	F2	Y	S3(conservative)	Y	R2	Release of Radioactivity; Exposure	Yes: Bounds Waterborne Releases of Radioactivity and Subsequent Exposure Bounding Scenario #5
20	General	N/A	Physical	Heavy precipitation, Flood	Injury	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
21	General	N/A	Physical	Heavy precipitation, Flood	Fatality, site access	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
22	General	N/A	Radionuclides	Ice storm/Severe winter storm	Release of radioactivity due to structural damage and loss of containment	F1	Y	S2	Y	R0	Release of Radioactivity; Exposure	No. Bounded by Tornado & Forest Fire
23	General	N/A	Radionuclides	Earthquake	Release of radioactivity due to structural damage and loss of containment	F2	Y	S2	Y	R1	Release of Radioactivity; Exposure	No. Bounded by Tornado & Forest Fire <i>(see also discussion regarding initiating event)</i>

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence (C)	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Resulting Consequence Group	Bounding Scenario
24	General	N/A	Physical	Earthquake	Injury	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
25	General	N/A	Physical	Earthquake	Fatality	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
26	General	N/A	Radionuclides	Dam failure and flooding	Release of radioactivity due to water ingress and mobilization of radionuclides	F0	N	S3(conservative)	Y	R0	Screened Out	Screened Out
27	General	N/A	Physical	Dam failure and flooding	Injury	F0	N	S2	Y	R0	Screened Out	Screened Out
28	General	N/A	Physical	Dam failure and flooding	Fatality	F0	N	S4	Y	R1	Screened Out	Screened Out
29	General	N/A	Electricity	Failure to isolate power, general construction activity	Electric shock (injury)	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
30	General	N/A	Electricity	Failure to isolate power, general construction activity	Electrocution (Fatality)	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
31	General	N/A	Physical	Public intrusion	injuries	F2	Y	S1	Y	R0	Conventional Injury	Conventional Health & Safety

Note:
Conventional health & safety events are addressed collectively in Section 8.3.3.

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Table H.2 – Operation of Batch Mixing Plant

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Operation of batch mixing plant: 1.2 Assign material storage areas. 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations 1.10 Wash (trucks, sluices/pipes) 1.11 Dewater pit, emplace sediments into voids.	8.1 8.3.001	Construction material	Spill of construction material	Site contamination	F3	Y	S0	N	R0	Screened Out	Screened Out
2	Operation of batch mixing plant: 1.3 Set up mixing stations (incl. electrical) 1.4 Truck in water supply 1.6 Construct wash pit 1.7 Level area for pumper 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations 1.10 Wash (trucks, sluices/pipes) 1.12 Demobilize batch plant	8.1.003 8.3.001 8.4.006	Physical	Equipment failure while setting up batch mixing plant	Drop of heavy equipment and personal injuries	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
2	Operation of batch mixing plant: 1.3 Set up mixing stations (incl. electrical) 1.4 Truck in water supply 1.6 Construct wash pit 1.7 Level area for pumper 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations 1.10 Wash (trucks, sluices/pipes) 1.12 Demobilize batch plant	8.1.003 8.3.001 8.4.006	Physical	Equipment failure while setting up batch mixing plant	Drop of heavy equipment and fatality	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
3	Operation of batch mixing plant: 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations	8.1.003	Chemical	Overflow / failure of wash-out pit liner	Release of chemicals outside the pit (i.e. high pH water)	F2	Y	S0	N	R0	Screened Out	Screened Out
4	Operation of batch mixing plant: 1.10 Wash (trucks, sluices/pipes)	8.1.003	Physical	Contact with corrosive materials (cement or concrete)	Personal injuries (chemical burns)	F3	N	S0	Y	R0	Screened Out	Screened Out
5	Operation of batch mixing plant: 1.2 Assign raw material storage areas.	8.1.003	Construction materials	Uncontrolled release of these materials due to weather (heavy rain) or erosion causing the stock piles to collapse or have material slide toward the river		F2	Y	S0	N	R0	Screened Out	Screened Out

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
6	Operation of batch mixing plant: 1.3 Set up mixing stations (incl. electrical) 1.4 Truck in water supply 1.6 Construct wash pit 1.7 Level area for pumper 1.8 Mix grout to formula 1.9 Truck/pipe grout to locations 1.10 Wash (trucks, sluices/pipes) 1.12 Demobilize batch plant	8.1.003 8.3.001 8.4.006		See General Items No. 1 to No. 9 (excl 3)		-	-	-	-	-	N/A	N/A

Note: Conventional health & safety events are addressed collectively in Section 8.3.3.

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Table H.3 – Grouting of Below-Grade Structures

No	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Grouting of below grade structures: 2.3.5 fill used fuel storage bay. 2.3.6 fill lower areas 2.3.7 install slip pipes for reactor vault 2.3.8 fill reactor vault 2.3.9 fill end access and tube withdrawal rooms 2.3.10 fill boiler room 2.3.11 fill balance of nuclear area.	8.3.0 01	Construction material	Spill of construction material	Site contamination	F3	Y	S0	N	R0	Screened Out	Screened Out
2	Grouting of below grade structures: 2.3.5 fill used fuel storage bay. 2.3.6 fill lower areas 2.3.7 install slip pipes for reactor vault 2.3.8 fill reactor vault 2.3.9 fill end access and tube withdrawal rooms 2.3.10 fill boiler room 2.3.11 fill balance of nuclear area.	8.3.0 01	Radionuclides	Failure of current structure (this does not include small cracks in the building walls or floors)	Release of radionuclides outside the structure	F1	Y	S2	Y	R0	Release of Radioactivity; Exposure	No. Bounded by Tornado
3	Grouting of below grade structures: 2.3.5 fill used fuel storage bay. 2.3.6 fill lower areas 2.3.7 install slip pipes for reactor vault 2.3.8 fill reactor vault 2.3.9 fill end access and tube withdrawal rooms 2.3.10 fill boiler room 2.3.11 fill balance of nuclear area.	8.3.0 01	Hydrogen Gas	Contact of grout with aluminum materials from the reactor	Hydrogen generation and potential for fire or explosion	F1	Y	S2	Y	R0	Hydrogen generation and potential for fire or explosion	Hydrogen Release is Assessed as Part of Planned Normal Operations
4	Grouting of below grade structures: 2.1.1 Seal required holes from pipes, vents, etc. 2.3.10 fill boiler room 2.3.11 fill balance of nuclear area.	8.3.0 07 8.3.0 01	Radionuclides / Chemicals	Failure to seal all holes and pathways to outside of the building (this includes omitting a hole or pathway or failure of the seal)	Release of radionuclides and chemicals outside the building	F1	Y	S2	Y	R0	Release of Radioactivity; Exposure Release of Haz. Chemicals; Exposure	<i>Long-Term Safety is Assessed in Postclosure Safety Assessment</i>

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
5	Grouting of below grade structures: 2.1.3 Drill holes for grout passage, air release, heat dissipation. 2.2.1 Drill holes, top & bottom of Helium storage tanks 2.2.2 Drill holes, top and bottom of steam generator 2.2.3 Drill holes, top and bottom of boiler 2.2.4 Drill holes, top and bottom of dump tank 2.2.5 Drill holes, top and bottom of vault cooling vent runways 2.2.7 Drill access into reactor vault via fueling machine room	8.3.0 07 8.2.0 05	Radionuclides	Failure to drill hole for air release and heat dissipation (this results in partial grouting and poor containment in long-term)	Release of radionuclides outside the structure	F2	Y	S2	Y	R1	Release of Radioactivity; Exposure	<i>Long-Term Safety is Assessed in Postclosure Safety Assessment</i>
6	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	Physical	Working underground and confined spaces in IDLH (e.g. low oxygen)	Injury and emergency escape restriction	F2	Y	S1	Y	R0	Conventional Injury (Restricted Response)	Conventional Health & Safety
7	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	Physical	Working underground and confined spaces in IDLH (e.g. low oxygen)	Injury	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
8	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	Physical	Working underground and confined spaces in IDLH (e.g. low oxygen)	Fatality	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
9	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	Radionuclides	Accidental exposure to radioactivity	Exposure to radiological dose during demolition of walls, cutting holes, cutting vessels and pipes (this is the exposure beyond the level expected during planned demolition activities which will be assessed under "Normal Conditions").	F2	Y	S3	Y	R1	Exposure to Radioactivity (Direct/External)	Yes: Bounds Exposure to Direct/External Radioactivity Bounding Scenario #6

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
10	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	Radionuclides	Underground fire (e.g. from small equipment fuel spill)	Airborne release of radionuclides	F1	Y	S1	Y	R0	Release of Radioactivity; Exposure	Yes: Bounds Below-Ground/Indoor Airborne (Fire) Releases of Radioactivity & Subsequent Exposure Bounding Scenario #8
11	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	Combustible materials	Underground fire (e.g. from small equipment fuel spill)	Smoke inhalation and workers injuries due to burning of combustibles	F1	Y	S2	Y	R0	Release of Haz. Chemicals; Exposure	Yes: Bounds Below-Ground/Indoor Airborne (Fire) Releases of Haz. Chemicals & Subsequent Exposure Bounding Scenario #9
12	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	Asbestos	Asbestos exposure during transfer and emplacement	Asbestos release and exposure	F2	Y	S1	Y	R0	Release of Haz. Chemicals; Exposure	No: Bounded by Indoor Fire Release & Exposure to Haz. Chemicals
13	Grouting of below grade structures: 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	Radionuclides	Release of radionuclides from removed contaminated equipment / components from laydown area	Release of radionuclides and worker exposure	F1	Y	S1	Y	R0	Release of Radioactivity; Exposure	No: Exposure to radionuclides released from drilling/cutting is included in 'Exposure to Direct/External Radioactivity'.
14	Removal of PCBs from Boiler Room Ceiling 2.1 Room Prep. (sealing, drilling, slip pipe installs, etc.) 2.2 Systems Prep. (drilling, sealing)	8.3.0 07 8.2.0 05	PCBs	PCBs exposure during removal of light ballasts	PCBs release and exposure	F2	Y	S0	N	R0	Release of Haz. Chemicals; Exposure	Assessed as part of: Exposure to Haz. Chemicals when Performing Decommissioning Tasks (Bounding Scenario #7)

Note: Conventional health & safety events are addressed collectively in Section 8.3.3.

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Table H.4 – Removal of above-grade structures

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity ? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Radionuclides	Accidental exposure to radioactivity	Exposure to radiological dose during demolition of walls, cutting steel beams, and pipes (this is the exposure beyond the level expected during planned demolition activities which will be assessed under "Normal Conditions").	F2	Y	S1	Y	R0	Exposure to Radioactivity (Direct/External)	No: Bounded by similar task & consequence for preparation of below-grade rooms (which produce less air exchange, higher concentrations, and higher doses)
2	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Combustible materials	Ignition of combustibles (e.g. from equipment fuel spill)	Smoke inhalation and workers injuries due to burning of combustibles	F1	Y	S1	Y	R0	Release of Haz. Chemicals; Exposure	No: Bounded by indoor fire in below-grade nuclear areas room prep.

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity ? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
3	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	HEPA Filter medium	Combustion of HEPA filters	Release of radionuclides	F1	Y	S1	Y	R0	Release of Radioactivity; Exposure	No: Bounded by indoor fire in below-grade nuclear areas room prep.
4	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Radioactivity	Ignition of combustibles including bitumen roofing materials	Airborne release of radioactivity	F1	Y	S1	Y	R0	Release of Radioactivity; Exposure	No: Bounded by Forest Fire Scenario

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity ? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
5	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	PCB	Accidental exposure	PCB exposure during removal of fluorescent light ballasts	F2	Y	S0	N	R0	Screened Out	Screened Out
6	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Lead	Accidental exposure	Lead exposure during removal of lead-based paint and from accidental release from laydown area	F2	Y	S0	N	R0	Screened Out	Screened Out

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity ? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
7	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Toxic / corrosive chemicals	Accidental exposure	Chemical exposure	F2	Y	S1	Y	R0	Release of Haz. Chemicals; Exposure	<p>Yes: Bounds Exposure to Haz. Chemicals when Performing Decommissioning Tasks (e.g. Cutting, Drilling). <i>(PCBs also assessed as part of this scenario, driven by Table H-3, Item #14)</i></p> <p>Bounding Scenario #7</p>
8	Demolition of Reactor Hall: 3.0 Removal transite from the building exterior. 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Asbestos	Accidental exposure	Asbestos exposure during removal of insulation and old construction materials	F2	Y	S0	N	R0	Screened Out	Screened Out
9	Demolition of Reactor Hall: 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms	8.3.006	Physical Radioactivity	Collapse of unstable structures	Personal injury	F2	Y	S2	Y	R1	Conventional Injury Release of Radioactivity; Exposure	Conventional Health & Safety

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity ? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
10	Demolition of Reactor Hall: 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms	8.3.006	Physical Radioactivity	Collapse of unstable structures	Fatality	F1	Y	S4	Y	R2	Conventional Injury Release of Radioactivity; Exposure	Conventional Health & Safety
11	Fill below grade structure with grout: 3.5 Grout first level in condenser pit 3.7 Grout 2nd level in condenser pit 3.9 Grout 3rd level in condenser pit	8.3.001	Construction material	Spill of construction material	Site contamination	F3	Y	S0	N	R0	Screened Out	Screened Out
12	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006	Radionuclides	Storm water entering the underground areas while the above ground structure is removed	Release of radionuclides	F2	Y	S1	Y	R0	Release of Radioactivity; Exposure	No: Bounded by precipitation flood scenario.
13	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown. 3.2 Sizing of material (cutting/crushing) 3.3 Set up laydown area & clearance surveys 3.4 Emplace steel & rubble in condenser pit (fill to 380 level) 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.8 Emplace steel & rubble in condenser pit (fill to 425 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms 3.12 Emplace block wall rubble in furnace room	8.3.006		See General Items No. 1, 2, 29, and 30		-	-	-	-	-	N/A	N/A

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No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
14	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown.	8.3.006	Physical	Accidental collapse of stack	Personal injury	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
15	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown.	8.3.006	Physical	Accidental collapse of stack	Fatality	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
16	Demolition of Reactor Hall: 3.1 Conventional hvy equip. knockdown.	8.3.006	Radioactivity	Accidental collapse of stack	Release of radioactivity	F1	Y	S1	Y	R0	Release of Radioactivity; Exposure	<p>Yes: Different exposure pathways involved. Nature of exposure is sufficiently different so as to warrant evaluation.</p> <p>Bounding Scenario #10</p>
17	Demolition of Reactor Hall: 3.6 Emplace steel & rubble in condenser pit (fill to 400 level) 3.10 Demo. walls & blocks in control room and change rooms 3.11 Collapse ceilings - furnace & adjacent rooms	8.3.006	Physical Radioactivity	Collapse of unstable structures	Release of radioactivity outside the structure	F1	Y	S1	Y	R0	Conventional Injury Release of Radioactivity; Exposure	<p>Conventional Health & Safety</p> <p>No: Bounded by forest fire scenario.</p>

Note: Conventional health & safety events are addressed collectively in Section 8.3.3.

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Table H.5 – Removal of Guard House

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence (C)	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Demolition of Guard House: 3.13 Remove recyclables from guard house 3.14 Demolish and emplace in furnace room & adjacent areas	8.3.006	Combustible materials	Ignition of Combustibles	Smoke inhalation and workers injuries due to burning of combustibles (wooden shelving units and platforms, plastic conduits, paper, cardboard, wood, etc.)	F1	Y	S2	Y	R0	Release of Haz. Chemicals; Exposure	No: Bounded by Below-Grade/Indoor Fire
2	Demolition of Guard House: 3.13 Remove recyclables from guard house 3.14 Demolish and emplace in furnace room & adjacent areas	8.3.006	Asbestos	Accidental exposure	Asbestos exposure during removal of insulation and old construction materials	F1	Y	S0	N	R0	Screened Out	Screened Out
3	Demolition of Guard House: 3.13 Remove recyclables from guard house 3.14 Demolish and emplace in furnace room & adjacent areas	8.3.006	Lead	Accidental exposure	Lead exposure during removal of lead-based paint	F1	Y	S0	N	R0	Screened Out	Screened Out
4	Demolition of Guard House: 3.13 Remove recyclables from guard house	8.3.006	Physical	Collapse of unstable structures	Personal injury, fatality	F2	Y	S2	Y	R1	Conventional Injury	Conventional Health & Safety
5	Demolition of Guard House: 3.13 Remove recyclables from guard house	8.3.006	Physical	Collapse of unstable structures	Personal injury, fatality	F1	Y	S4	Y	R2	Conventional Injury	Conventional Health & Safety
6	Demolition of Guard House	8.3.006		See General Items No. 1 and 2.		-	-	-	-	-	N/A	N/A

Note: Conventional health & safety events are addressed collectively in Section 8.3.3.

Table H.6 – Removal of Generator

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Removal of Emergency Generator	8.4.006	-	See General Items No. 6, 29, and 30	-	-	-	-	-	-	N/A	N/A

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Table H.7 – Demolish Pressure Relief Pit

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	Radioactivity	Accidental exposure	Gamma, beta, and alpha exposure	F2	Y	S1	Y	R0	Exposure to Radioactivity (Direct/External)	No: Bounded by similar task & consequence for preparation of below-grade rooms (which involves greater source term, less air exchange, higher concentrations, and higher doses)
2	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	Asbestos	Accidental exposure	Asbestos exposure during removal of insulation and old construction materials	F2	Y	S0	N	R0	Screened Out	Screened Out
3	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	Radioactivity	Collapse of unstable structures	Release of radioactivity outside the pit due to loss of containment in case of major damage to the foundation and walls	F1	Y	S2	Y	R0	Release of Radioactivity; Exposure	No: Bounded by stack collapse.
4	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	Construction material	Spill of construction material	Site contamination	F3	Y	S0	N	R0	Screened Out	Screened Out
5	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	Construction material	Failure of drain seal	Release of construction materials into the drain system	F2	Y	S0	N	R0	Screened Out	Screened Out
6	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001		See General Items No. 1 and 2		-	-	-	-	-	N/A	N/A
7	Demolition of pressure relief pit: 3.16 Demolish above-grade portion & fill with grout.	8.3.006 8.3.001	Radioactivity	Drop of demolished structures into the pit	Release of radioactivity outside the structure	F1	Y	S1	Y	R0	Conventional Injury Release of Radioactivity; Exposure	Conventional Health & Safety

Note: Conventional health & safety events are addressed collectively in Section 8.3.3.

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Table H.8 – Installation of Concrete Cap & Engineered Barrier

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence (C)	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Install Concrete Cap and Engineered Barrier: 4.1.3 Pour concrete, level & shape	8.4.005	Construction material	Spill of construction material	Site contamination	F3	Y	S0	N	-	Screened Out	Screened Out
2	Install Concrete Cap and Engineered Barrier	8.4.005		See General Items No. 1 to No. 8 (excl. 3)		-	-	-	-	-	N/A	N/A

Table H.9 – Final Site Restoration

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence (C)	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Final Site Restoration	8.4.006 8.4.003.24999		See General Items No. 1 to No. 8 (excl. 3)		-	-	-	-	-	N/A	N/A

Table H.10 – Long-Term Care & Maintenance

No.	Project Activity	WBS	Hazardous Agent	Hazardous Event	Consequence (C)	Prelim. Frequency Rating	Credible Frequency (Y/N)	Prelim. Severity Rating	Credible Severity? (Y/N)	Prelim. Risk Rating	Consequence Type	Bounding Scenario
1	Long Term care and Maintenance	N/A		See General Items No. 1 and 2		-	-	-	-	-	N/A	N/A



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