Canadian Nuclear Laboratories | Laboratoires Nucléaires Canadiens

Safety Analysis Report

Near Surface Disposal Facility Safety Analysis Report

Near Surface Disposal Facility (NSDF)

232-508770-SAR-002
Revision 2

2020 October

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octobre 2020

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1. INTRODUCTION

Canadian Nuclear Laboratories (CNL) operates Chalk River Laboratories (CRL), a Nuclear Research Facility located in Renfrew County, in the Province of Ontario. The CRL site operates under Nuclear Research and Test Establishment Operating Licence [1-1] and Licence Condition Handbook [1-2] issued by the Canadian Nuclear Safety Commission (CNSC), pursuant to the Class 1 Nuclear Facilities Regulations [1-3] and Nuclear Substances and Radiation Devices Regulations [1-4].

Canadian Nuclear Laboratories proposes to develop the Near Surface Disposal Facility (NSDF) Project to establish a safe, local and permanent means for the disposal of solid Low-Level Waste (LLW) at its CRL site. The NSDF will provide a safe, permanent solution at the CRL site for the disposal of LLW, and will replace the current CNL practice of placing this waste in interim storage. The NSDF is intended to dispose of LLW currently in interim storage, as well as LLW arising from building decommissioning and environmental remediation activities, enduring laboratory operations, and commercial sources. The LLW placed in the NSDF is expected to contain chemical constituents, which will be limited through the application of the land disposal requirements in Ontario Regulation 347, General – Waste Management [1-5].

The NSDF is being designed, licensed and built as a multi-cell facility, including:

- Engineered Containment Mound (ECM) that is composed of 10 disposal cells for the disposal and containment of LLW. The ECM includes a multilayer base liner system and a multilayer final cover system, where LLW will be placed in between. The ECM has a total waste capacity of 1 000 000 m^3, a design life of 550 years, and an operational life of 50 years.
- Wastewater Treatment Plant (WWTP) that treats leachate, contact water and process wastewater to meet effluent discharge targets.
- Vehicle Decontamination Facility (VDF) that is used for decontamination and maintenance of equipment and vehicles.
- Support buildings that enable operation, and site infrastructure.

The facility development is a phased approach:

- Phase 1, development of the ECM with total LLW capacity of 525 000 m^3, accommodating LLW currently in storage and LLW to be generated for a 20 - 25 year period.
- Phase 1, development of the WWTP, VDF, support buildings, and site infrastructure.
- Phase 2, development of the ECM with total waste capacity of 475 000 m^3, will increase the ECM to the total capacity of 1 000 000 m^3.

Canadian Nuclear Laboratories' intent is to obtain a Licence to Construct the NSDF, and this report is provided in support of the licensing application. The NSDF intends to be approved as a new nuclear disposal facility with its own Facility Authorization [1-6]. The NSDF Project was originally intended to be approved via an amendment to the Waste Management Areas (WMAs) Facility Authorization [1-7].

The NSDF Safety Analysis Report (SAR) will be updated during the life of the Facility, and specifically, will be updated following successful commissioning, to demonstrate that the Facility will provide for safe operation on the designated site over the proposed plant life.

Figure 1-1 shows the NSDF lifecycle and the applicable NSDF safety documentation for the lifecycle timeframes.

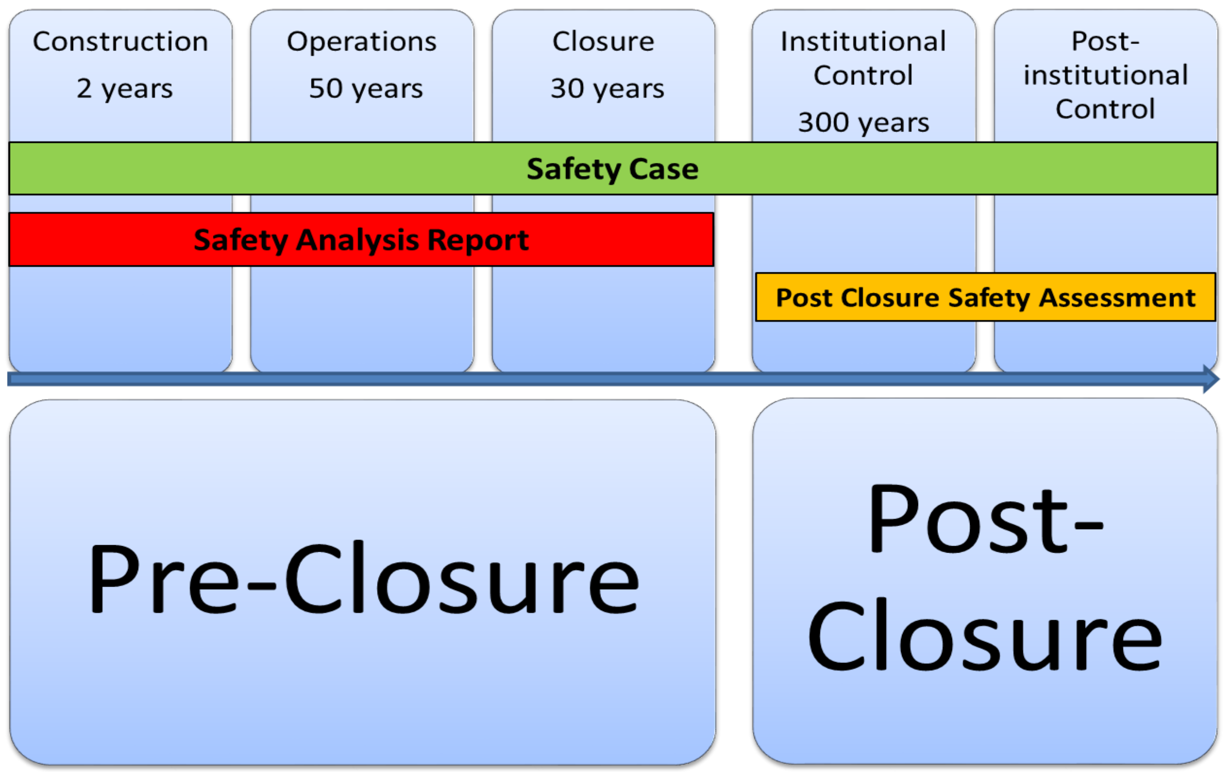

Figure 1-1 Near Surface Disposal Facility Lifecycle and Safety Documents

1.1 Waste Management Background

The WMAs at CRL, provide various facilities for storing a variety of radioactive wastes, ranging in activity from very low levels up to that of irradiated nuclear fuel. The WMAs are licensed as one WMAs Facility. Currently, there are nine physically distinct WMAs plus dispersal areas and other facilities that are licensed as the WMAs Facility.

Waste emplacements began in approximately 1946, and the wastes originate in part from the operation of CRL and in part from various Canadian off-site organizations such as isotope users, isotope manufacturers, hospitals, Government agencies, industrial plants, and commercial radioactive waste brokerage firms. Currently, there are two general types of WMAs Facilities;

operating and non-operating facilities [1-7]. Operating facilities are permitted to receive waste and non-operating facilities are not approved to receive waste for storage [1-7]. Both types of facilities are in a state of continued surveillance and inspection. No addition of wastes shall be made to the inventories of stored radioactive wastes in the WMA non-operating facilities.

1.2 Purpose

The purpose of this SAR, is to demonstrate the adequacy of the NSDF design in support of an application for a Licence to Construct the NSDF, a new nuclear facility.

The intention of this SAR, is to demonstrate to the CNSC that the proposed design of the new facility conforms to regulatory requirements and guidance provided by the CNSC and the International Atomic Energy Agency (IAEA), and if constructed as designed, will provide for safe operation on the designated site over the proposed operational facility life.

The purpose of the safety analysis is to identify the hazards, describe how hazards are controlled and or mitigated, and describe the management system in place to ensure the controls are effectively and consistently applied. The safety analysis is made up of several elements that collectively demonstrate how safety is achieved against an agreed set of safety acceptance criteria.

1.3 Scope

The scope of this SAR, is to present the operational safety analysis of the NSDF based on the detailed design package, proposed operations and identified hazards. The safety analysis scope includes all credible events identified through hazard analysis and Operating Experience (OPEX).

The timeframe assessed is the NSDF pre-closure phase that includes the construction period, 50 year operations period, and 30 year closure period including the decommissioning of redundant facilities at closure.

The NSDF SAR assesses the safety of on-site and off-site human receptors and the environment for normal operations and accident conditions. Nuclear safety is assessed for normal operations and the accident conditions; Anticipated Operational Occurrences (AOOs), Design Basis Accidents (DBAs) and Beyond Design Basis Accidents (BDBAs) including Design Extension Conditions (DECs). Design Extension Conditions are assessed as a subset of BDBAs [1-8]. Conventional health and safety is assessed for normal operations and conventional industrial accidents.

Events identified in the safety analysis are classified into the following classes:

- Anticipated Operational Occurrences.
- Design Basis Accidents.
- Beyond Design Basis Accidents including DECs.
- Conventional health and safety (non-radiological events).

This report forms part of the licensing submission for the Licence to Construct.

The configuration control on the content of the NSDF SAR will be managed following the procedure, Safety Report Issues List and Analysis of Record [1-9]. An Analysis of Record will be prepared when the NSDF SAR is approved for use.

1.3.1 Scope Exclusion

The post-closure safety analysis is not within the scope of this report and is documented in the Post-Closure Safety Assessment Report [1-10].

1.4 Safety Analysis Objectives

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

The objectives of this safety analysis are to demonstrate the following requirements under normal operations, AOOs, DBAs and BDBAs including DECs, in the NSDF Facility:

- The safety of the off-site public, on-site personnel and workers is protected.
- Demonstrate that the dose acceptance criteria are met.
- There are no significant adverse impacts on the environment.
- Demonstrate the adequacy of the NSDF design [1-3].
- Demonstrate that the proposed design of the NSDF conforms to regulatory requirements and guidance provided by the CNSC and IAEA.

The objectives of this safety analysis as defined in Deterministic Safety Analysis [1-8] are:

- Confirm that the design of the nuclear Facility meets its design and safety requirements.
- Derive Operational Limits and Conditions (OLCs) that are consistent with the design and safety requirements.
- Demonstrate that the management of the AOO and DBA is possible by automatic response of either the control systems or safety systems in combination with prescribed worker actions.
- Assist in demonstrating that safety goals, that may be established to limit the safety risks posed by the nuclear facility, are met.
- Assist in establishing and validating accident management procedures and guidelines.

1.5 Regulatory Documentation

The key regulatory documentation used during the preparation of the safety analysis includes but is not limited to:

- Nuclear Safety and Control Act (NSCA) [1-11] and its Regulations.
- Deterministic Safety Analysis [1-8].
- Waste Management, Volume III: Assessing the Long Term Safety of Radioactive Waste Management [1-12].
- Waste Management, Framework for Radioactive Waste Management and Decommissioning in Canada [1-13].

1.6 International Atomic Energy Agency Guidance Documentation

The key IAEA documentation used as guidance during the preparation of the safety analysis includes:

- Disposal of Radioactive Waste [1-14].
- The Safety Case and Safety Assessment for the Disposal of Radioactive Waste [1-15].
- Near Surface Disposal Facilities for Radioactive Waste [1-16].
- Monitoring and Surveillance of Radioactive Waste Disposal Facilities [1-17].

1.7 Facility Owner

The NSDF is owned by Atomic Energy of Canada Limited (AECL) (Government of Canada) and operated by CNL. The overall responsibility for safe operations lies with the NSDF Facility Authority (FA).

1.8 Facility Classification

The NSDF is classified as a Class 1B Facility, and the Class I Nuclear Facilities Regulations [1-3] and other relevant Regulations issued under the Nuclear Safety Control Act [1-11] apply.

1.9 Hazard Category

The NSDF is classified as Hazard Category 2 on the ascending scale of 1 to 4 in use by CNL [1-18]. This classification implies that the potential for significant consequences is limited to within the facility boundary of the disposal facility [1-18].

In this context, "significant consequence" is defined as a serious human injury or significant adverse impact to the environment, or a situation where a regulatory limit that defines health, safety or environmental performance is exceeded [1-19].

1.10 Report Structure

The structure of the report is:

- Section 1 provides an introduction and overview to the report.
- Section 2 provides the description of the site characteristics.
- Section 3 provides the description of the safety functions, safety principles including the acceptance criteria for safe operation and accident events.
- Section 4 provides the design and operational requirements for the Facility, and includes the description of the Health, Safety, Security, Environment and Quality (HSSE&Q) Programs.
- Section 5 provides the detailed description of the NSDF Facilities including Structures, Systems and Components (SSCs).
- Section 6 provides the Facility design basis including states of the Facility.
- Section 7 provides a description of the safety features including designed safety features, engineered safety features and SSCs important to safety that play a major role in reducing Operating Staff exposure to radiation.
- Section 8 describes the building services Instrumentation and Control (I&C) within the NSDF Facilities.
- Section 9 describes the NSDF processes and the monitoring for the Facility.
- Section 10 describes the NSDF Operations and Maintenance (O&M), including conduct of operations, administrative structure, training, work control, and maintenance that ensure safe operation of the Facility.
- Section 11 describes the RP Program and the predicted Facility radiological safety zones to ensure the safety of the Operating Staff and on-site personnel.
- Section 12 describes the commissioning of the Facility.
- Section 13 provides a description of the OPEX for relevant near surface disposal and long-term waste management facilities. The objective of this section is to demonstrate that the Facility can be operated safely during the proposed operating period.
- Section 14 provides the safety analysis. This section describes the safety analysis process and the basis for the selection of the initiating events and scenarios and accidents. Resulting doses to the NSDF Staff, on-site receptors and off-site receptors from normal operations and accident conditions are calculated, and then the calculated doses are shown to meet the acceptance criteria established in Section 3.
- Section 15 provides the OLCs for safe operation.
- Section 16 describes the decommissioning strategy.
- Section 17 describes the safety analysis conclusion to support the safety of the NSDF.

- Appendices provide detailed information on technical calculations completed for the safety analysis.

1.11 Abbreviations

AECL	Atomic Energy of Canada Limited
AMAD	Activity Median Aerodynamic Diameter
ALARA	As Low As Reasonably Achievable
AOO	Anticipated Operational Occurrence
ARF	Airborne Release Fraction
ATS	Automatic Transfer Switch
BAS	Building Automation System
BDBA	Beyond Design Basis Accident
CA	Controlled Area
CAM	Continuous Air Monitor
CCL	Compacted Clay Liner
CIP	Clean-in-Place
CNL	Canadian Nuclear Laboratories
CNSC	Canadian Nuclear Safety Commission
COPC	Contaminants of Potential Concern
CRL	Chalk River Laboratories
CSA	Canadian Standards Association
CSCS	Components for Safety Classified Systems
CSD	Criticality Safety Document
CWPS	Contact Water Pump Station
D&WM	Decommissioning and Waste Management
DBA	Design Basis Accident

DBE	Design Basis Earthquake
DBT	Design Basis Tornado
DCF	Dose Conversion Factor
DCP	Dose Control Point
DEC	Design Extension Condition
DOE	Department of Energy
DRL	Derived Release Limit
ECC	Engineering Change Control
ECM	Engineered Containment Mound
EF	Enhanced Fijita
EIS	Environmental Impact Statement
EMR	East Mattawa Road
EmP	Emergency Preparedness
EnvP	Environmental Protection
EPP	Environmental Protection Plan
ERM	Environmental Remediation Management
FA	Facility Authority
FACP	Fire Alarm Control Panel
FHA	Fire Hazard Analysis
FME	Foreign Material Exclusion
FMEA	Failure Modes Effects and Analysis
FMECA	Failure Mode Effects and Criticality Analysis
FWPS	Fire Water Pump Station
HDPE	High-Density Polyethylene

HEPA	High Efficiency Particulate Air
HSSE&Q	Health, Safety, Security, Environment and Quality
HVAC	Heating, Ventilation, and Air Conditioning
GAC	Granular Activated Carbon
GCL	Geosynthetic Clay Liner
I&C	Instrumentation and Control
IAEA	International Atomic Energy Agency
ICP	Institutional Control Period
ICRP	International Commission on Radiological Protection
IEEE	Institute of Electrical and Electronics Engineers
ISO	International Organization for Standardization
IX	Ion Exchange
LCH	Licence Conditions Handbook
LCS	Leachate Collection System
LDA	Liquid Dispersal Area
LDS	Leak Detection System
LFG	Landfill Gas
LPF	Leak path Factor
LLD	Lessons Learned
LLPDE	Linear Low-Density Polyethylene
LLRW	Low-Level Radioactive Waste
LLRWMO	Low-Level Radioactive Waste Management Office
LLW	Low-Level Waste
MAR	Material at Risk

mASL	metres Above Sea Level
MCP	Management Control Procedure
MCTOW	Maximum Certified Take-Off Weight
mbgs	metres below ground surface
MSA	Mechanical Service Attendant
NBCC	National Building Code of Canada
NEW	Nuclear Energy Worker
NFCC	National Fire Code of Canada
NFPA	National Fire Protection Association
NRU	National Research Universal
NSCA	Nuclear Safety and Control Act
NSDF	Near Surface Disposal Facility
NV	No Value
O&M	Operations and Maintenance
OLC	Operational Limits and Conditions
OPEX	Operating Experience
OPSS	Ontario Provincial Standard Specification
OSC	Operations Support Centre
OSH	Occupational Safety and Health
OWS	Operator Work Station
PCB	Polychlorinated Biphenyl
PDP	Preliminary Decommissioning Plan
PGWMF	Port Granby Waste Management Facility
PIE	Postulated Initiating Event

PLC	Programmable Logic Controller
PM	Particulate Matter
PPE&C	Personal Protective Equipment and Clothing
PSHA	Probabilistic Seismic Hazard Assessment
PVC	Polyvinyl Chloride
PWPS	Potable Water Pump Station
QA	Quality Assurance
RF	Respirable Fraction
RP	Radiation Protection
SAR	Safety Analysis Report
SAC	Strong Acid Cation
SARA	Species at Risk Act
SCADA	Supervisory Control and Data Acquisition
SFM	Special Fissionable Material
SPD	Standard Proctor Density
SPM	Suspended Particulate Matter
SS	Stainless Steel
SSCs	Structures, Systems and Components
SWMP	Surface Water Management Pond
TDG	Transportation of Dangerous Goods
TSS	Total Suspended Solids
TSWRPA	Temporary Storage Waste Receiving and Processing Area
UPS	Uninterruptable Power Supply
VC	Valued Components

VDF	Vehicle Decontamination Facility
VOC	Volatile Organic Compounds
WAC	Waste Acceptance Criteria
WMAs	Waste Management Areas
WP	Work Permit
WS	Wingspan
WTC	Waste Treatment Center
WWTP	Waste Water Treatment Plant

1.12 Definitions

The following definitions used throughout this report, are primarily from the Glossary of CNSC Terminology [1-20] and the IAEA Safety Glossary [1-21].

Accident	Any unintended event, including worker errors, equipment failures or other mishaps, the consequences or potential consequences of which are significant from the point of view of protection or safety. With respect to Nuclear Criticality Safety, the term **accident or accident sequences** means events or event sequences, including external events, that lead to violation of the sub criticality margin (that is, to exceeding the upper subcritical limit) [1-20].
Accident Conditions	Deviations from normal operation more severe than AOO. Accident conditions include DBAs and BDBAs [1-20].
Active Component	A component who's functioning depends on an external input such as actuation, mechanical movement or supply of power.
Administrative Controls	Provisions relating to organization and management procedures, record keeping, assessment, and reporting necessary to ensure the safe operation of a Facility.
Anticipated Operational Occurrence	An operational process deviating from normal operation which is expected to occur once or several times during the operating lifetime of the Nuclear Facility but which, in view of the appropriate design provisions, does not cause any significant damage to items important to safety nor lead to accident conditions [1-20]. These include events with frequencies of occurrence greater than or equal to 10^{-2} events per year.

As Low as Reasonably Achievable (ALARA)	A principle of RP that holds that exposures to radiation are kept ALARA, social and economic factors taken into account [1-20].
Barrier	A physical obstruction that prevents or inhibits the movement of people, radionuclides or some other phenomenon (e.g. fire), or provides shielding against radiation [1-21].
Beyond Design Basis Accident (BDBA)	Accidents falling outside the design envelope of a Nuclear Facility's safety systems (accident conditions more severe than those of a DBA) [1-20]. These include events with frequencies of occurrence less than 10^{-5} per year.
Bulk waste	Waste that is a large mass, in large quantities and is not containerized nor contained within a package for final disposal.
Contact Water	Water that has come in contact with waste and is considered contaminated.
Containment	A method or physical structure, designed to prevent or control the release of nuclear or hazardous substances [1-20].
Contamination	Radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places [1-21].
Controlled Area (CA)	Chalk River Laboratories site area within which normal working conditions, including unplanned events, require all personnel to follow well-established RP procedures and practices.
Critical Group	A uniform or reasonably homogeneous group of people whose characteristics (such as habits, location or age), cause them to be representative of the more highly exposed individuals, receiving the highest effective dose or equivalent dose (as applicable) than other groups in the exposed population [1-20].
Daily Cover	Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face, to control the release of fugitive dust from the surface of the waste. The daily cover consists of 0.15 m layer of clean soil or an alternative daily cover material that is pre-approved for use including tarpaulin, fixative (crusting agent), or similar temporary cover system material.
Decontamination	The complete or partial removal of contamination by a deliberate physical, chemical or biological process [1-21].

Defence-in-depth	A hierarchical deployment of different levels of diverse equipment and procedures to prevent the escalation of AOOs and to maintain the effectiveness of physical barriers placed between a radiation source or radioactive material and workers, members of the public or the environment, in operational states and, for some barriers, in accident conditions [1-20].
Design Basis	The range of conditions and events taken explicitly into account in the design of a Nuclear Facility, according to established criteria, such that the Facility can withstand this range without exceeding authorized limits. Note**:** Design extension conditions are not part of the design basis [1-20].
Design Basis Accident	Accident conditions against which the Nuclear Facility is designed according to established design criteria, and for which the damage to the fuel and/or the release of radioactive material are kept within authorized limits [1-20]. These include all events with frequencies of occurrence equal to or greater than 10^{-5} per year, but less than 10^{-2} per Facility year. This class of events also includes any events that are used as a design basis for a safety system, regardless of whether the estimated frequencies are less than 10^{-5} per year.
Design Extension Conditions	A subset of BDBAs that are considered in the design process of the Facility in accordance with best-estimate methodology to keep releases of radioactive material within acceptable limits [1-20]. Design Extension Conditions could include severe accident conditions [1-20].
Design Life	The period of time during which a Facility or component is expected to perform according to the technical specifications to which it was produced [1-21].
End-state	With respect to decommissioning, the proposed physical, chemical and radiological condition of a Facility at the end of the decommissioning program. Note: Where a decommissioning program is to take place in discrete phases, the interim end-state objectives for each phase should be defined [1-20].
Environment	The component of the earth including [1-20]: a) Land, water, and air, including all layers of the atmosphere. b) All organic and in-organic matter and living organisms. c) The interactive natural system that includes components referred to in (a) and (b).

Event	Any unintended occurrence, including operating error, equipment failure or other mishap, or deliberate actions on part of others, the consequences or potential consequences of which are not negligible from the point of view of protection or safety [1-20].
Hazardous substance	A substance, other than a nuclear substance, that is used or produced in the course of carrying on a licensed activity and that may pose a risk to the environment or the health and safety of persons [1-20].
Infrequently performed operations	Any work, experimental, or testing activities seldom performed (e.g. less often than once per year), with high potential risk to the public, site, environment or Facility, and involving SSCs required in service or which may be required in case of emergency [1-22].
Interim Cover	The interim cover consists of 0.3 m layer of clean soil or clean sand that is overlain by a sacrificial liner to promote non-contact surface water run-off, and minimize precipitation infiltration into the waste material. The interim cover is applied to: 1) waste disposal areas that will remain inactive for more than 30 days; and 2) waste disposal areas that have reached the design waste fill grade.
Leachate	Water that has percolated through the disposed LLW within the ECM and leached out some of the constituents.
Licensed Inventory	The maximum radioactivity of significant radionuclides that the NSDF will accept. Note: Significant radionuclides are the radionuclides that were identified in the NSDF Reference Inventory [1-23].
Limiting Conditions of Operation	A set of rules that establish key constraints on equipment or operations, for normal, safe operation of the Facility, activity, equipment or project. They include limits on operating parameters, requirements relating to minimum operable equipment and minimum staffing and prescribed actions to be taken by Operations personnel [1-24].
Low-Level Waste	Radioactive solid waste that contains material with radionuclide content above established clearance levels and exemption quantities, but that generally has limited amounts of long-lived activity [1-20].
Multiple barriers	Two or more natural or engineered barriers used to isolate radioactive waste in, and to prevent or to inhibit migration of radionuclides from, a repository [1-21].

Multiple safety functions	In the context of the fulfilment of multiple safety functions by a disposal system, the containment and isolation of waste (the confinement function), is fulfilled by two or more natural or engineered barriers of the disposal Facility, by means of diverse physical and chemical properties or processes, together with operational controls [1-21].
Near Surface Disposal Facility	An engineered facility where waste is emplaced for disposal [1-21]. A Facility for radioactive waste disposal located at or within a few tens of metres of the Earth's surface [1-21].
Non-Contact Water	Water that has not been in contact with waste materials.
Normal Operation	The operation of a nuclear facility within specified operational limits and conditions [1-20].
Nuclear substance	Means [1-20]: a) deuterium, thorium, uranium or an element with an atomic number greater than 92; b) a derivative or compound of deuterium, thorium, uranium or of an element with an atomic number greater than 92; c) a radioactive nuclide; d) a substance that is prescribed as being capable of releasing nuclear energy or as being required for the production or use of nuclear energy; e) a radioactive by-product of the development, production or use of nuclear energy; and f) a radioactive substance or radioactive thing that was used for the development or production, or in connection with the use, of nuclear energy.
Operational limits and conditions	A set of rules setting forth parameter limits or conditions that ensures the functional capability and the performance level of equipment for safe operation of a nuclear facility. This set of limits is monitored by or on behalf of the operator and can be controlled by the operator [1-20].
Operational Wastewater	Wastewater generated during the course of facility operations including decontamination wastewater, laboratory wastewater, and wastewater generated during WWTP operations including recycle flow.
Packaged Waste	Waste contained in rigid containers or packages for disposal.

Passive component	A component that functions without depending on an external input such as actuation, mechanical movement or supply of power [1-20].
Passive safety	A design feature that functions without depending on an external input such as actuation, mechanical movement or supply of power.
Performance testing	Testing done to determine whether a system meets specified acceptance criteria [1-20].
Receptor	Any person or environmental entity that is exposed to radiation, or a hazardous substance, or both. A receptor is usually an organism or a population, but it could also be an abiotic entity such as surface water or sediment [1-20].
Reference Inventory	The radiological inventory of significant radionuclides [1-23] that was used to inform the design and safety analyses.
Sacrificial liner	The sacrificial liner is a Linear Low-Density Polyethylene (LLDPE) geomembrane that promotes non-contact surface water run-off and minimizes precipitation infiltration.
Structures, Systems and Components	A general term encompassing all of the elements of a Facility or activity that contribute to protection and safety. Structures are the passive elements: buildings, vessels, shielding, etc. A system comprises several components, assembled in such a way as to perform a specific (active) function. A component is a discrete element of a system. Some examples are wires, transistors, integrated circuits, motors, relays, solenoids, pipes, fittings, pumps, tanks, and valves [1-20].
Wastewater	The product of the three waste streams; leachate, contact water and operational wastewater.

1.13 References

[1-1] *Nuclear Research and Test Establishment Operating Licence*, Chalk River Laboratories, Licence Number NRTEOL-01.00/2028, Expiry Date: 2028 March 31.

[1-2] *Licence Conditions Handbook*, NRTEOL-LCH-01.00/2028, CRL-508760-HBK-002, Revision 1, Effective 2019 February 25.

[1-3] *Class I Nuclear Facilities Regulations*, SOR/2000-204.

[1-4] *Nuclear Substances and Radiation Devices Regulations*, SOR/2000-207.

[1-5] Ontario Environmental Protection Act, *General – Waste Management*, R.R.O. 1990, Regulation 347.

[1-6] *Facility Authorization for the Operation of the Near Surface Disposal Facility at the Chalk River Laboratories*, 232-00583-FA-001, Revision 3, 2020 October.

[1-7] *Facility Authorization for the Operation of the Waste Management Areas at the Chalk River Laboratories*, WMA-00583-FA-001, Revision 15, 2018 November.

[1-8] CNSC, *Deterministic Safety Analysis,* REGDOC-2.4.1, 2014 May.

[1-9] *Safety Report Issues List and Analysis of Record*, CW-503210-PRO-569, Revision 0, 2010 September.

[1-10] Arcadis, *Post-Closure Safety Assessment 3rd Iterations to the NSDF Project,* 232-509240-ASD-004, Revision 1, 2020 October.

[1-11] *Nuclear Safety Control Act*, c. 9, 1997.

[1-12] CNSC, Waste Management, Volume III: *Assessing the Long Term Safety of Radioactive Waste Management*, REGDOC-2.11.1, 2018 May.

[1-13] CNSC, *Waste Management, Framework for Radioactive Waste Management and Decommissioning in Canada*, REGDOC-2.11, 2018 December.

[1-14] IAEA, Disposal of Radioactive Waste, SSR-5, 2011.

[1-15] IAEA, *Safety Case and Safety Assessment for Radioactive Waste,* SSG-23, 2012.

[1-16] IAEA, *Near Surface Disposal Facilities for Radioactive Waste*, SSG-29, 2014.

[1-17] IAEA, *Monitoring and Surveillance of Radioactive Waste Disposal Facilities*, SSG-31, 2014.

[1-18] Memo, R. Kingsbury to U. Senaratne, *Notification of Near Surface Disposal Facility Hazard Category Change*, 232-508770-021-000, 2020 March 24.

[1-19] *Independent Technical and Readiness Review*, 900-514300-MCP-002, Revision 0, 2017 April.

[1-20] CNSC, *Glossary of CNSC Terminology*, REGDOC-3.6, 2018 August.

[1-21] IAEA, *IAEA Safety Glossary – Terminology Used in Nuclear Safety and Radiation Protection*, 2018 Edition, STI/PUB/1830, 2019 June.

[1-22] *Infrequently Performed Operations*, 900-508200-MCP-008, Revision 1, 2019 November.

[1-23] *Near Surface Disposal Facility Reference Inventory Report*, 232-508600-REPT-003, Revision 3, 2020 April.

[1-24] *Preparation of Operational Limits and Conditions*, 900-508770-FID-003, Revision 0, 2018 October.

2. SITE CHARACTERISTICS

The CRL site is operated by CNL and is located in Renfrew County, on the southern shore of the Ottawa River approximately 185 km northwest of Ottawa. The site is located within the boundaries of the Corporation of the Town of Deep River. The Ottawa River forms the northeastern boundary of the CRL site. The area around the site consists of gently rolling hills and many small lakes. The location of the CRL site is displayed in Figure 2-1.

The CRL site has an area of approximately 4 000 hectares and extends approximately 6.5 km inland from the Ottawa River. Chalk River Laboratories is designated into three radiological areas [2-1]. The Plant Road and parking lots are designated Uncontrolled Areas, the “built-up” area and WMAs are designated Controlled Areas (CAs) and the remaining areas (the “bush” areas) are designated Supervised Areas [2-1].

The NSDF site is approximately 37 hectares located within the Perch Lake Basin, approximately 1 km southwest of the CRL built-up area and south of Plant Road. The approximate geographic coordinates of the NSDF Project are 46 02’ 33” N, 77 22’ 13” W. A fence surrounds NSDF and access is via a secondary road, East Mattawa Road (EMR), off the Plant Road. The NSDF site is located east of WMA A, north of Perch Lake and is in close proximity to the Perch Lake Wetlands [2-2].

The Engineered Containment Mound (ECM) elevation ranges from approximately 163 meters above sea level (mASL) to 202 mASL, which correspond to the lowest elevation of the base liner system and highest elevation of the final cover system, respectively. The location of the NSDF within CRL is displayed in Figure 2-2.

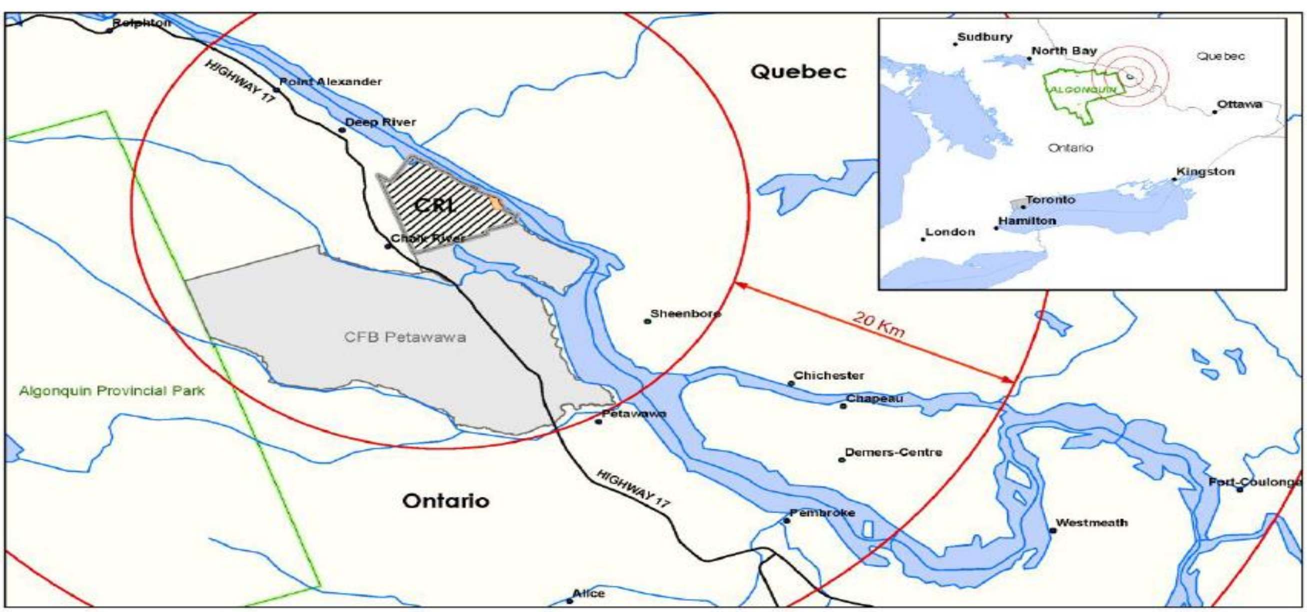

Figure 2-1 Location of Chalk River Laboratories

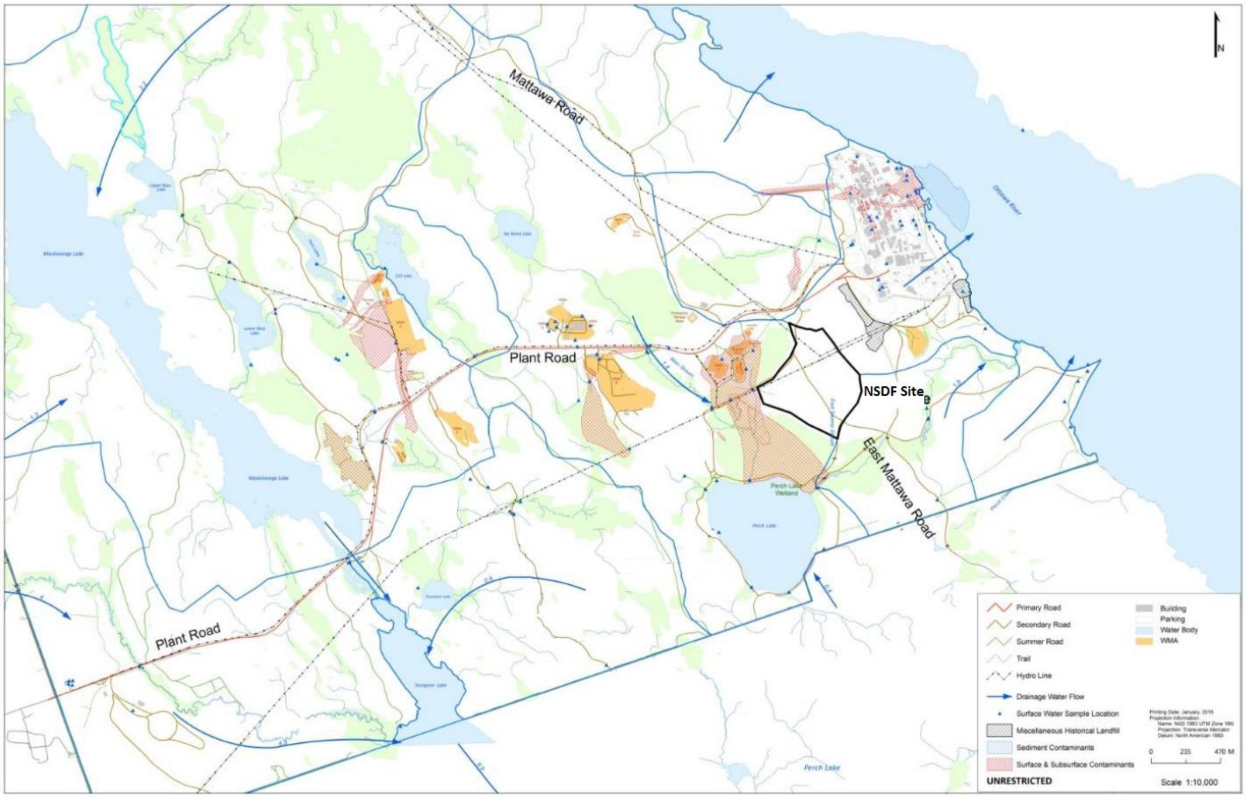

Figure 2-2 Location of Near Surface Disposal Facility Site within Chalk River Laboratories Site

2.1 Population Relevant to the Analysis

The location of population centres near the CRL site are shown in Figure 2-1.

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

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

The Village of Chalk River has approximately 1 200 residents and is approximately 7 km to the west of the CRL main campus. Deep River, with approximately 4 100 residents, is about 9 km to the northwest of the CRL main campus. Surrounding these communities are the Townships of Rolphton, Buchanan, Wylie, and McKay, which, with Chalk River, form the Municipality of Laurentian Hills. The total population of Laurentian Hills is approximately 2 800 residents. The Town of Petawawa, comprised of the former village of Petawawa, the amalgamated surrounding Petawawa townships and the military Garrison, is 20 km downstream from CRL and has a total combined population of approximately 17 200 residents. The other main population centre is the City of Pembroke with about 15 940 residents, is 34 km southeast of the CRL site. Laurentian Valley Township surrounding Pembroke, has a population of approximately 10 000 residents. North Bay is approximately 140 km west up river, and Ottawa is approximately 185 km down river.

The portion of Pontiac Regional County Municipality in the Province of Quebec, north and east of the river and opposite the site, is normally uninhabited, except during the summer months when seasonal cottage dwellers may be present. The closest permanent residents in the Pontiac Regional County Municipality are approximately 3 km southeast of the CRL site, in the Harrington Bay area. The closest centres of population on the Quebec side are Fort William and Municipality of Sheenboro, about 16 km down river, with combined populations of about 150 residents.

In 2011, the population density within 20 km and 40 km radii of the site was approximately 18.30 and 7.60 persons/km^2, respectively (the population of the region reflects permanent residents only).

2.2 Nearby Industrial, Transportation and Military Facilities

In the region surrounding CRL, land use primarily consists of forestry, recreation and tourism, with limited agriculture, trapping and mining.

Based on the information from the Ontario Mining Association [2-3], the closest active mining operations are Tatlock Quarry (calcium carbonate) located in Clayton, Ontario (~165 km from CRL) and base metal mines in Sudbury, Ontario (~310 km from CRL). There are abandoned mines within Renfrew County in the Dorset district, which were primarily quarries for granite, gneiss and feldspar [2-4].

Military facilities are located near the CRL site, including Garrison Petawawa, located 20 km downstream, and a military airport, located 12 km south of CRL. Garrison Petawawa features approximately 465 buildings over a 300 km^2 area.

The major transportation corridor is the Trans-Canada Highway (Ontario Highway 17), runs northwest of the CRL site, and carries approximately 7 050 cars per day [2-5]. The local road network consists of paved and gravel roads originating at the highway. There are two high-level airways, approximately 5 500 m and higher, that include air space over CRL. These airways are Montreal and North Bay, designated J596, and Killaloe and Shibougamau designated J597, which average 14, and one to three movements per day, respectively [2-5]. The frequency of flights for these two airways is estimated to be approximately 5 400 per year [2-5]. The widths of J596 and J597 airways over CRL are calculated to be 27 km and 9 km, respectively [2-5].

The frequency of aircraft movements associated with operations at the neighbouring Garrison Petawawa is considered sensitive information and therefore, is not available [2-5]. Military flights do not necessarily follow the airways described above [2-5]. A conservative estimate is three per day, for an annual total of 1 000 [2-5]. This frequency is judged to be sufficiently conservative to include any additional contribution from light aircraft flying along the course of the Ottawa River [2-5].

2.3 Adjacent Facilities

The NSDF site is adjacent to WMA A and the Liquid Dispersal Area (LDA). The LDA and the WMA A are west of the NSDF site. Waste Management Area A is a 1.2 hectare area located within the Perch Lake Basin, south of the Plant Road approximately 1.2 km west of the built-up area. The LDA is located south of Plant Road, east of and adjacent to WMA A and includes Reactor Waste Dispersal Pit 1, Reactor Waste Dispersal Pit 2 (plus two overflow pits), Chemical Waste Dispersal Pit (plus one overflow pit), and Laundry Pit. The Inactive Landfill is located east of the NSDF site.

2.4 Meteorology of the Site and Region

The meteorology of the site and region includes wind and climate.

2.4.1 Wind Speed and Direction

An on-site CRL meteorological station records wind speed and direction at ground level (1.5 m), 30 m and 60 m. Figure 2-3 shows the annual and seasonal wind rose diagram, measured at ground level at the on-site meteorological station. Winds are predominantly from the northwest and southeast.

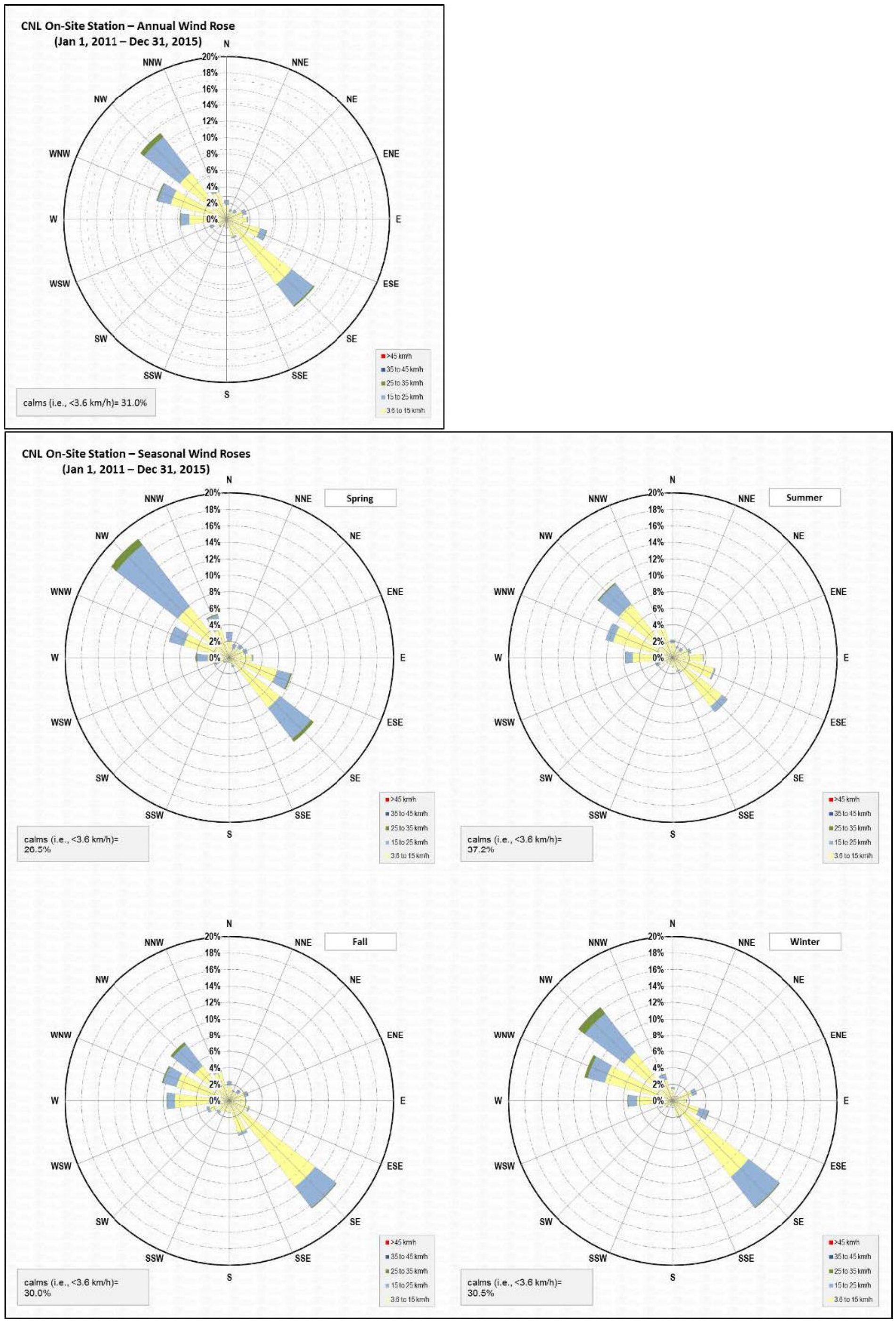

Figure 2-3 Annual and Seasonal Wind Roses for the CNL On-Site Data (2011 January to 2015 December)

2.4.1.1 Tornado and Extreme Wind

The CRL Site Characteristics Report has included a Tornado Analysis and identification of a Design Basis Tornado (DBT) [2-5]. The DBT for the CRL site is an upper Enhanced Fijita 2 (EF2) tornado with maximum wind speed of 220 km/h, based on the Canadian definition of an EF2 tornado [2-5]. The DBT for the CRL site was reviewed in 2018 after a series of tornadoes occurred in the Ottawa Valley, and the current choice of an upper EF2 tornado for the CRL site DBT remains an appropriate selection [2-6].

Based on a map of confirmed tornados produced by Environment Canada, see Figure 2-4, CRL is considered to be within the Eastern Canadian portion of the tornado prone zone. The DBT for the CRL has been selected based on a return frequency of 1 in 100 000 years (10^{-5}/year).

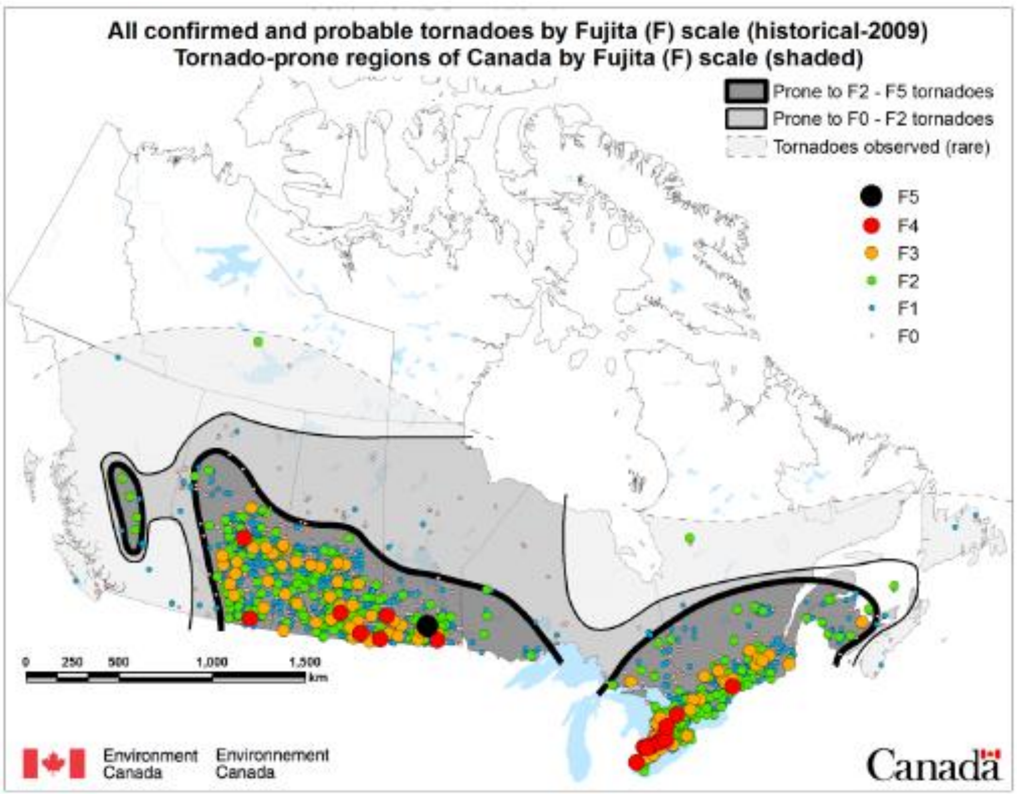

Figure 2-4 Annual Environment Canada Map of Tornado Zones in Canada

2.4.2 Climate

The climate at the CRL site is considered to be humid continental, characterized by warm summers, cold winters and no distinct dry season.

The current climate for the NSDF Project was developed using the available daily meteorological date from the Chalk River AECL climate station, collected for the period of 1981 through to 2006, closely matching the current climate normal of 1981 through to 2010 [2-7].

The Chalk River AECL climate station is located approximately 1 km north of the NSDF Project centroid. For the period 1981 through 2006, less than 1% data is missing from the Chalk River climate station data for the temperature and precipitation with the exception of 1986 [2-7]. Table 2-1 presents the climate normal and trends for the Chalk River AECL climate station, 1981 to 2006 [2-7].

The 30-year (1981 to 2010) climate normal from the Chalk River AECL station calculates an average daily temperature of approximately 5.6°C, while the daily average temperature in the winter season is approximately -9.3°C, and the daily average temperature in the summer season is approximately 19.1°C. Annual precipitation of approximately 859 millimetres equivalent (mm[eq]) is calculated for the region, with the highest precipitation typically occurring in the summer at 252 mm[eq].

Table 2-1
Climate Normal and Trends for the Chalk River AECL Climate Station, 1981 to 2006 [2-7]

Climate Indices and Units	Normals	Decadal Trend
Total precipitation (mm)	852.0	+9.6
Spring Total precipitation (mm)	201.1	-12.0
Summer Total precipitation (mm)	251.1	+21.7
Fall Total precipitation (mm)	243.9	+9.9
Winter Total precipitation (mm)	155.9	-0.4
Total snowfall (cm)	181.5	-3.2
Total rainfall (mm)	675.5	+31.1
Number of days with >20 mm rainfall (#)	6.3	+1.3
Number of days with >15 cm snowfall (#)	1.1	+0.0
Average annual temperature (°C)	5.7	+0.4
Average spring temperature (°C)	5.0	+0.0
Average summer temperature (°C)	19.0	+0.4
Average fall temperature (°C)	7.5	+0.7
Average winter temperature (°C)	-9.3	+0.7
Maximum daily temperature (°C)	33.8	+1.3

2.5 Geology

The CRL site is located within the Central Gneiss belt of the Grenville Structural Province of the Canadian Shield. Structurally, the CRL site is located within the Ottawa-Bonnechere Graben or rift valley, which trends from northwest to southeast from Lake Nipissing to the St. Lawrence River, occupying a 60 km-wide by 70 km-long area. The Ottawa River occupies the eastern bounding fault of the rift valley, with the CRL site located on the western edge of the river.

Two main fracture or faulting zones are present at the CRL site: the Mattawa Fault, which lies below the Ottawa River and consists of the northeast boundary of the property, and the Maskinonge Lake lineament in the southwest area of the property. Within the Perch Lake Basin, a moderate probable fracture zone extends approximately east–west through the upper portion of the basin. Bedrock within the Perch Lake Basin and surroundings is primarily composed of quartz monzonitic, monzonitic and monzodioritic gneisses with some occurrence of granitic-granodioritic and leucodioritic gneisses.

Bedrock in the area consists of highly altered gneissic rock (coarse grained metamorphic rock) and felsic igneous rock of late Precambrian-early Paleozoic age. Bedrock at the CRL site has been grouped into three main assemblages as shown on Figure 2-5 [2-8]. The bedrock within the Perch Lake Basin and the NSDF site has been mapped as quartz monzonitic, monzonitic and monzodioritic gneisses of Assemblage B. Assemblage C (composed of granitic, granodioritic and leucodioritic gneisses), has been mapped at the bedrock surface under the eastern portion of the NSDF site, while a mafic dyke has been mapped near the northwest corner of the NSDF site [2-8].

The regional topography of the CRL site is shown on Figure 2-6 and regional surficial geology of the CRL site is shown on Figure 2-7 [2-8]. A widespread, but thin deposit of glacial till, overlies the bedrock in most areas where overburden is present.

For the lower portion of the Perch Lake Basin and the NSDF site, ground surface elevations range from a low of approximately 156 mASL within the low-lying and relatively flat terrain bordering the north side of Perch Lake to a high of 197 mASL along the crest of the ridge to the east of EMR that separates the Perch Lake and Ottawa River drainage basins.

As shown on Figure 2-7, surficial geology within the low-lying areas of the Perch Lake Basin is predominately composed of recent organic soils. Sand and glacial till are present at surface near topographic highs, such as the NSDF site.

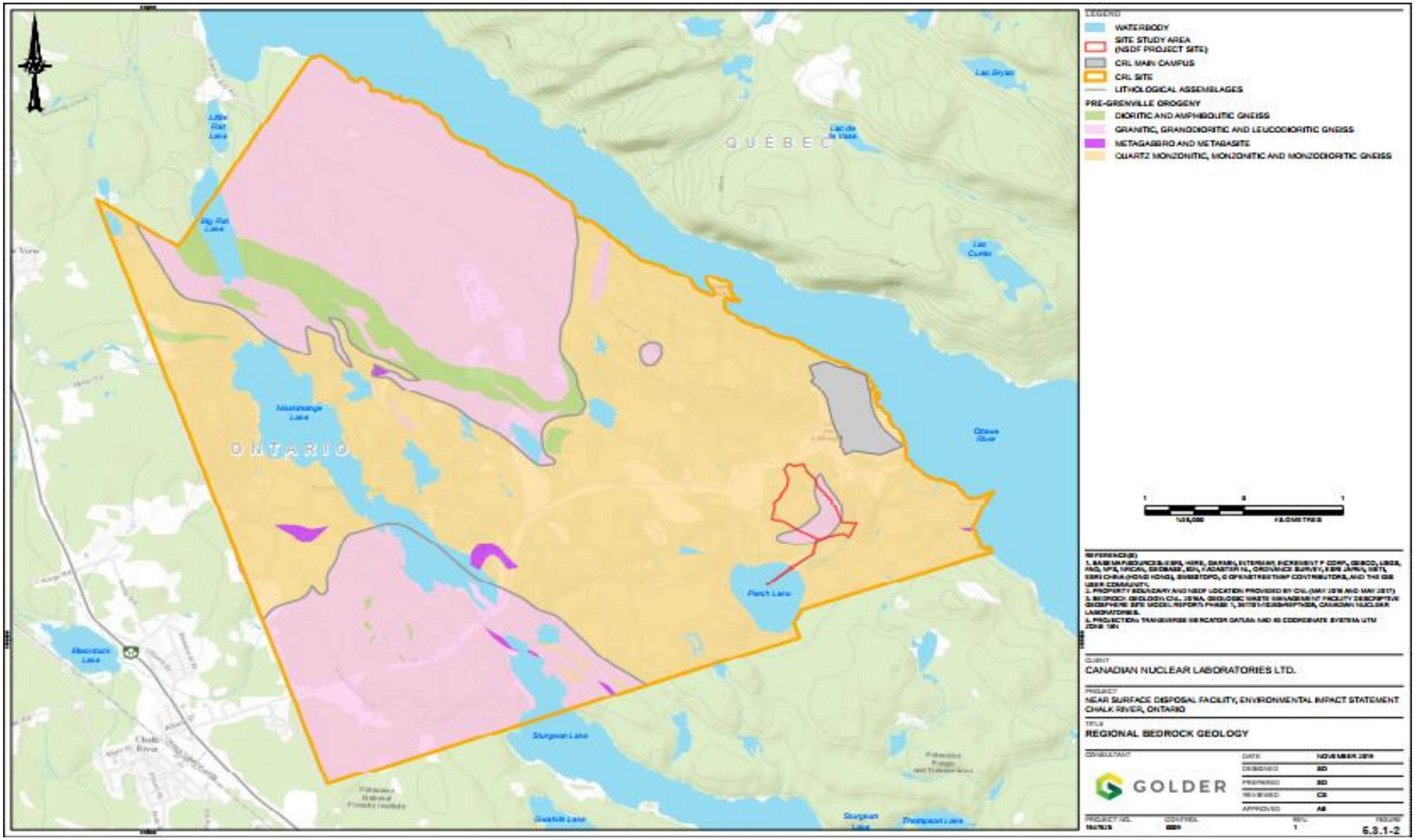

Figure 2-5 Bedrock Geology of Chalk River Laboratories Site [2-8]

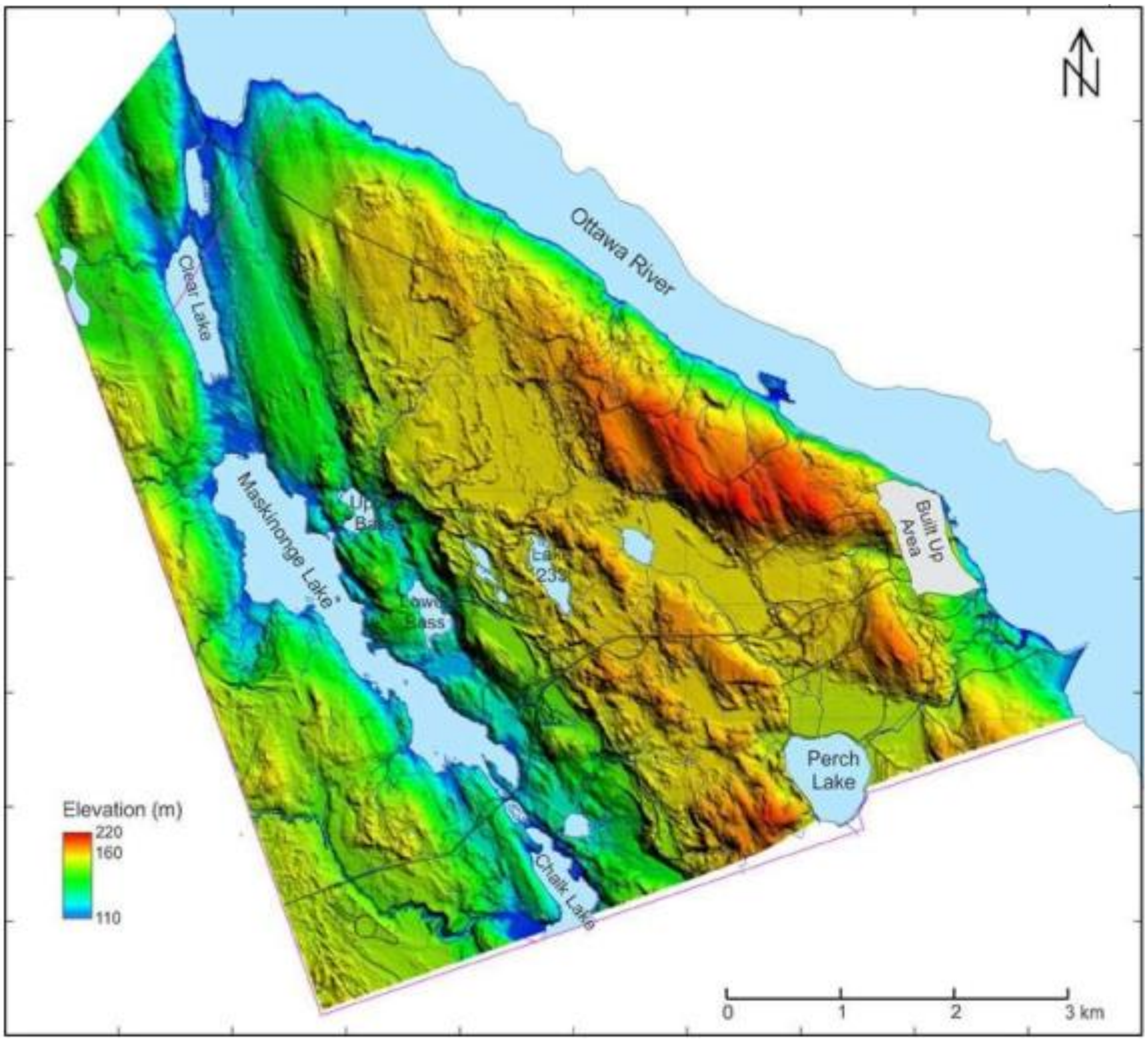

Figure 2-6 Topography of Chalk River Laboratories Site [2-8]

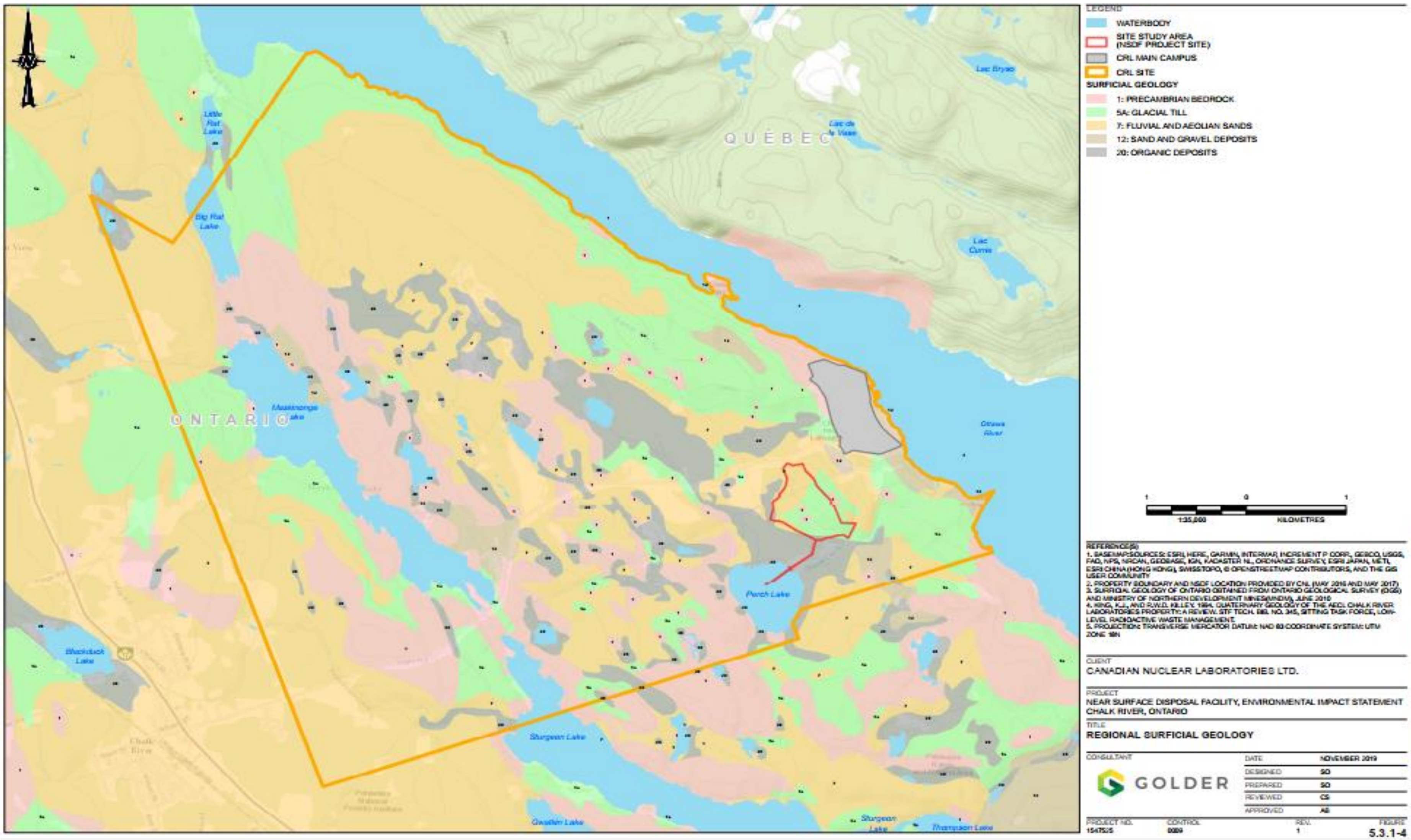

Figure 2-7 Surficial Geology of Chalk River Laboratories Site [2-8]

2.6 Geology of the NSDF Site and Lower Perch Lake Basin

The geology of the NSDF site was characterized through a multidisciplinary site characterization consisting of intrusive and non-intrusive investigation completed under several phases, as summarized in the following reports:

- Subsurface Geotechnical Survey of the Proposed Near Surface Disposal Facility at Chalk River Laboratories [2-9].
- Multidisciplinary Subsurface Investigation Phase 1 [2-10].
- Multidisciplinary Subsurface Investigation Phase 2 [2-11].
- Multidisciplinary Subsurface Investigation Phase 3 [2-12].
- Multidisciplinary Subsurface Investigation for the NSDF Project - Phase 4 [2-13].
- Hydraulic Conductivity (Slug Test) Results for PH17-001 to PH17-010 [2-14].
- Wood Geotechnical Investigation (Ring Road for Effluent to Perch Lake) [2-15].
- Geotechnical Report [2-16].

The Geotechnical Report [2-16] summarizes the subsurface data to support the development of the NSDF detail design, and demonstrates how the existing data is utilized for the NSDF detail design. Bedrock elevation, overburden thickness, and stratigraphy of the NSDF site have been characterized in the multiple phases of subsurface investigation required for developing the NSDF design and numerical models [2-9], [2-10], [2-11], [2-12], [2-13], [2-14], and [2-15]. Site characterization also included determination of relevant material properties of soil (overburden) and rock through laboratory and field testing.

The NSDF multidisciplinary site characterization included non-intrusive and intrusive surveys. The non-intrusive survey included two sets of Ground Penetrating Radar surveys, that were conducted to map the bedrock elevation at the NSDF site with radar profile lengths of 3 400 m for the first set and 10 154 m for the second set of Ground Penetrating Radar surveys. The intrusive survey included 70 boreholes, 25 test pits, 50 groundwater monitoring wells, four geophysics, and field and laboratory tests (e.g. seismic Cone Penetration Tests, hydraulic conductivity). The maximum depth of boreholes at the NSDF site is up to approximately 32.9 metres below the ground surface (mbgs), characterizing the overburden and the shallow depth bedrock.

Topography and local drainage features are shown on Figure 2-8 [2-8]. The NSDF site is located in the central portion of the lower Perch Lake Basin.

Figure 2-9 is a bedrock topography map for the NSDF site that was generated using stratigraphic data [2-8]. The bedrock topography is dominated by the ridge that delineates the eastern boundary of the Perch Lake Basin and the depression or valley that runs from the northwest corner of WMA A, to the southeast towards Perch Creek. The bedrock ridge reaches an elevation of approximately 192 mASL and dips to the northwest and southeast, to an elevation of 165 mASL at Plant Road and 155 mASL at Perch Creek. The bedrock valley is composed of a western portion that slopes irregularly from north to south and a southern portion that slopes irregularly from east to west. These two portions meet just north of where the Main Stream discharges to Perch Lake. Bedrock in that area is at an elevation of 120 mASL. The northwestern portion of the NSDF site is underlain by a spur from the bedrock valley, at an elevation of 151 mASL. The ridge that delineates the western boundary of the Perch Lake Basin is shown reaching an elevation of 175 mASL at the limit of the map on Figure 2-9.

Within the Perch Lake Basin, a moderate probable fracture zone extends approximately east-west through the upper portion of the basin. Bedrock within the Perch Lake Basin and surroundings is primarily composed of quartz monzonitic, monzonitic and monzodioritic gneisses with some occurrence of granitic-granodioritic and leucodioritic gneisses.

Figure 2-10 shows the interpreted overburden thickness at the NSDF site [2-16]. Overburden is the soil or unconsolidated material that overlies the bedrock surface.

The overburden geology at the NSDF site consists primarily of fine sands, underlain locally by glacial till. The sands are interpreted to be the result of Aeolian reworking of precursor fluvial sands and silts laid down in the late Pleistocene/early Holocene period by an early phase of the Ottawa River. Unconsolidated glacial and post-glacial deposits in the Perch Lake Basin have been subdivided into six main units [2-8]:

- Glacial till.
- Basal sand and gravel.
- Clayey silt.
- Middle sand.
- Interstratified silt and sand.
- Upper sand.

Within the area of the NSDF site, unconsolidated deposits are locally thicker in the area to the north and east, reaching more than 26 m thick at the northern terminus of the bedrock ridge. The sedimentary geology in the Perch Lake Basin is illustrated in cross-section on Figure 2-11 [2-8].

<u>Glacial Till</u>

Glacial till covers a large portion of the bedrock surface and is thickest in the areas of the bedrock lows. Glacial till thins to the east towards the bedrock ridge. Where present, glacial till is generally less than 12 m thick but reaches thicknesses of up to 15 m within the bedrock valley and 24 m in the area to the north of the eastern bedrock ridge. Glacial till is locally thicker along a line that extends from the northern edge of the eastern bedrock ridge to the south of the East Swamp, ending approximately 250 m northeast of where the East Stream meets the Main Stream. In this area, the glacial till ranges from 3 to 8 m in thickness. Within the southern portion of the NSDF site (where bedrock is close to ground surface), the till is generally less than 1 m thick. Glacial till within the Perch Lake Basin consists of poorly sorted boulders, cobbles and gravel in a silty sand to sandy silt matrix, with no visible stratification.

Basal Sand and Gravel

A basal sand and gravel unit overlies the glacial till in a limited area of the western portion of the Perch Lake Basin. This unit ranges from 3.5 to 5.5 m in thickness within the bedrock valley to the north of Perch Lake and Perch Creek. The unit has also been found to underlie WMA A and the South Swamp, in thicknesses ranging from 1 to 4 m. This unit is not present in the NSDF site.

Clayey Silt

The clayey silt is generally present in the southwest portion of the Perch Lake Basin, where there are depressions in the surfaces of the till and the bedrock. Where present, the clayey silt is generally less than 2 m thick, but is more than 5 m thick in the bedrock depression approximately 200 m north of Perch Lake. North of the NSDF site, the clayey silt unit ranges in thickness from 0.5 to 1.5 m, being thickest to the east along EMR. Clayey silt in the Perch Lake Basin is fluvial in origin and consists of laminations of coarser and finer fractions. The clay content of this unit, as determined through grain size analysis, is less than 20% by weight.

Middle Sand

As with the other sedimentary units, the middle sand is thickest in the areas of the bedrock depressions. This unit generally fills the bedrock valley and ranges in thickness from 2 m to 9 m in this area. Middle sand is also present in the southern portion of Reactor Pit 2 (up to 4 m in thickness) and on the northern and southern flanks of the eastern bedrock ridge that delineates the Perch Lake Basin (up to 3 m in thickness in the south and 2 m thickness in the north). The middle sand has been classified as moderately well sorted fine sand through the results of grain size analyses.

Interstratified Sand and Silt

Where present, the interstratified sand and silt unit is generally less than 0.4 m thick but can reach thicknesses of up to 2 m locally (i.e. near the point of discharge from Perch Lake to Perch Creek and to the south and west of WMA A). This unit has been encountered in the northern portion of the NSDF site at thicknesses of less than 0.4 m. The interstratified silt and sand consist of alternating layers of fine to very fine sand and sandy silts. Individual layers are on the order of several centimetres.

Upper Sand

The upper sand unit is the uppermost sand unit in the Perch Lake Basin. The base of the upper sand unit is defined by either the top of the interstratified silt and sand unit, or by an inferred contact with the middle sand. The unit is thickest where the bedrock valley abuts the bedrock ridge that delineates the western boundary of the Perch Lake Basin. In this area, the unit can be up to 13 m thick. The upper sand unit is also locally thicker through an area extending from Plant Road, south through Reactor Pit 1 and Reactor Pit 2, then extending west through the southern portion of WMA A. In this area, the unit reaches thicknesses of up to 10 m. The upper sand unit is present in the NSDF site at a relatively uniform thickness of approximately

1 m. There is a localized area to the immediate southwest of the NSDF site where the upper sand thickness increases to approximately 5 m. In comparison to the middle sand, the upper sand is slightly coarser and better sorted.

Surficial Soils

This material was generally a mixture of organic and mineral soil components. A layer of leaf litter and organic silt (topsoil), 50 to 230 mm thick was encountered at the ground surface. No purely organic soils were encountered during the 2016 geotechnical investigations at the NSDF site.

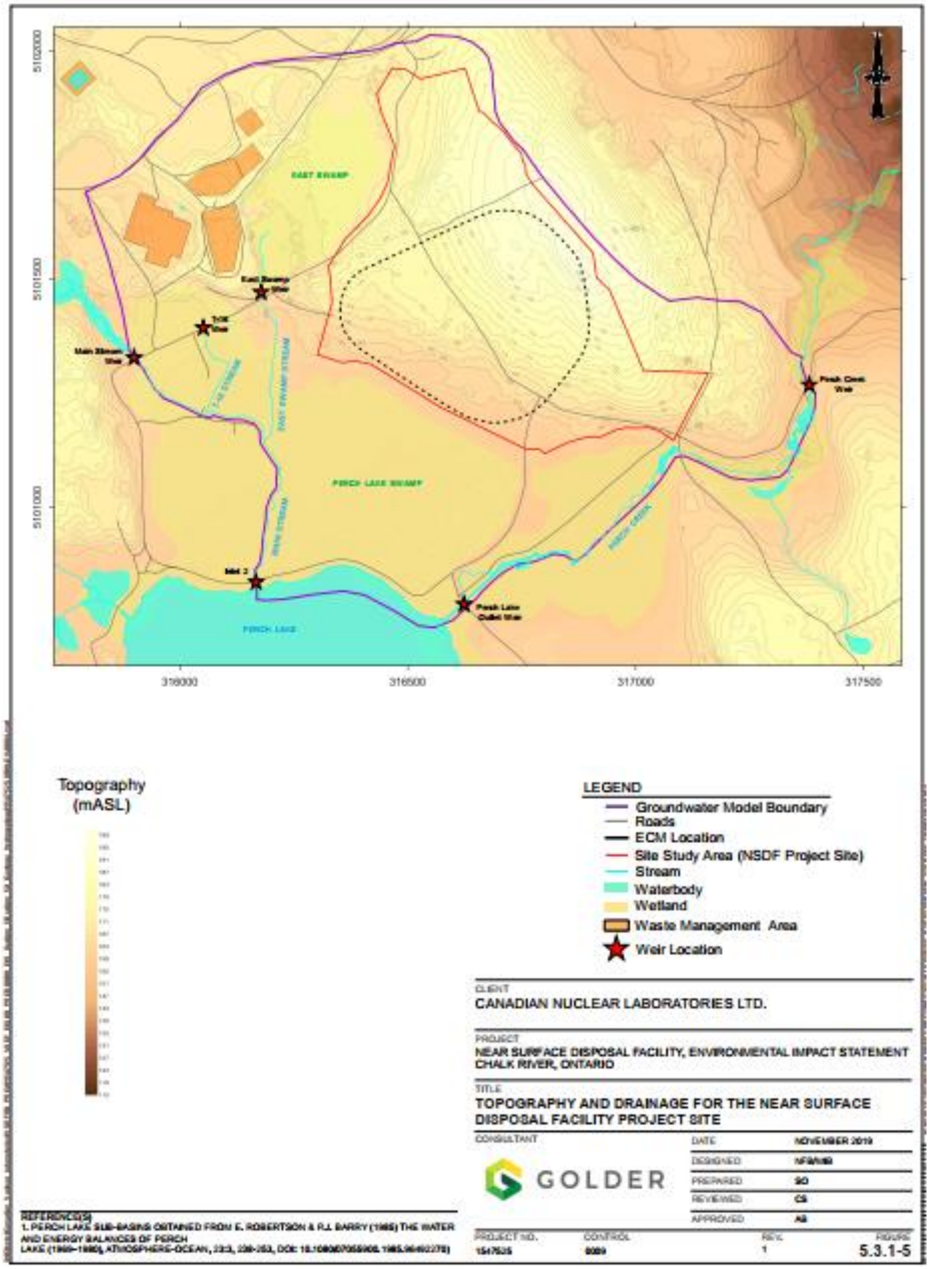

Figure 2-8 Topography and Drainage for the NSDF Site [2-8]

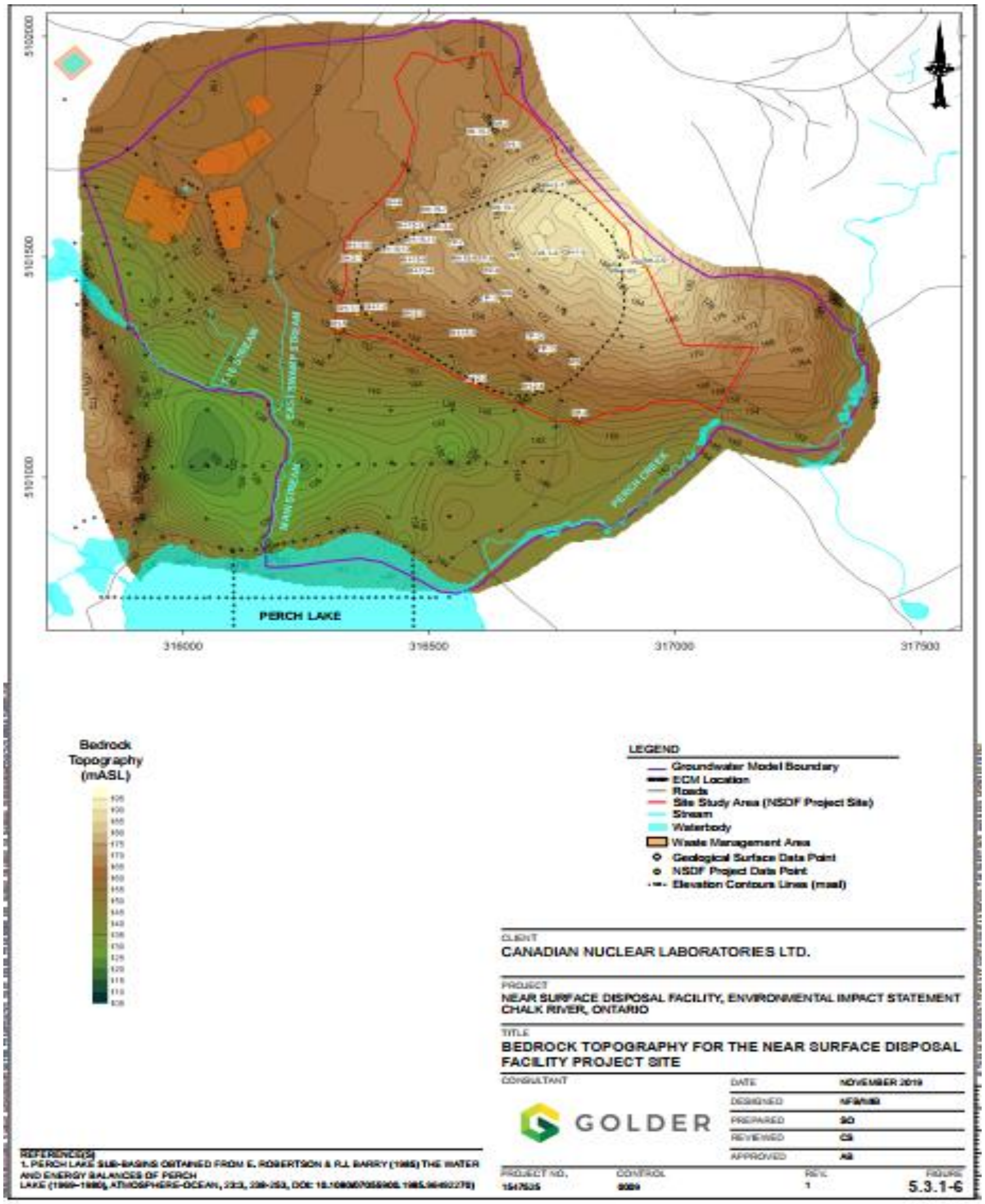

Figure 2-9 Bedrock Topography for the NSDF Site [2-8]

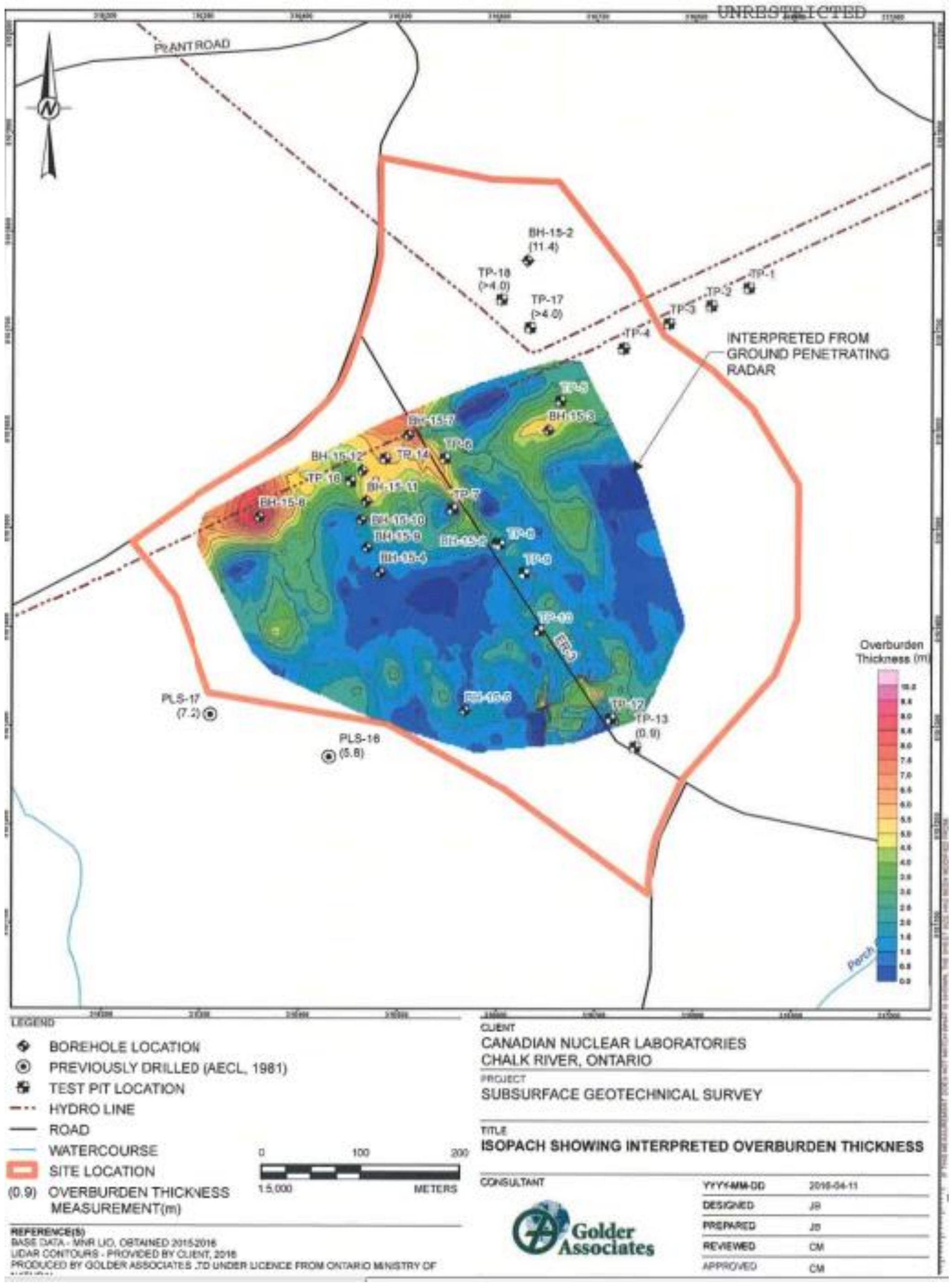

Figure 2-10 Interpreted Overburden Thickness [2-16]

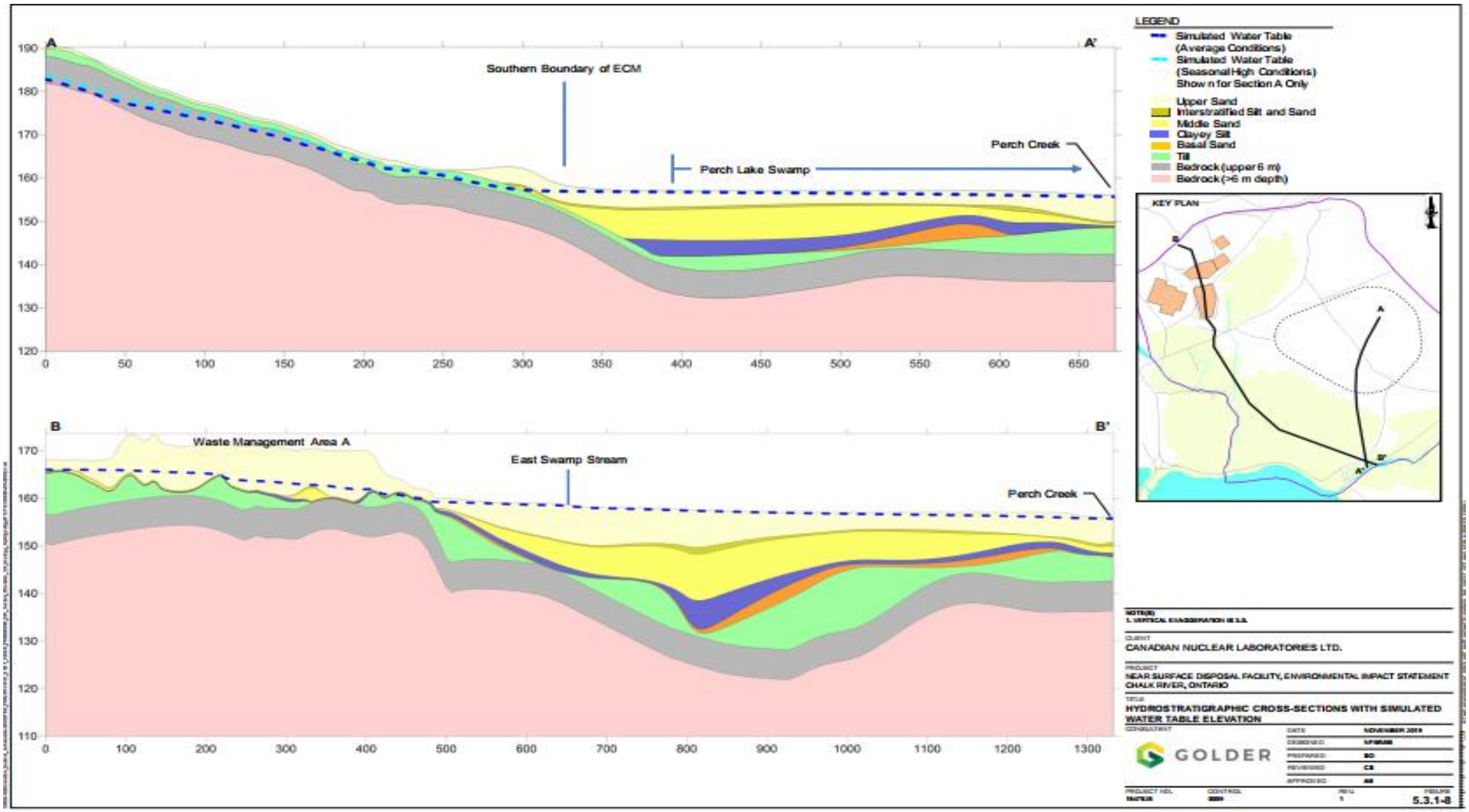

Figure 2-11 Hydrostratigraphic Cross Sections with Simulated Water Table Elevation [2-8]

2.7 Hydrology of the Site and Region

Hydrology of the site and region includes groundwater elevation, flow, quality, and hydraulic conductivity.

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

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

The water level in the Ottawa River along the CRL property boundary, is controlled by a set of rapids at Cotnam Island located approximately 40 km downstream, and by adjustments to the discharge rate at the Des Joachims hydroelectric dam, approximately 30 km upstream of the CRL property boundary on the Ottawa River. The mean monthly Ottawa River water levels measured at Pembroke Monitoring Station (36 km downstream of CRL), have ranged from 110.8 mASL in 2005 August to 113.1 mASL in 1960 May. The average water elevation recorded at this station is 111.5 mASL.

2.7.1 Groundwater Elevation and Flow

Several waterbodies exist within the CRL site, and the on-site waterbodies and drainage basins are shown in Figure 2-12. Within the ECM perimeter, groundwater flow is from the northeast, discharging in Perch Creek, which discharges into the Ottawa River. The majority of the remaining infiltration area on the NSDF site drains west into East Swamp Creek, which discharges into Perch Lake, which feeds Perch Creek. The Perch Lake Basin includes the Perch Creek catchment, and drains 15% of the CRL site.

Modelling has indicated that groundwater released from the WWTP outfall area travels towards the west, ultimately discharging at the East Swamp. Approximately half of the groundwater discharges to the East Swamp immediately downgradient from the WWTP outflow area, whereas the remaining groundwater follows a deeper flow path and discharges at the East Swamp Stream after approximately three years [2-13]. Groundwater at the ECM itself follows a flow path towards the south-southeast, with the majority of groundwater discharging to Perch Creek after a transit time of five to eight years [2-13].

Precipitation at the NSDF site recharges a shallow groundwater system which includes the overburden and upper few metres of fractured bedrock. Ground surface elevations at the NSDF site range from a low of 156 mASL near the north side of Perch Lake, to a high of 197 mASL at the crest of the ridge that separates Perch Lake and Ottawa River drainage basins [2-13]. Groundwater at the site generally flows in the southwesterly direction, with flows becoming parallel to the Perch Lake surface drainage in the low saturated lands west of the site. Soil samples analyzed by the geotechnical survey are estimated to have hydraulic conductivity generally ranging from 10^{-5} to 10^{-6} m/s [2-9].

Figure 2-13 shows the average groundwater table elevations [2-8]. In general, groundwater flow is dominated by surface and bedrock topography, the lower elevations with thicker overburden deposits and the higher elevations with thinner overburden deposits [2-16]. Within the thicker overburden deposit, groundwater occurs within the overburden, and to an extent, within the bedrock as one approaches higher elevations [2-16]. At higher elevations where thinner overburden depth was observed, groundwater occurs within the bedrock [2-16]. In general:

- Groundwater flow is controlled by topography and properties of overburden and bedrock.
- At the NSDF site toward the top of the ridge, the overburden is thin and water table is located in bedrock.
- Towards the East Swamp and Perch Lake wetlands, the overburden layer is much thicker and the water table is located within overburden.
- Groundwater flow rates are much higher in overburden due to higher hydraulic conductivity than in bedrock.

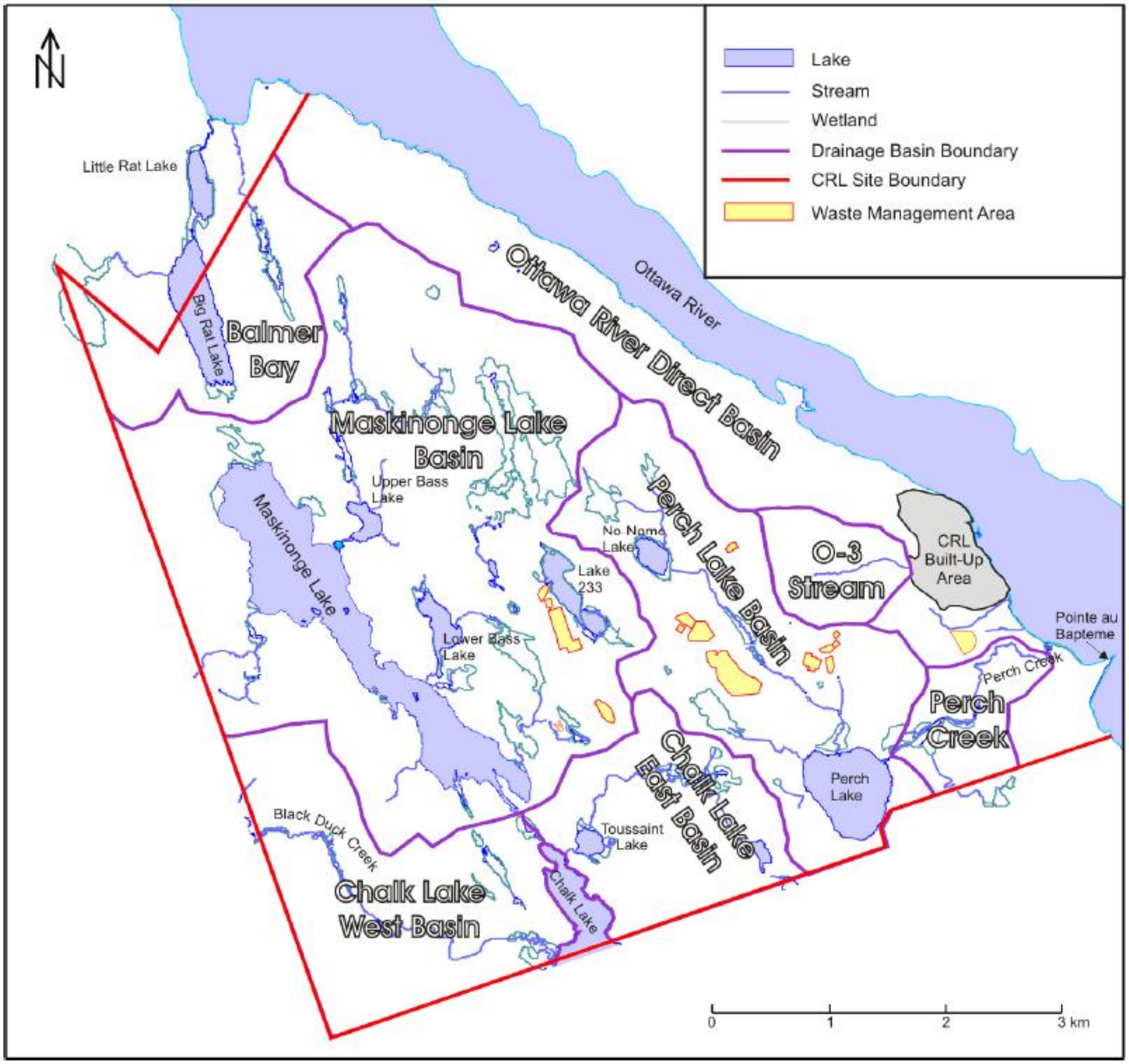

Figure 2-12 Chalk River Laboratories Drainage Basins

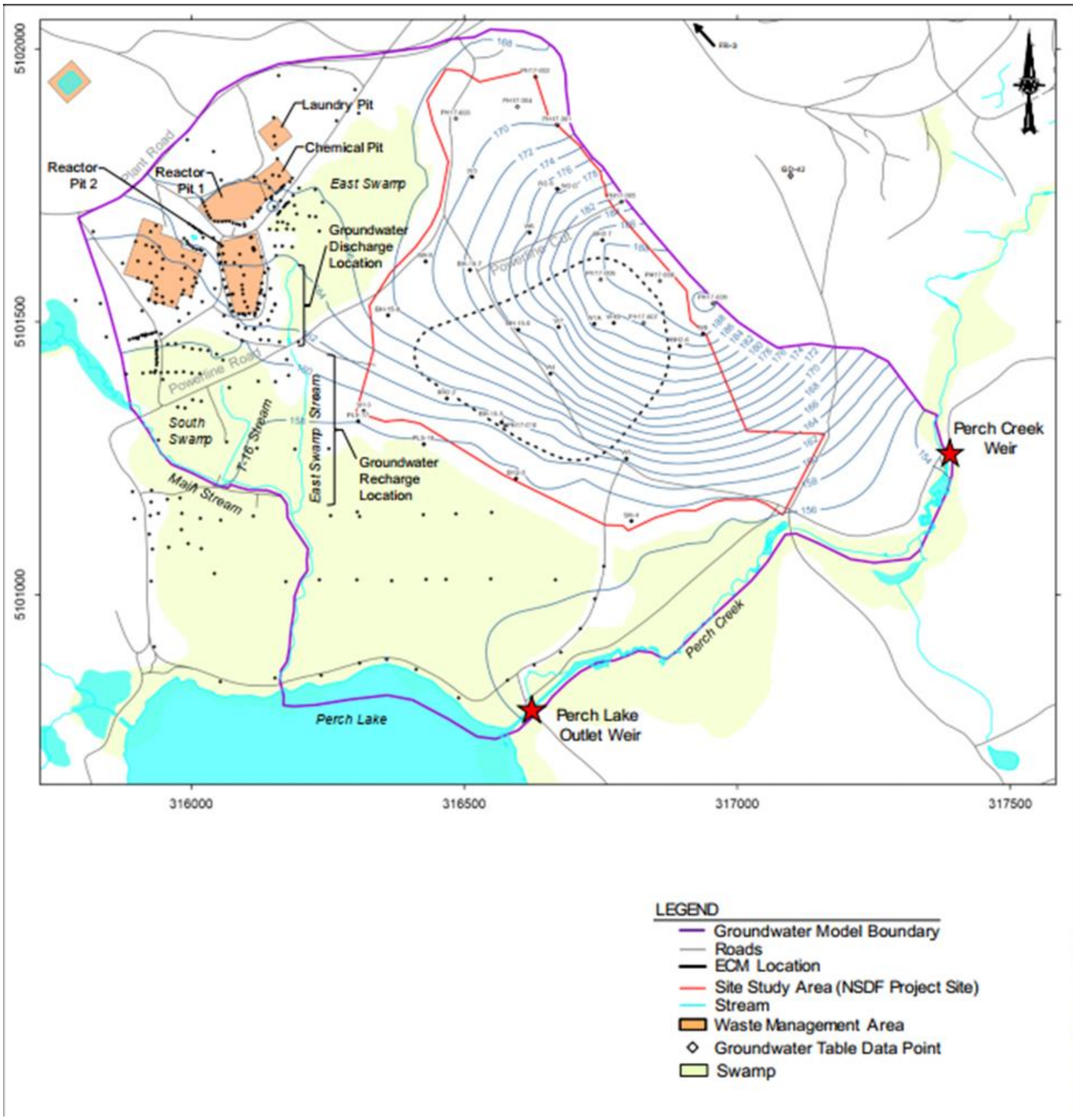

Figure 2-13 Average Groundwater Table Elevation [2-8]

2.7.2 Hydraulic Conductivity

During the site selection phase, the site characterization included estimation of hydraulic conductivity of overburden using empirical method from the results of grain-size distributions. During detailed design phase, the site characterization included laboratory and field testing to determine hydraulic conductivity of the overburden and the upper layer bedrock. The tests included permeameter tests, single well tests, pumping tests, and borehole dilution tests

[2-10], [2-11], [2-12], [2-13], [2-14], [2-15], and [2-16]. Hydraulic conductivity depends on the properties and types of overburden (soil) and rock mass. Observed hydraulic conductivity at the NSDF site by 2017 was based on the results of hydraulic conductivity tests that were suitable for analysis and interpretation and can be summarized below [2-17]:

- Overburden materials were found to have variable hydraulic conductivity range from 1.4×10^{-7} m/s to 1.6×10^{-5} m/s with geometric mean of 1.4×10^{-6} m/s based on the results of eight hydraulic response tests.
- The bedrock-overburden interface has a range of hydraulic conductivity from 7.2×10^{-6} m/s to 3.1×10^{-5} m/s, slightly higher than the overburden based on the results of five hydraulic response tests.
- The bedrock was found to have hydraulic conductivity range from 2.3×10^{-9} m/s to 1.5×10^{-5} m/s with a geometric mean of 9.2×10^{-8} m/s based on the results of nineteen hydraulic response tests. The bedrock materials were characterized as having very low hydraulic conductivity due to very closely packed mineral assemblages.
- As characterization of the NSDF site has progressed, additional hydraulic conductivity measurements have been conducted thus expanding the data set that were suitable for analysis and interpretation [2-18]. Overburden hydraulic conductivity was in the range from 5.7×10^{-7} m/s to 1.6×10^{-5} m/s with a geometric mean of 1.6×10^{-6} m/s based on the results of fourteen hydraulic response tests. Hydraulic conductivity in bedrock was found to range from 2.3×10^{-9} to 1.5×10^{-5} m/s with a geometric mean of 1.4×10^{-7} m/s based on the results of twenty six hydraulic response tests. Although the geometric means have shifted slightly, these more recent hydraulic conductivity data sets of the overburden material and bedrock are within the range of values from historical testing.

2.7.3 Groundwater Quality

Groundwater quality was examined in the NSDF site through characterization of hydro chemical and radiological characterization of the groundwater. These data sets are required for the design of the WWTP, developing hydrogeology model and contaminant transport, and evaluating potential incompatibilities between groundwater and the ECM base liner system components and subsurface cut-off wall materials [2-16].

Based on the results of the testing program for hydrochemistry exploration at the NSDF site [2-16], the following conclusions were determined:

- Corrosion effects to concrete elements in contact with soil overburden materials, would have a negligible degree of exposure to sulphate attack based on Canadian Standards Association (CSA) A23.1 Guidelines.
- Measured resistivity, pH, and chloride content are considered non-corrosive to buried metallic elements in accordance with ANSI/AWWA C105/A21.5-05.
- The site soils are generally neutral pH; therefore, concerns associated with acidic degradation to the Compacted Clay Liner (CCL), High-Density Polyethylene (HDPE)

geomembrane, and Geosynthetic Clay Liner (GCL) materials from the site soil materials are negligible.

- The current analytical test results and the threshold values indicated in the Base Liner and Leachate Compatibility Evaluation [2-19] for the ECM liner components (HDPE membrane, GCL, and CCL), indicate that existing site hydrochemistry concentration levels are within acceptable levels. Therefore, the liner components are not anticipated to be susceptible to degradation from contact with native subsurface soils and groundwater.

In 2016, the results indicated that some wells have a relative increase in sodium, potassium, alkalinity, or sulphate, as well as a relative increased alkalinity, and calcium or sodium and potassium [2-16].

Since groundwater chemistry can vary seasonally and over time, additional monitoring wells and sampling events across the NSDF were recommended to determine potential seasonal variations in groundwater quality. Further groundwater sampling to characterize the chemical and radiological characteristics were completed at the NSDF site in 2017 and 2018 [2-20]. Based on data up to 2018 January, the following was concluded:

- The radiological analyses of the samples did not encounter elevated concentrations of tritium, alpha or beta emitting radionuclides, or gamma emitters.
- Small residual effects from the drilling remain in the samples from some of the monitoring wells, and that these effects are most evident in wells that produce water only sparingly. In general, however, the groundwater quality below and adjacent to the proposed NSDF site is consistent with background expectation for this area.

Groundwater wells have been developed and groundwater quality monitoring at the NSDF site will be continuing through the future phases of the NSDF Project. The groundwater wells in the ECM footprint will be decommissioned prior to construction to limit potential preferential flow paths. Groundwater monitoring wells surrounding the ECM footprint that have been developed for operational control monitoring will continue to be used for monitoring of groundwater elevation and quality during the future NSDF Project phases (i.e. construction and operation) [2-21]. This operational control groundwater quality monitoring has been incorporated into the CRL Groundwater Monitoring Program.

2.8 Seismicity of the Site and Region

The CRL site is located by the Ottawa River within the Ottawa Valley, a northwest-southeast-trending physiographic valley underlain by the Ottawa-Bonnechere graben, an arm of the Saint Lawrence Rift and a zone of relatively high seismicity [2-22]. The Ottawa-Bonnechere graben is adjacent to and southwest of the western Quebec seismic zone. Although the site is located within the continental interior, and far from active plate boundaries, the pre-existing structures formed in earlier tectonic settings are still capable of generating seismicity that can pose a hazard to the region. This seismicity has included several moderate (**M** >6) historical earthquakes in the area. The historical seismicity of northeastern United States and southeastern Canada from 1627 to 2017 is shown in Figure 2-14 [2-22].

A site-specific Probabilistic Seismic Hazard Assessment (PSHA), has been conducted for the NSDF site to determine the design ground motions [2-22]. Seismicity in the study area is concentrated within reactivated rift systems, especially the St. Lawrence Rift system, including the main northeast-trending rift and the associated northwest-trending Ottawa Bonnechere, Timiskaming, and Saugenay grabens, as well as the Charlevoix seismic zone and the Great Meteor Hotspot zone [2-23] and [2-24]. Earthquakes in western Quebec occur at depths from 1 km to 26 km, with shallow focus events, 1 km – 7 km, characterized by random spatial distribution, deep events, >18 km, confined to a few distinct clusters and intermediate depth events, 8 km to 18 km, clustered along a diffuse linear band [2-25].

Significant seismic events in the region surrounding Ontario, Canada have been considered in the PSHA and listed in Table 2-2. On-going seismic monitoring at the CRL, identified the Locksley earthquake of 2015 October 20, which occurred at 19:34 local time. The earthquake was centered approximately 40 km from the CRL site and had an earthquake magnitude of approximately 3.7 [2-26]. Another earthquake was recorded approximately 10 km from the CRL site on 2016 May with magnitude 3.5 [2-26]. Although these are not significant seismic events, they are the most significant earthquakes recorded in the vicinity of the CRL site since 2010 [2-22].

All seismic capable faults in the project region were considered [2-22]. The Lapetan Rift Margin seismotectonic zone, is the main contributing seismic source to the overall hazard at all return periods. The results of the PSHA [2-22], provide Uniform Hazard Response Spectra at annual frequency of exceedance of 4×10^{-4}, 1×10^{-4}, and 10^{-5} or return periods of 2 500 years, 10 000 years, and 100 000 years. The study results in the design Peak Horizontal Ground Acceleration of 0.55g and 0.25g for 10 000 year and 2 500 year earthquakes, respectively for 0.1 sec Spectral Acceleration [2-22].

Table 2-2
Significant Seismic Events in the Region Surrounding Ontario, Canada Considered in the NSDF Site-Specific Probabilistic Seismic Hazard Assessment [2-22]

Year	Location	Moment Magnitude (M)	Distance from CRL site (km)	"Direction" from CRL site
1663	Charlevoix (St. Lawrence Valley region in the La Malbaie region of Quebec)	M ~7	600	Northeast
1732	Montreal, Western Quebec	M 6 ¼	300	East of CRL Site
1893	Montreal, Montreal region	M 5.1	330	East
1925	Charlevoix-Kaouraska (St. Lawrence river region, near Charlevoix, Quebec)	M 6.2	630	North East
1935	Lake Timiskaming (in western Quebec)	M 6.2	160	West-northwest
1944	Cornwall, Ontario – Massena, New York	M 5.8	250	East-Southeast
1988	Saguenay, Quebec	M 5.9	535	East
2013	Ladysmith, Quebec	M 4.6	88	East

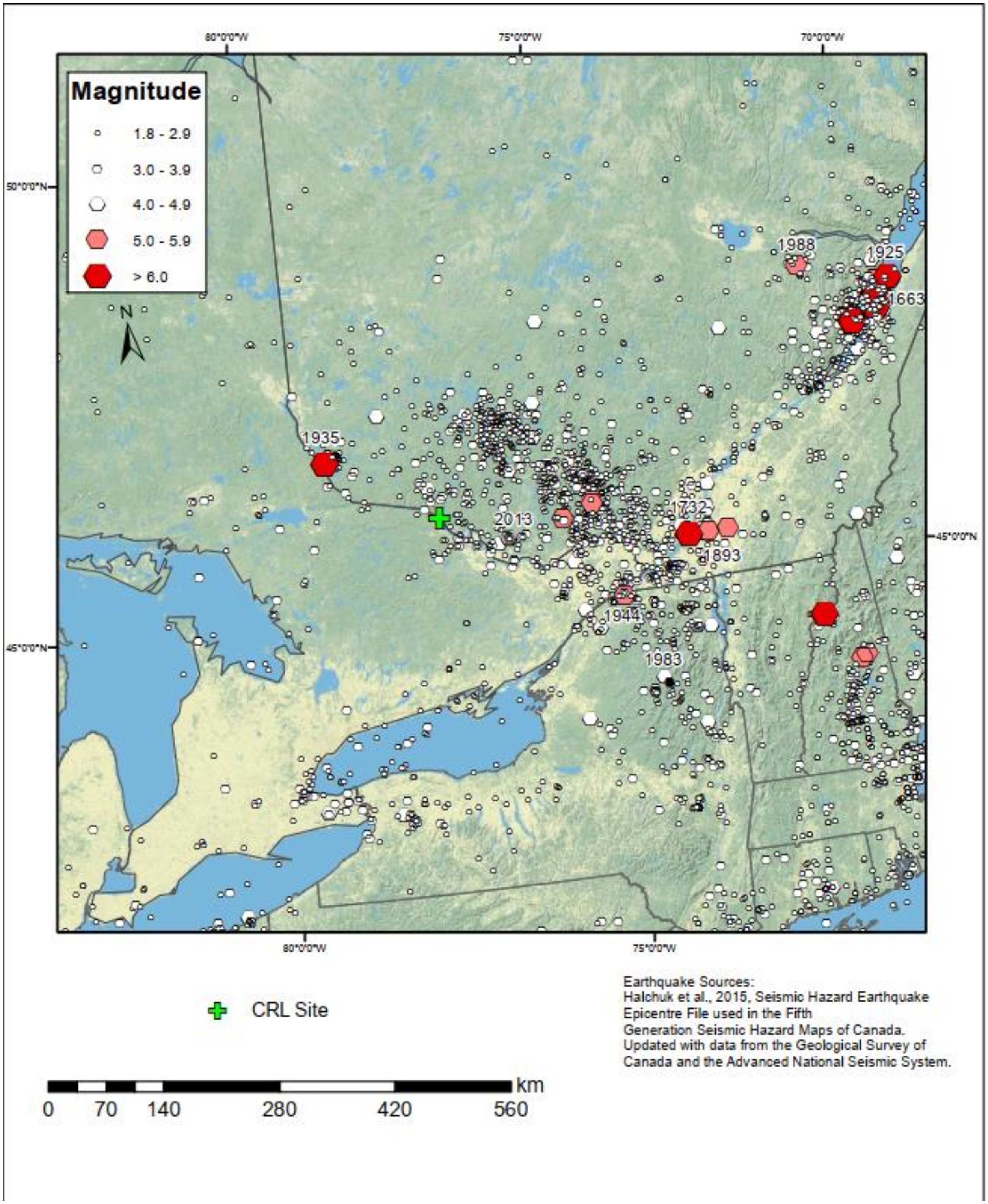

Figure 2-14 Historical Seismicity of Northeastern United States and Southeastern Canada (1627 – 2017) [2-22]

2.9 Potential for Natural Fires or Explosions

Historically, forest fires have been limited at the CRL site, although some have occurred on adjacent property, and several serious fires have occurred on Garrison Petawawa property over the past three decades. Numerous fires have occurred at the old Chalk River Garbage Disposal Site, and Deep River Disposal Site between Chalk River and Deep River. Several developed into serious fires, but were quickly contained by firefighting agencies and never threatened AECL property [2-5].

Atomic Energy of Canada Limited completed a Forest Fire Study [2-27], to consider the potential threat to CRL facilities resulting from a wildfire. The scenarios considered included a fire spreading to the AECL boundary line from neighboring property, or a wildfire originating on AECL property due to human caused activities or lightning [2-27].

The following potential sources of ignition were identified in the study [2-27]:

- Sparks from vehicle exhaust.
- Accumulations of flammable materials around hot exhaust systems and engine parts, which could catch fire and transfer burning material to forest fuels.
- Unextinguished smoking materials.
- Hydro transmission lines.
- Hot carbon deposits discharged from diesel truck exhaust stacks on Plant Road or near the Baggs Road Disposal Site.
- Lightning.
- Campfires lit by trespassers.
- Improper disposal and burning of garbage discarded near the disposal site when the site is closed.
- Natural gas pipeline.

Based on the study [2-27], 5 m flammable free buffer zones were installed around Restricted Area buildings and outside WMA and LDA chain link fences. Brush and dangerous trees were removed from the vicinity of on-site hydro lines. Firebreaks were constructed along the southern, western, and northwestern property boundaries, as well as five internal locations. These serve to reduce the adverse effects of sub-surface and slow moving surface wildfires.

Chalk River Laboratories has an on-site fire department with 24 hour a day, seven days a week fire-fighting capability. The CRL fire department has the capability to respond to two separate fires simultaneously.

A natural gas pipeline runs along Highway 17, approximately 500 m away from the CRL site boundary at its closest point. Additionally, a natural gas main runs down Plant Road and is used to supply building heating needs at the NSDF.

2.10 Terrestrial Environment

Terrestrial fauna and flora are characterized in the Terrestrial Environment section of the Environmental Impact Statement (EIS) [2-8]. The CRL site is primarily forested. Forests are mixed wood and deciduous, dominated by poplar species such as aspen, red maple, with stands of eastern white pine and spruce species. Several small lakes and streams exist on the CRL site, which make up 7% of the total area. Wetlands are also common, and account for 14% of the CRL site area.

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

There are no wetlands, flooded areas, or aquatic habitat features within the NSDF site. The area surrounding the NSDF site includes a mix of forested vegetation communities and wetlands, as well as Perch Lake and Perch Creek.

The EIS documents the selection of Valued Components (VC) to represent elements of the environment that are considered to have economic, social, biological, conservation, aesthetic, and/or ethical value, and are likely to be affected by the NSDF Project. This included consideration of species that are identified on Schedule 1 of the Federal Species at Risk Act (SARA). Biodiversity surveys conducted at CRL, have determined that there are 20 terrestrial species of risk listed on Schedule 1 of SARA that occur within the CRL property. Each species was evaluated to determine whether or not its presence was likely within the NSDF Project footprint, or surrounding area. Those with a low likelihood of occurrence, or for which effects of the NSDF Project were unlikely, were excluded as VCs. A full list of SARA listed species, with confirmed observation records within the CRL property, is documented in the Terrestrial Environment section of the EIS [2-8]. The VCs that were subsequently selected in the EIS for terrestrial flora and fauna are [2-8]:

- Vegetation communities.
- Migratory birds.
- Canada warbler.
- Eastern whip-poor-will.
- Eastern wood-pewee.
- Golden-winged warbler.
- Wood thrush.
- Bats - little brown myotis, northern myotis, and tricoloured bat.
- Blanding's turtle.

- Eastern milk snake.
- Monarch butterfly.

2.11 Aquatic Environment

The NSDF site is located primarily within the Perch Creek and Perch Lake Watershed. Chalk River Laboratories is located in a reach of the Ottawa River extending approximately 90 km between La Passe and the Des Joachims hydroelectric dam. At least 55 fish species have been documented in this area, including one provincially rare species - the River Redhorse [2-28] and [2-29]. Commonly caught fish from the Ottawa River include Walleye, Northern Pike, Channel Catfish, Smallmouth Bass, and Lake Sturgeon.

An inventory of fish in nine waterbodies within the CRL site was performed in summer 1980, with follow-up inventory investigations performed in 1996 and 1997, 2016 and 2017, and in 2018. Forty-one fish species were collected during the 1980 field program, including 13 species collected in the Perch Creek and Perch Lake Watershed. Surveying in 1980, determined that within the Perch Creek basin, seven species were exclusive to lower Perch Creek, including Common Shiner, Longnose Dace, Fallfish, White Sucker, Johnny Darter, Logperch, and Mottled Sculpin. These species are assumed to also occur in the Ottawa River near the outlet of Perch Creek. Dominant species in the upper Perch Creek included Fathead Minnow, Pearl Dace, and Creek Chub. Abundant cyprinid species in Perch Lake included Bluntnose Minnow and Pearl Dace, and the dominant large-bodies species in the lake included Yellow Perch, Brown Bullhead, and Pumpkinseed. The dominant species in Main Stream were Pearl Dace and Fathead Minnow, and the only species captured in East Swamp Stream was Pearl Dace.

Following the baseline investigations performed in 1980, Northern Pike was introduced to or recolonized in Perch Lake, in the late 1980s causing changes to the population dynamics of local species of fish. The once abundant population of Yellow Perch was reduced in size, and forage species, such as Creek Chub, Bluntnose Minnow, Fathead Minnow, Pearl Dace, and Blacknose Shiner were similarly affected. However, Perch Lake continues to support a large-bodied fish community that is similar to that recorded in 1980, which includes a mix of cool water species such as Perch, and warm water species such as Brown Bullhead and Pumpkinseed.

The dominant vegetation form in Perch Lake is a floating leafed plant cover of fragrant water-lily and water shield. Closer to the shore, narrow leafed emergent bands of slender sedge, twig rush, and broad-leaved arrowhead grow in profusion in the shallow water, as does common cattail and pickerelweed. In the deeper water, fully or partially submerged vegetation is dominated by common bladderwort, flat-leafed bladderwort, fennel-leafed pondweed, big-leaf pondweed, and stonewort's, grow along the bottom. Along the north shore and elsewhere, a broad leafed emergent cover of pickerelweed contrasts with water-lilies. The outer fringe of this zone is known as Perch Lake Marsh. This open marsh may be considered to be part of the lake, with which it is physically continuous.

The VCs that were selected in the EIS for aquatic biota are [2-8]:

- Perch Creek and Perch Lake Watershed fish habitat.
- Perch Creek and Perch Lake Watershed fish community.
- Fish species of conservation concern: Lake Sturgeon, American Eel, Northern Brook Lamprey, and River Redhorse.

2.12 References

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3. MANAGEMENT OF SAFETY

This section summarizes the safety objectives, safety goals, safety principles, CNL's internal safety philosophy, acceptance criteria, and applicable codes and standards applied to the operation and design of the NSDF.

3.1 Safety Philosophy

Canadian Nuclear Laboratories operating philosophy includes the commitment to nuclear safety as well as the health, safety and security of the employees, communities and environment [3-1]. Safety values underpin a healthy safety culture, foster an environment of interdependence, and promote a respect for safety as the overriding priority in decision making [3-1].

The following CNL corporate policies, provide direction and expectations to management and employees on Health Safety Security Environment and Quality (HSSE&Q) [3-1]:

- Safety and Health [3-2].
- Environment [3-3].
- Nuclear Safety [3-4].
- Security [3-5].

In accordance with CNL's Nuclear Safety Policy [3-4], the following traits and principles are embraced and fostered:

- We are personally responsible for nuclear safety.
- We have a questioning attitude to avoid complacency.
- Our communications maintain a focus on nuclear safety.
- Our leaders demonstrate a commitment to nuclear safety in their decisions and behaviours.
- Our decisions that affect nuclear safety are systematic, rigorous and thorough.
- We create a respectful work environment to ensure trust and respect permeates our organization.
- We value opportunities to continuously learn.
- We identify and correct issues commensurate with their safety significance.
- We maintain a work environment where employees feel free to raise nuclear safety concerns.
- We plan and control work activities to maintain safety.

Assuring safety at CNL encompasses nuclear safety, as well as the broader HSSE&Q landscape including operations, maintenance, chemistry, engineering, OPEX, human performance, RP, Occupational Safety and Health (OSH), fire protection, EnvP, security, and emergency preparedness.

The key HSSE&Q functional support area programs at CNL are listed below and details of the HSSE&Q Programs are documented in Section 4.4:

- Emergency Preparedness (EmP).
- Environmental Protection (EnvP).
- Fire Protection.
- Nuclear Criticality Safety.
- Nuclear Materials and Safeguards Management.
- Occupational Safety and Health.
- Performance Assurance.
- Pressure Boundary.
- Radiation Protection.
- Security.
- Transportation of Dangerous Goods.
- Waste Management.

3.2 Safety Functions

The fundamental safety functions that the NSDF must fulfill during normal operations, AOO and DBA conditions are:

- Containment of radioactive materials.
- Control of operational discharges of radioactive and hazardous substances, as well as limitation of accidental releases.
- Monitoring of safety critical parameters to guide worker actions.

3.3 Safety Objectives and Long-Term Safety Requirements

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

In addition, three safety objectives documented in the IAEA's Fundamental Safety Principles [3-6] and the safety objective for a radioactive waste disposal facility documented in the IAEA's Disposal of Radioactive Waste [3-7], are applicable to the NSDF:

- To control the radiation exposure of people and the release of radioactive material to the environment [3-6].
- To reduce the likelihood of events that might lead to a nuclear chain reaction, or a loss of control over radioactive material or any other source of radiation [3-6].

- To mitigate the consequences of such events if they were to occur [3-6].
- "…site, design, construct, operate and close a disposal facility so that protection after its closure is optimized, social and economic factors being taken into account. A reasonable assurance also has to be provided that doses and risks to members of the public in the long-term, will not exceed the dose limit for members of the public and other risk constraints" [3-7].

Long-term safety assessments of a facility or contaminated site, should provide reasonable assurance that the regulatory radiological dose limit for public exposure (currently 1 mSv/y) will not be exceeded [3-8]. The long-term safety requirements as documented in Assessing the Long-Term Safety of Radioactive Waste Management [3-8] are:

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

3.3.1 Radiological Protection of Persons

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

Compliance with the NSCA [3-9], the Regulations issued under the Act, and the CNL RP Program requirements [3-10], and ALARA Program [3-11], ensures appropriate RP and provides a system of dose limitation.

The Radiation Protection Regulations [3-12] regulatory effective dose and equivalent dose limits for normal operations are stated in Table 3-1 and [3-13]. The action levels [3-14], [3-15], and emergency dose limits [3-12], [3-13] for radiation exposure to workers are stated in Table 3-2 and Table 3-3, respectively.

Table 3-1
Regulatory Occupational and Public Effective and Equivalent Dose Limits for Normal Operations [3-13] [3-12]

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

[1] For pregnant NEW, the annual effective dose limit is 4 mSv for the balance of the pregnancy.
[2] When skin is unevenly irradiated, the equivalent dose received by the skin is the average equivalent dose over the 1 cm^2 area that received the highest equivalent dose.

Table 3-2
Occupational Radiation Exposures Action Levels for Chalk River Laboratories [3-14] [3-15]

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

Notes:

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

Table 3-3
Emergency Response Dose Limits [3-13] [3-12]

Action	Effective Dose (mSv)	Equivalent Dose to the Skin (mSv)
Actions to minimize dose consequences, for members of the public, associated with the release of radioactive material.	100	1 000
Actions to prevent health effects of radiation that are fatal or life-threatening, or that result in a permanent injury.	500	5 000
Actions to prevent the development of conditions that could significantly affect people and the environment.	500	5 000

3.3.1.1 Criticality Prevention

Nuclear criticality in the Facility shall be prevented. The nuclear criticality safety objectives are to ensure the proper handling of Fissionable Material to render incredible or eliminate the potential of a nuclear criticality accident, to protect all persons, property and environment from the effects of a nuclear criticality accident, to comply with applicable site licence requirements, and to ensure that the use, handling, movement, and storage of Fissionable Material are controlled.

3.3.2 Radiological Protection of the Environmental

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

The priorities with respect to releases of radiological substances to the environment will be prevention first, then mitigation, and then accommodation such that exposures are minimized and ALARA. Accommodation of releases of radiological substances to the environment implies that the release meets benchmark values and/or the acceptance criteria for the protection of persons and non-human biota.

The dose to the critical group due to the sum of all radioactive releases in any period of 12 consecutive months shall not exceed 0.3 mSv [3-15]. Action levels (ALs) for environmental releases will be calculated and established and aim to alert CNL of a potential loss of control of their environmental protection program [3-15].

3.3.3 Protection of Persons and the Environment from Hazardous Substances

Exposure of personnel to hazardous substances in the workplace shall be kept ALARA taking economic and social factors into consideration, but under no circumstance shall exposure to a hazardous substance exceed the Threshold Limit Values adopted by the American Conference of Governmental Industrial Hygienists [3-16], which have also been adopted by the CNL OSH Program as described in [3-17].

Canadian Nuclear Laboratories has limited the chemical characteristics of the waste inventory (including toxicity) by requiring the waste to meet the land disposal and leachate requirements of Ontario's Regulation 347, General – Waste Management [3-18] thus, constraining the hazardous substances within the waste inventory to levels not posing an unreasonable risk to the public or environment.

3.3.4 Risk Limitation Objective

The acceptance criteria for frequencies and radiological consequences developed for accidents in facilities are applied to the NSDF [3-19]. These are presented in Table 3-4.

There are no non-radiological hazards within the NSDF or operations in the NSDF that pose a risk to people outside of the NSDF. Within the NSDF, the non-radiological risks are limited to standard occupational risks related to an industrial environment. These risks are addressed by the OSH Program [3-17] and CNL work practices.

3.4 Safety Principles

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

- Defence-in-depth principle.
- ALARA principle.
- Nuclear Safety Culture.

3.4.1 Defence-in-Depth Principle

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

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

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

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

- Elimination of the hazard.
- Reduce/Replace the hazard.
- Isolate the hazard.
- Control the hazard.
- Personnel Protective Equipment.
- Policies, procedures and documents.

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

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

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

Five levels of defence-in-depth are defined by the CNSC for consideration when designing nuclear power plants as described in Design of Reactor Facilities: Nuclear Power Plants, REGDOC-2.5.2 [3-20]. These levels of defence-in-depth are applicable to safety analyses performed for nuclear facilities as described in Deterministic Safety Analysis, REGDOC-2.4.1 [3-21]. As shown in Section 7.4 and Table 7-1, the NSDF design [3-22] has used three levels of defence-in-depth: Levels 1 – 3 based on the guidance in REGDOC-2.5.2 [3-20].

3.4.2 As Low As Reasonably Achievable Principle

The ALARA principle is a process of optimization to manage exposure situations. The ALARA principle is applied to activities involving radiation exposure to ensure that the magnitude of individual exposures, the number of people exposed, and the risk of unplanned exposures, are kept ALARA and economic and social factors are taken into account [3-11].

The essential elements of ALARA for normal operation are [3-11]:

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

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

The ALARA principle in the NSDF is achieved by implementing zoning and access control measures, by providing adequate shielding for structures and waste packages with high radiation fields, by providing process equipment segregation, radiation alarms in place, continuous monitoring, and worker training and approved procedures. Further reduction in operating staff doses is achieved by minimizing releases through periodic inspection and preventive maintenance of equipment.

Protective measures against the hazards of ionizing radiation is considered to be optimized when further reductions in radiation doses are outweighed by the additional efforts and costs required for their implementation. This principle applies to all phases throughout the life cycle of a Facility, from design to decommissioning, and is a particularly important consideration when developing the operational procedures.

3.4.3 Nuclear Safety Culture

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

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

3.5 Safety Goals

The following sections detail the safety goals for the construction, operation, and closure phases of the NSDF to satisfy the CNL corporate Safety and Health Policy [3-2], safety objectives, and safety principles. Canadian Nuclear Laboratories is to provide a safe and healthy working environment for all its employees, contractors and other persons who access our sites in order to prevent injury and occupation illness, in accordance with the Canada Labour Code Part II and its associated regulations [3-2]. Canadian Nuclear Laboratories' Safety and Health Policy [3-2], applies to every phase of the NSDF Project including the site preparation and construction.

3.5.1 Normal Operations

The target for the NSDF Operations is to have zero injuries from routine operations. This includes physical injuries resulting from industrial type accidents.

The safety goal for normal operation is to keep the radiation exposures to on-site staff and to the most exposed group in the general public resulting from NSDF operations:

- ALARA taking social and economic factors into consideration [3-11].
- Below the CNSC regulatory effective dose limits and less than the equivalent dose limits set by the CNSC as given in Table 3-1.
- Below the RP Program's Action Levels [3-16] as per Table 3-2.
- Below the EnvP Program's Action Levels [3-24].

The RP Action Levels apply to all doses received from CNL's activities involving ionizing radiation [3-14]. The Action Levels reflect the levels of radiation exposure that are indicative of a possible loss of control of some part of the RP Program and trigger specific actions to be taken [3-14], as defined by the Radiation Protection Regulations [3-12].

The release limits and action levels for radionuclides released to the environment from CRL as documented in the Environmental Protection condition of the Licence Conditions Handbook (LCH) [3-15] and the Derived Release Limits (DRL) [3-25] for CRL, provide an upper limit to designers to ensure that this goal is achievable.

The NSDF has been designed to the codes and standards that are applicable at the time of design. New facilities are designed in a manner so that the potential release of radionuclides during normal operation is less than a target of one percent of the corresponding release limits [3-15] and DRL [3-25] for CRL. This is the safety target for the NSDF and is used to ensure that normal operational doses, radioactive releases and environmental emissions are controlled to ALARA. For normal operations, exposures should be below RP Program Action Levels [3-14], unless appropriate approvals have been obtained.

3.5.2 Accidents

The dose acceptance criteria for accidents in Table 3-4 are from the CNL Safety Analysis Program document, Safety Analysis for Decommissioning and Waste Management [3-19], and are applicable to the NSDF Project. The dose acceptance criteria for accidents in Table 3-4 aligns with regulatory documentation and were derived on the following basis.

Deterministic Safety Analysis, REGDOC-2.4.1 [3-21], and Design of Reactor Facilities: Nuclear Power Plants, REGDOC-2.5.2 [3-20] provide the dose acceptance criteria for members of the public for two classes of events: AOOs, and DBAs, where:

- Anticipated Operational Occurrences include all events with frequencies of occurrence equal to or greater than 10^{-2} per reactor year.
- Design Basis Accidents include events with frequencies of occurrence equal to or greater than 10^{-5} per reactor year, but less than 10^{-2} per reactor year.

Deterministic Safety Analysis, REGDOC-2.4.1, [3-21], Design of Reactor Facilities: Nuclear Power Plants, REGDOC-2.5.2 [3-20], and Design of Small Reactor Facilities, RD-367 [3-26] establish the following acceptance criteria for members of the public, for AOOs and DBAs:

- 0.5 mSv for any AOO.
- 20 mSv for any DBA.

These dose limits apply to new Nuclear Power Plants [3-20], and the values adopted for the dose acceptance criteria for AOOs and DBAs are consistent with accepted international practices, and take into account the recommendations of the IAEA and the International Commission on Radiological Protection (ICRP). Thus, the dose acceptance criteria for the public or the off-site receptor for AOO and DBA in REGDOC-2.4.1 [3-21], Design of Small Reactor Facilities, RD-367 [3-26], and REGDOC-2.5.2 [3-20] are applicable to the NSDF Project. The public is the off-site receptor.

Deterministic Safety Analysis, REGDOC-2.4.1 [3-21], Design of Small Reactor Facilities, RD-367 [3-26] and Design of Reactor Facilities: Nuclear Power Plants, REGDOC-2.5.2 [3-20] do not provide dose acceptance criteria for on-site personnel (workers), resulting in CNL's Safety Analysis Program developing the dose acceptance criteria for on-site personnel. The dose acceptance criteria for on-site personnel in Table 3-4 of the SAR, was informed by Radiation Protection Regulations [3-12], Deterministic Safety Analysis, REGDOC-2.4.1 [3-21], Design of Reactor Facilities: Nuclear Power Plants, REGDOC-2.5.2 [3-20], and Design of Small Reactor Facilities, RD-367 [3-26]. From [3-20], and [3-26], for normal operations, doses are controlled to remain below the limits prescribed in the Radiation Protection Regulations [3-12] (see Table 3-1). Radiation doses to the public and to site personnel shall be ALARA [3-20], and [3-26]. The on-site dose acceptance criteria of 5 mSv for AOOs was selected based on the value being an order of magnitude greater than the 0.5 mSv public dose limit for an AOO in [3-21], [3-20] and [3-26], and being an order of magnitude less than the regulatory occupational dose limit of 50 mSv [3-12]. The on-site dose acceptance criteria of 50 mSv for DBAs was selected based on the annual occupational regulatory limit of 50 mSv in the Radiation Protection Regulations [3-12].

The dose acceptance criteria for accidents in Table 3-4 is applicable to the NSDF Project and aligns with regulatory dose acceptance criteria documented in Radiation Protection

Regulations [3-12], REGDOC-2.4.1 [3-21], REGDOC-2.5.2 [3-20], and Design of Small Reactor Facilities, RD-367 [3-26].

The spectrum of accidents is divided into three frequency ranges, AOO, DBA and BDBA. The frequencies and consequences of credible accidents, AOOs, DBAs and DECs, are evaluated, and then compared to numerical acceptance values with the exception of DECs, which are qualitatively assessed.

"Selected BDBAs" including DECs, when identified, may be assessed for dose to the receptors based on their potential for doses significantly in excess of DBAs, and the acceptability of the dose to the receptors, determined on a case-by-case basis. The frequency range for which accident dose limits are set is 10^{-6} to $<10^{-5}$ per year. Events that are predicted to occur less frequently than this have no limits set on resultant dose. Beyond design basis accidents with potentially severe consequences are not subject to consequence analysis. This type of event includes an aircraft crash where the event frequency may be calculated as required. Any safety assessment of the Facility focuses on the robust features of the design, which limit the ultimate consequences of such events. Information on these events has been provided to the Emergency Preparedness Program.

Note that the frequency of occurrence and associated doses of AOOs and DBAs, may either be calculated or may be assessed qualitatively for the event sequences considered to ensure that the acceptance criteria have been satisfied.

Table 3-4
Dose Acceptance Criteria for Accidents [3-19]

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

[a] on-site personnel, not directly involved in the accident.
[b] when identified, dose assessments should be performed, and if the dose exceeds the 20 mSv DBA limit, emergency procedures should be reviewed to determine if new mitigating measures can be identified.
[c] includes DECs.

3.5.2.1 Anticipated Operational Occurrences

Occasional events are AOOs with a frequency of greater than or equal to 10^{-2}. Anticipated Operational Occurrences are deviations from normal operation, expected to occur once or several times during the operating lifetime of the Facility, but which, in view of the appropriate design provisions as confirmed by the safety analysis, do not cause any significant damage to items important to safety nor lead to accident conditions. If there are frequent AOOs with measurable dose to the worker, then the ALARA principle will be applied [3-11].

3.5.2.2 Design Basis Accidents

The design approach taken for DBAs, rare events with a frequency of $\geq 10^{-5}$ to $<10^{-2}$, e.g. rare structural failures, and damaging low-frequency external events, is to design and build to standards appropriate to the usage intended, e.g. accepted engineering codes to preclude structural failure and/or to perform safety analysis to demonstrate that applicable dose limits are met.

3.6 Acceptance Criteria

Table 3-1 shows the regulatory effective and equivalent dose limits for radiation exposures resulting from normal operations of the Facilities [3-13] and [3-12]. Table 3-2 shows the occupational radiation exposure action levels for workers at CRL. Exposures to the Operating Staff, on-site personnel and off-site public will be kept ALARA, and well below the regulatory limits.

While not part of safety analysis dose acceptance criteria, Table 3-3 shows the Emergency Response Dose Limits for emergency responders, which are applied during the control of an emergency and the consequent immediate and urgent remedial work [3-14]. All radiological doses received from emergency actions shall be justified, unnecessary exposures shall be avoided and dose shall be ALARA [3-14].

As stated above, Table 3-4 presents the dose acceptance criteria for accidents, radiological event risks to on-site personnel and the public [3-19]. Three event frequency ranges, each with associated dose limits, are identified in Table 3-4.

The acceptance criteria or benchmark values for radiological dose to non-human biota are:

- 100 µGy/h (2.4 mGy/day) for terrestrial organisms [3-27].
- 400 µGy/h (9.6 mGy/day) for aquatic organisms [3-27].

These values are used in Environmental Risk Assessment of CRL [3-27], and are based on benchmark values recommended by the National Council on Radiation Protection and Measurements, the IAEA and the United Nations Scientific Committee on the Effects of Atomic Radiation.

The American Conference of Governmental Industrial Hygienists threshold limit values for chemical substances, will be used as the acceptance criteria for occupational exposures to chemical substances [3-16].

3.7 Codes and Standards

This section summarizes the codes and standards that are applicable to the conduct of the safety analysis for the NSDF. Note that this list is not all-inclusive; a full list including Ontario codes and standards is included in the Design Requirements [3-28].

Canadian Standards Association (CSA)

- Guidelines for calculating DRL for radioactive material in airborne and liquid effluents for normal operation of nuclear facilities, CSA N288.1-14 [3-29].
- Guidelines for calculating the radiological consequences to the public of a release of airborne radioactive material for nuclear reactor accidents, CSA N288.2-14 [3-30].
- Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills, CSA N288.4-10 [3-31].
- Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills, CSA N288.6-12 [3-32].
- Groundwater Protection Programs at Class I Nuclear Facilities and Uranium Mines and Mills, CSA N288.7-15 [3-33].
- CSA N292.0-14/N292.3-14 Package [3-34] - Consists of:
    - General Principles for the Management of Radioactive Waste and Irradiated Fuel, CSA N292.0-14; and
    - Management of Low- and Intermediate-Level Radioactive Waste, CSA N292.3-14.
- Management System Requirements for Nuclear Facilities, CSA N286-12 [3-35].
- Fire Protection for facilities that Process, Handle, or Store Nuclear Substances, CSA N393-13 [3-36].

Federal Legislation and Codes

- Canadian Environmental Assessment Act (2012) [3-37].
- Canada Labour Code (2016) [3-38].
- Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health [3-39].
- National Building Code of Canada (NBCC), 2015 [3-40].
- National Fire Code of Canada (NFCC), 2015 [3-41].
- National Guidelines for Hazardous Waste Landfills, [3-42].

3.8 References

[3-1] *Management System*, 900-514100-MAN-001, Revision 1, 2020 August.

[3-2] *Safety and Health*, 900-510400-POL-001, Revision 1, 2018 November.

[3-3] *Environmental Policy*, 900-509200-POL-001, Revision 0, 2017 June.

[3-4] *Nuclear Safety*, 900-508200-POL-001, Revision 0, 2017 November.

[3-5] *Security*, 900-508720-POL-001, Revision 1, 2019 November.

[3-6] International Atomic Energy Agency, *Fundamental Safety Principles*, SF-1, STI/PUB/1273, 2006 November.

[3-7] International Atomic Energy Agency, *Disposal of Radioactive Waste,* SSR-5, 2011.

[3-8] CNSC, Waste Management, Volume III, *Assessing the Long-Term Safety of Radioactive Waste Management*, REGDOC-2.11.1, Volume III, 2018 May.

[3-9] *Nuclear Safety and Control Act*, S.C. 1997, c.9.

[3-10] *Radiation Protection*, 900-508740-PRD-001, Revision 3, 2018 June.

[3-11] *ALARA*, 900-508740-STD-013, Revision 0, 2018 December.

[3-12] *Radiation Protection Regulations*, SOR/2000-203.

[3-13] *Regulatory Limits for Internal and External Exposure*, 900-508740-MCP-004, Revision 0, 2018 July.

[3-14] Radiation Protection *Action Levels*, 900-508740-MCP-006, Revision 1, 2020 August.

[3-15] CNSC, *Licence Conditions Handbook for Chalk River Laboratories,* NRTEOL-LCH-01.00/2028, CRL-508760-HBK-002, Revision 1, Effective 2019 February 25.

[3-16] American Conference of Governmental Industrial Hygienists, *Threshold Limit Values for Chemical Substances and Physical Agents and Biological Exposure Indices.*

[3-17] *Occupational Safety and Health*, 900-510400-PDD-001, Revision 2, 2018 April.

[3-18] Ontario Regulation, R.R.O. 1990, *Regulation 347: General – Waste Management*, under Environmental Protection Act, R.S.O. 1990, c. E.19.

[3-19] *Safety Analysis for Decommissioning and Waste Management*, 900-508770-STD-001, Revision 1, 2018 July.

[3-20] CNSC, *Design of Reactor Facilities: Nuclear Power Plants*, REGDOC-2.5.2, 2014 May.

[3-21] CNSC, *Deterministic Safety Analysis*, REGDOC-2.4.1, 2014 May.

[3-22] AECOM, *Design Description*, 232-503212-DD-001, Revision 1, 2019 May.

[3-23] *Near Surface Disposal Facility Effluent Discharge Targets*, 232-106499-REPT-002, Revision 0, 2019 October.

[3-24] *Administrative Levels and Action Levels for CRL Air and Liquid Radioactive Effluents*, 900-509200-STD-008, Revision 1, 2020 January.

[3-25] *Derived Release Limits (DRLS) for AECL's Chalk River Laboratories*, CRL-509200-RRD-001, Revision 2, 2018 August.

[3-26] CNSC, *Design of Small Reactor Facilities*, RD-367, 2011 June.

[3-27] *Environmental Risk Assessment of Chalk River Laboratories*, ENVP-509220-REPT-003, Revision 0, 2019 January.

[3-28] AECOM, *Design Requirements*, 232-503212-DR-001, Revision 2, 2019 April.

[3-29] CSA Group, *Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities,* N288.1-14. 2014.

[3-30] CSA Group*, Guidelines for Calculating the Radiological Consequences to the Public of a Release of Airborne Radioactive Material for Nuclear Reactor Accidents*, N288.2-14, 2014.

[3-31] CSA Group, *Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills*, N288.4-10, 2010.

[3-32] CSA Group, *Environmental risk assessments at Class I Nuclear Facilities and Uranium Mines and Mills*, N288.6-12, 2012.

[3-33] CSA Group, *Groundwater protection Programs at Class I Nuclear Facilities and Uranium Mines and Mills*, N288.7-15, 2015.

[3-34] CSA Group, *General Principles for the Management of Radioactive Waste and Irradiated Fuel (N292.0-14) and Management of Low- and Intermediate-Level Radioactive Waste* (N292.3-14), 2014.

[3-35] CSA Group, *Management System Requirements for Nuclear Facilities*, N286-12, 2012.

[3-36] CSA Group, *Fire Protection for Facilities that Process, Handle, or Store Nuclear Substances*, CSA N393-13, 2016 May.

[3-37] *Canadian Environmental Assessment Act (CEAA)*, S.C. 2012, c. 19, s. 52.

[3-38] *Canada Labour Code*, R.S.C., 1985, c. L-2.

[3-39] Canadian Council of Ministers of the Environment (CCME), *Canadian Soil Quality Guidelines for the Protection of Environmental and Human Health,* Publication 1299, 1999.

[3-40] National Resource Council Canada, *National Building Code of Canada 2015*, 2015.

[3-41] National Resource Council Canada, *National Fire Code of Canada 2015*, 2015.

[3-42] Canadian Council of Ministers of the Environment (CCME), *National Guidelines for Hazardous Waste Landfills*, PN 1365, ISBN 10 1-896997-61-9, 2006.

4. DESIGN AND SAFETY REQUIREMENTS

This section describes the design and safety requirements for the NSDF Project, safety principles defined in Section 3, and applicable regulations. The requirements for the 550 year design life of the Facility (i.e. 50 year operational design life and 500 year post-closure design life), including those specific to safety, are documented in the NSDF Design Requirements [4-1].

4.1 General Design and Safety Requirements

The safety requirements considered during the NSDF design were derived from the following regulatory, guidance, codes, and standards:

- Nuclear Safety and Control Act [4-2].
- General Nuclear Safety and Control Regulations (SOR/2000-202) [4-3].
- Radiation Protection Regulations (SOR/2000-203) [4-4].
- Nuclear Substances and Radiation Devices Regulations (SOR/2000-207) [4-5].
- Class I Nuclear Facilities Regulations (SOR/2000-204) [4-6].
- IAEA SSR-5, Disposal of Radioactive Waste [4-7].
- IAEA SSG-29, Near Surface Disposal Facilities for Radioactive Waste [4-8].
- IAEA SSG-31, Monitoring and Surveillance of Radioactive Waste Disposal Facilities [4-9].
- IAEA SSG-23, The Safety Case and Safety Assessment for the Disposal of Radioactive Waste [4-10].
- CNSC REGDOC 2.11.1, Waste Management, Volume III: Assessing the Long-Term Safety of Radioactive Waste Management [4-11].
- CNSC REGDOC-2.4.3, Nuclear Criticality Safety [4-12].
- National Building Code of Canada 2015 [4-13].
- National Fire Code of Canada 2015 [4-14].
- Fire Protection for Facilities that Process, Handle or Store Nuclear Substances [4-15].

The overarching regulatory requirements are summarized as:

1. Take all reasonable precautions to protect the environment, and the health and safety of all persons.
2. Implement an integrated approach to physical protection and security.
3. Implement and maintain a waste accountancy system to characterize the on-site inventory.
4. Provide on-site personnel with the guidance and training to effectively fulfill their duties.
5. Demonstrate the continual evaluation of all safety aspects associated with the Facility, and the corrective actions implemented to address any identified deficiencies.

The relevant requirements of CNSC REGDOC 2.11.1, Volume III are [4-11]:

1. The management of radioactive waste is commensurate with its radiological, chemical, and biological hazard to the health and safety of persons and the environment and to national security.
2. The assessment of future impacts of radioactive waste on the health and safety of persons and the environment, encompasses the period of time when the maximum impact is predicted to occur.
3. The predicted impacts on the health and safety of persons and the environment from the management of radioactive waste are no greater than the impacts that are permissible in Canada at the time of the regulatory decision.
4. The measures needed to prevent unreasonable risk to present and to future generations from the hazards of radioactive waste are developed, funded and implemented as soon as reasonably practicable.

International Atomic Energy Agency's SSR-5 [4-7] and SSG-29 [4-8], state that the long-term safety of the NSDF is to be ensured by:

1. The capability of the features of the disposal Facility to contain the waste and isolate it from the accessible biosphere.
2. The capability of the features of the site to contribute to the containment and isolation of the waste.
3. The limitations placed on the radiological inventory, mainly with regard to long lived radionuclides, that can be disposed of in the Facility.
4. The measures for surveillance and control of the disposal Facility and its immediate surroundings that are applied to prevent, or restrict, any human activities that could disturb the Facility barriers and lead to increased exposures.

International Atomic Energy Agency's SSG-23 [4-10], provides guidance and recommendations for the development of the Safety Case and supporting safety assessment for the disposal of radioactive waste. These include:

1. Safety assessment is a major component of the Safety Case for a disposal Facility, and should take account of the potential radiological impacts of the Facility, both in operation and after closure.
2. For disposal facilities, particular consideration should be given to the need for assurance of safety over long time periods, commensurate with the half-lives and amounts of radionuclides contained in the waste.
3. Safety assessment should demonstrate whether the disposal Facility complies with applicable regulatory requirements.
4. Defining general considerations regarding safety requirements, the use of safety assessments, and the suggested iterative safety assessment process.

5. Providing specific guidelines for each step of the safety assessment process.

Requirements for ensuring nuclear criticality safety are specified in the CNSC regulatory document RD-327 [4-16] and guidance document GD-327 [4-17], including:

1. Specify limits and criteria for Fissionable Materials.
2. Describe requirements for demonstrating sub-criticality under normal and credible abnormal conditions.
3. Describe criteria for establishing the validity and areas of applicability of calculation methods used to establish nuclear criticality safety.
4. Establish the minimum physical constraints and limits on Fissionable Materials in order to ensure nuclear criticality safety with respect to handling, storing, processing, and transportation of certain Fissionable Materials.

4.1.1 Regulatory Requirements

The design shall meet all applicable licence requirements stated in the LCH [4-18], and in implementing programs, primarily Design Authority and Design Engineering [4-19]. A review of these requirements and criteria was performed and those that are relevant and specifically applicable to the design of the NSDF are summarized below:

- The design of the NSDF Facility, including all support facilities, is done in accordance with the NBCC [4-13], the NFCC [4-14], and Fire Protection for Facilities that Process, Handle or Store Nuclear Substances [4-15].
- The design of the NSDF Facility, including all support facilities, is done in accordance with requirements of the Canada Occupational Health and Safety Regulations [4-20].
- The NSDF design shall apply the defence-in-depth principle in order to prevent, or if prevention fails, to mitigate the consequences resulting from radioactive releases.
- The design shall provide multiple physical barriers to the uncontrolled release of radioactive substances to the environment, and an adequate protection of the barriers.
- The design shall include multiple physical barriers including a primary liner system and a secondary liner system including a CCL in the base liner system, and multiple barriers in the final cap system.
- The Facility shall be able to fulfill the following fundamental safety functions (during normal operation, AOOs, and DBA conditions):
    - Containment of radioactive materials and isolation from the accessible biosphere.
    - Control of operational discharges of radioactive and hazardous substances, as well as limitation of accidental releases.
    - Monitoring of safety critical parameters to guide worker actions.

- The design shall be supported by safety analyses that are of appropriate detail for the complexity of the NSDF. The objectives of the safety analysis shall be to:
  - Confirm that the design of the NSDF meets its design and safety requirements.
  - Derive or confirm OLC, which should be consistent with the design and safety requirements.
- The NSDF safety classified SSCs shall be designed to be tested, maintained, repaired and inspected or monitored periodically, to maintain integrity and functional capability over their lifetime, without undue risk to workers or significant reduction in their availability.
- The NSDF design shall ensure that all required systems, equipment and components in the nuclear Facility are qualified to perform their safety functions under the environmental conditions defined by the nuclear Facility's DBA[1].
- The NSDF design should support the OSH Program for the CRL site. To manage workplace safety hazards, the following requirements shall be addressed:
  - Hazards are evaluated, and eliminated or controlled, and the consequences of exposure to personnel are minimized.
  - Hazardous conditions are identified and, where practicable, physical barriers are installed.
  - Hazard information shall be communicated through signage and labels (e.g. hazardous products labels, arc flash labels, warning signs, etc.).
- The NSDF design shall support the CRL environmental management system, including an integrated environmental monitoring system that includes site-wide groundwater monitoring and that conforms to the CNSC regulatory document REGDOC-2.9.1, Environmental Protection: Environmental Principles, Assessments and Protection Measures [4-21], and the requirements set by CSA standard CAN/CSA-International Organization for Standardization (ISO) -14001 Environmental Management System [4-22], CSA standard N288.4, Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills [4-23], CSA standard N288.5, Effluent Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills [4-24], and CSA N288.7-15 Groundwater Protection Programs at Class 1 Nuclear Facilities [4-25]. The integrated environmental monitoring program shall support:
  - The radiological and hazardous environmental monitoring programs.
  - Radiological and hazardous effluent monitoring.
  - The groundwater monitoring for the NSDF and the CRL CAs.

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[1] It is an objective that the Facility should be designed such that all DBAs result in "mild" conditions as per CSA N290.13 and therefore, Environmental Qualification would not be required.

4.2 Design Requirements

This section describes the design requirements of the NSDF. These include site-specific requirements, as well as CNL site-wide requirements pertaining to RP and EnvP, security and access control, training, and maintenance activities. The design requirements are documented in the NSDF Design Requirements [4-1] and include:

- The operational design life of the Facility shall be 50 years. The ECM shall be designed for a design life of 550 years.
- All design elements, planning, architectural, and engineering shall be fully co-ordinated, and consistent in adherence to best design practices.
- The design phase shall include a project EnvP Plan that minimizes the environmental impacts of the project and incorporates the mitigation measures, and best management practices.
- The WWTP process design shall be based on bench-top and pilot scale tests with the anticipated wastewater/leachate contaminants of potential concern. The final system/equipment design shall be validated by pilot scale test.
- Establish a sustainable development plan to be developed during the design phase. It shall define the goals and actions for integrating sustainable development in the design and operation.

The design requirements traceability matrix documented in the Design Requirements [4-1], demonstrates that the design conforms to the design requirements.

4.2.1 Applicable Codes and Standards

The codes and standards applicable to the ECM, WWTP, Support Buildings, and Site Infrastructure are listed in Table 4-1 [4-1].

Table 4-1
Applicable Codes and Standards for the Near Surface Disposal Facility Design Elements

Code/Standard #	Code/Standard Title (Description/Notes)	ECM	WWTP	Support Buildings	Site Infrastructure
International					
ISO 9001:2015	Quality Management Systems - Requirements	✓	✓	✓	✓
ANSI Y14 Engineering	Engineering Drawings and Related Documentation	✓	✓	✓	✓
ISO 14001: 2015	Environmental Management System - Requirements	✓	✓	✓	
ANSI/EIA-748	Earned Value Management Systems	✓	✓	✓	✓
ASHRAE 62.1	Ventilation for Acceptable Indoor Air Quality	NA	✓	✓	NA
ANSI/UL 900	Test Performance of Air Filter Units	NA	✓	✓	NA
ANSI/UL 586	Standard for Safety for High-Efficiency, Particulate, Air Filter Units	NA	✓	NA	NA
ASME B31.1	Power Piping	NA	✓	✓	✓
ASME B31.3	Process Piping	NA	✓	✓	NA
ASME B&PV Code, Sec VIII, Div 1	Rules for Construction of Pressure Vessels	NA	✓	✓	NA
ASME Sec IX	Welding and Brazing Qualifications	NA	✓	✓	NA
ASME B31.8	Gas Transmission and Distribution Piping Systems	NA	✓	✓	✓
ASME B31E	Standard for the Seismic Design and Retrofit of Above-Ground Piping Systems	✓	✓	✓	✓
ANSI Z223.1-2012	National Fuel Gas Code	NA	✓	✓	✓
American Water Works Association	Standards	NA	✓	NA	✓
American Water Works Association	Manuals of Practice	NA	✓	NA	✓
API 651	Cathodic Protection of Aboveground Petroleum Storage Tanks	NA	✓	NA	NA
API 650	Welded Tanks for Oil Storage (Design loads for Equalization Tanks)	NA	✓	NA	NA
API 520	Sizing, Selection, and Installation of Pressure-relieving Devices.”	NA	✓	NA	NA
ACI 350-06	Code Requirements for Environmental Engineering Concrete Structures and Commentary	NA	✓	✓	NA
DOE G 420.1-1A	Non-Reactor Nuclear Safety Design Guide	NA	✓	NA	✓
National Fire Protection Association (NFPA) 780, 2017	Standard for the Installation of Lightning Protection Systems	NA	✓	✓	✓

Code/Standard #	Code/Standard Title (Description/Notes)	ECM	WWTP	Support Buildings	Site Infrastructure
NFPA 820, 2016	Standard for Fire Protection in Waste Water Treatment and Collection Facilities	NA	✓	NA	NA
NFPA 2001	Standard on Clean Agent Fire Extinguishing Systems	NA	✓	NA	NA
IEEE Std. 80	IEEE Guide for Safety in AC Substation Grounding	NA	NA	NA	✓
IEEE Std. 141	IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (Red Book)	NA	✓	✓	✓
IEEE Std. 142	IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems (Green Book)	NA	✓	✓	✓
IEEE Std. 242	IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (Buff Book)	NA	✓	✓	✓
IEEE Std. 399	IEEE Recommended Practice for Power Systems Analysis (Brown Book)	NA	✓	✓	✓
IEEE Std. 446	IEEE Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications (Orange Book)	NA	✓	✓	✓
IEEE Std. 450-2010	IEEE Recommended Practice for Maintenance, Testing, and Replacement of Vented Lead-Acid Batteries for Stationary Applications	NA	✓	✓	✓
IEEE Std. 485-2010	Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications	NA	✓	✓	✓
IEEE Std. 493	IEEE Recommended Practice for the Design of Reliable Industrial and Commercial Power Systems (Gold Book)	NA	✓	✓	✓
IEEE Std. 519	IEEE Recommended Practice and Requirements for Harmonic Control in Electric Power Systems	NA	✓	✓	✓
IEEE Std. 551	IEEE Recommended Practice for Calculating Short- Circuit Currents in Industrial and Commercial Power Systems (Violet Book)	NA	✓	✓	✓
IEEE Std. 944-1996	IEEE Recommended Practice for the Application and Testing of Uninterruptible Power Supplies for Power Generating Stations	NA	✓	✓	✓
IEEE Std. 946-2004	IEEE Recommended Practice for the Design of DC Auxiliary Power Systems for Generating Systems	NA	✓	✓	✓
IEEE Std. 1100	IEEE Recommended Practice for Powering and Grounding Sensitive Electronic Equipment (Emerald Book)	NA	✓	✓	✓

Code/Standard #	Code/Standard Title (Description/Notes)	ECM	WWTP	Support Buildings	Site Infrastructure
IEEE Std. 1584 and Amendments	IEEE Guide for Performing Arc-Flash Hazard Calculations	NA	✓	✓	✓
ISA 5.1-2009	Instrumentation Symbols and Identification	NA	✓	✓	NA
GRI GM13	Test Methods, Test Properties and Testing Frequency for HDPE Smooth and Textured Geomembranes	✓	NA	NA	NA
National Policy Committee (ANSI Standards Activities) – 2015	Regional ANSI Standards	✓	NA	✓	NA
ANSI/AHRI Standard 1061 2014	Performance Rating of Air to Air Exchangers for Energy Recovery Heat Equipment	NA	NA	✓	NA
ANSI/AHRI Standard 401 2015	Performance Rating of Liquid to Liquid Heat Exchangers	NA	NA	✓	NA
ANSI/AIHA Z9.5-2012	Laboratory Ventilation	NA	✓	NA	NA
ANSI/API 521	Pressure-relieving and De-pressuring Systems	NA	NA	✓	NA
ANSI/HFES-100-2007	Human Factors Engineering of Computer Workstations	NA	NA	✓	NA
IEC 62040-1	Uninterruptible Power System (UPS)	NA	✓	✓	NA
IEC 62040-2	Semiconductor converters – Uninterruptible Power System (UPS)	NA	✓	✓	NA
IEC 62040-3	Uninterruptible Power Systems (UPS) – Method Of Specifying The Performance And Test Requirements	NA	✓	✓	NA
National					
MOE-2003	Stormwater Management Planning and Design Manual	✓	NA	NA	NA
Health Canada's Guidelines for Canadian Drinking Water Quality	Guidelines for Canadian Drinking Water Quality	NA	NA	✓	✓
S.C. 1997, c.9	Applicable Canadian Nuclear Safety and Control Act (CNSA) regulations, including Nuclear Safety Control Act	✓	✓	✓	✓
SOR/2000-204	Class I Nuclear Facilities Regulations and Associated Regulatory Act	✓	✓	✓	✓
S.C. 1999, c. 33	Canadian Environmental Protection Act	✓	✓	✓	✓
CNSC REGDOC-2.5.2	Design of Reactor Facilities: Nuclear Power Plants	✓	✓	✓	✓
CNSC REGDOC-2.9.1	Environmental Policy, Assessments, and Protection Measures	✓	✓	✓	✓
CSA N292.0-14	General Principles for the Management of Radioactive Waste and Irradiated Fuel	✓	✓	✓	NA
CSA N292.3-14	Management of Low and Intermediate Level Radioactive Waste	✓	✓	✓	NA

Code/Standard #	**Code/Standard Title (Description/Notes)**	**ECM**	**WWTP**	**Support Buildings**	**Site Infrastructure**
CSA N288.4-10 (R2015)	Environmental Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills	✓	✓	✓	NA
CSA N286.7.1-09	Quality Assurance (QA) of Analytical, Scientific, and Design Computer Programs	✓	✓	NA	NA
CSA N288.5-11	Effluent Monitoring Programs at Class I Nuclear Facilities and Uranium Mines and Mills	✓	✓	✓	NA
CSA N288.7-15	Groundwater Protection Programs at Class 1 Nuclear Facilities	✓	✓	NA	NA
CSA N288.6-12	Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills	✓	✓	✓	NA
CSA N289.3	Design Procedures for Seismic Qualification of Nuclear Power Plants	✓	NA	NA	NA
CSA N290.5	Requirements for electrical power and instrument air systems of CANDU nuclear power plants	NA	✓	✓	NA
CSA Z412	Guideline on Office Ergonomics	NA	NA	✓	NA
CNSC REGDOC-2.4.3	Nuclear Criticality Safety	✓	✓	✓	NA
CNSC G-224	Environmental Monitoring Program at Class 1 Nuclear Facilities	✓	✓	✓	✓
CNSC G-276	Human Factors Engineering Program Plans	✓	✓	✓	✓
CNSC G-278	Human Factor's Verification and Validation Plans	✓	✓	✓	✓
NBCC (2015) (unless stated otherwise)	The National Building Code of Canada, 2015	NA	✓	✓	✓
NFCC (2015)	The National Fire Code of Canada, 2010	NA	✓	✓	✓
CAN-CSA C22.1,C22.2 (2015)	Canadian Electrical Code Part II	NA	✓	✓	NA
CAN/CSA C282-15	Emergency Electrical Power Supply for Buildings	NA	✓	✓	NA
CAN/CSA A23.1/23.2-14	Concrete Materials and Methods of Concrete Structures/Methods of Test for Concrete	✓	✓	✓	✓
CAN/CSA A23.3-14	Design of Concrete Structures	✓	✓	✓	✓
CAN/CSA B51-03 (Reaffirmed 2007)	Boiler, Pressure Vessel and Pressure Piping Code	NA	✓	✓	✓
CAN/CSA B52-13	Mechanical Refrigeration Code	NA	✓	✓	NA

Code/Standard #	**Code/Standard Title (Description/Notes)**	**ECM**	**WWTP**	**Support Buildings**	**Site Infrastructure**
CAN/CSA N285.0-08 CAN/CSA N285.0-12	General requirements for pressure-retaining systems and components in CANDU nuclear power plants/Material Standards for reactor components for CANDU nuclear power plants	✓	✓	NA	NA
CSA N393-13	Fire protection for facilities that process, handle or store nuclear substances	NA	✓	NA	NA
CAN/CSA S16-14	Limit States Design of Steel Structures	NA	✓	✓	NA
CSA Z316.5	Fume Hoods and Associated Exhaust Air Systems	NA	✓	NA	NA
R.S., c. L-2, 1985	Canada Labour Code	✓	✓	✓	✓
NPCC-2015	National Plumbing Code of Canada	NA	✓	✓	NA
LEED Canada-NC 1.0	LEED Canada for New Construction and Major Renovations 2010, Canada Green Building Council	NA	✓	✓	NA
CAN/ULC-S524	Standard for Installation of Fire Alarm Systems	NA	✓	✓	NA
CAN/ULC-S536	Standard for Inspection and Testing of Fire Alarm Systems	NA	✓	✓	NA
CAN/ULC-S537	Standard for Verification of Fire Alarm Systems	NA	✓	✓	NA
CAN/ULC S111	Standard Method of Fire Test for Air Filter Units	NA	✓	✓	NA
CAN/ULC S115	Standard Method of Fire Test of Fire Stop	NA	✓	✓	NA
CAN/CSA Z462 -2018	Work Place Electrical Safety	NA	✓	✓	NA
TAC 1999	Geometric Design for Canadian Roads	NA	NA	✓	✓
CISC	CISC Deign Guide “Crane Supporting Steel Structure”	NA	NA	✓	NA
Provincial					
MOE-2008	Ontario Ministry of Environment-Guidelines for Sewage Works	✓	NA	NA	NA
TRCA	Toronto and Region Conservation Authority (TRCA). 2006. Erosion & Sediment Control Guideline for Urban Construction.	✓	NA	NA	NA
OMT- 2016	Ontario Ministry of Transportation. Ontario Provincial Standards for Roads and Public Work	✓	NA	NA	✓
2015	Ontario Electrical Safety Code	NA	✓	✓	✓
	Ontario Occupational Health & Safety Act and Regulations for Construction Projects	✓	✓	✓	✓
	Technical Standards and Safety Act, 2000	✓	✓	✓	✓

Code/Standard #	Code/Standard Title (Description/Notes)	ECM	WWTP	Support Buildings	Site Infrastructure
	Ontario Building Code Part 7 (Plumbing)	NA	✓	✓	✓
	Ontario Provincial Standards Drawings and Specifications (for civil engineering)	✓	✓	✓	✓
	Ontario Environmental Protection Act, Ontario Regulation 347, General – Waste Management	✓	NA	NA	✓
	Ontario Regulation 232/98, 2011 Landfilling Sites	✓	NA	NA	NA
	Ontario Landfill Standards 2012, Ontario Ministry of the Environment	✓	NA	NA	✓
	Ontario Regulation 220-01	NA	✓	✓	NA
	Sheet Metal & Air Conditioning Contractors National Standard	NA	NA	✓	NA
Other					
Institute of Electrical and Electronics Engineers (IEEE 3003.2)	Recommended Practices for Equipment Grounding and Bonding for Industrial and Commercial Power Systems	NA	✓	NA	NA
ANETA- Automatic Transfer Switch	Electrical Acceptance Testing 2017	NA	✓	✓	NA
AASME 31.5	Refrigeration and Heat Transfer Components	NA	✓	✓	NA
ASHRAE 15	Safety Standard for Refrigeration Systems and Designation and Classification of Refrigerants	NA	✓	✓	NA
ASHRAE 110	Method of Testing Performance of Laboratory Fume Hoods	NA	✓	✓	NA
ASHRAE 111	Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air-Conditioning, and Refrigeration Systems	NA	✓	✓	NA
ASHRAE 135.1	Method of Test for Conformance to BACnet	NA	NA	✓	NA
Several standards published by the American Society for Testing and Materials (ASTM)	Applicable to design and testing of natural and manufactured engineered barrier components (e.g. GCL, HDPE geomembranes, geotextiles, CCL material, granular filter/drainage layer material, etc.)	✓	NA	NA	NA
CSA N289.1	General Requirements for Seismic Design and Qualification of CANDU Nuclear Power Plants	✓	NA	NA	NA
CSA N289.2	Ground Motion Determination for Seismic Qualification of Nuclear Power Plants	✓	NA	NA	NA
CSA 289.4-12	Testing Procedures for Seismic Qualification of CANDU Nuclear Power Plants	✓	NA	NA	NA

Code/Standard #	**Code/Standard Title (Description/Notes)**	**ECM**	**WWTP**	**Support Buildings**	**Site Infrastructure**
CSA N294	Decommissioning of facilities containing nuclear substances	✓	NA	NA	NA
CSA Z358.1	Emergency Eyewash and Shower Technology	NA	✓	✓	NA
CSA N289.5	Seismic Instrumentation Requirements for Nuclear Power Plants and Nuclear Facilities	✓	NA	NA	NA
ASHRAE 90.1 2013	Energy Standard for Buildings	NA	NA	✓	NA
NUREG-0700	Human-System Interface Design Review Guidelines	NA	✓	✓	NA
MIL-STD-1472G	Department of Defense Design Criteria Standard: Human Engineering	NA	✓	✓	NA

4.3 Safety Requirements

The design of the NSDF shall fulfill the following high-importance safety functions: control of radiation exposure to people and environment, containment and isolation of radioactive material, passive venting of gases, and criticality safety [4-1]. Safety is provided by multiple safety functions, including use of multiple barriers, duty/standby equipment, and controls, including monitoring, testing, and surveillance measures [4-1].

The safety requirements include [4-1]:

- Ensuring that radiation safety is provided by multiple engineered barriers.
- Ensuring that safety is provided by passive means during the post-closure period.
- Doses to members of the public do not exceed 0.3 mSv in a year from natural processes (i.e. all processes other than human intrusion into the waste).
- Compliance with the CRL site licence conditions and be licenced as a Radioactive Waste Disposal Facility.
- Compliance with the CNL Compliance Program requirements.
- Ensure compliance with the following dose rate constraints:
    - General office or equivalent: 0.5 µSv/h.
    - Normal work: 1 µSv/h.
    - Surface of shielding in areas of radioactive work: 10 µSv/h.
    - Surface of shielding in areas where radioactive material is stored: 10 µSv/h.

4.3.1.1 Radiological Protection of Persons

The NSDF design shall include provisions to ensure that potential radiation doses to the public and site personnel do not exceed prescribed limits and are ALARA for the life-cycle of the site including the post-closure phase. The design of the NSDF shall support the RP Program that ensures contamination and radiation doses received by individuals are monitored and controlled. The CNL RP Requirements [4-26], have established guidelines for dose rates within the general environment of nuclear facilities and in the workplace. The NSDF is designated as a CA and is subject to Radiological Zoning requirements of [4-26] and [4-27].

The design includes the following RP aspects:

- Radiation exposure and dose control.
- Radiation protection instrumentation and equipment.
- Personnel dosimetry.
- Radioactive contamination control.
- Near Surface Disposal Facility staff must notify the CNSC when an occupational radiation exposure exceeds an action level listed in Table 4-2 [4-26]. These action levels must be

reviewed, and if necessary, revised at least once every five years in order to validate their effectiveness.

Table 4-2
Occupational Radiation Exposures

Type of Dose	Action Level	
	mSv (rem) per four week or longer monitoring period (see Note 1)	mSv (rem) per year
Effective Dose	6 (0.6) (see Note 2)	20 (2)
Shallow Dose	100 (10)	200 (20)
Extremity Dose (see Note 3)	100 (10)	N/A
Internal Contamination	0.05 x Annual Intake Limit (ALI) (see Note 4)	
Localized area of the skin due to a single skin contamination incident (see Notes 3,5)	50 (5)	

Notes:
1. The monitoring period is normally four weeks, but may be longer if justified. The monitoring period shall not exceed three months.
2. Action levels for pregnant women shall be 0.3 mSv (0.03 rem) per four weeks to the abdomen.
3. Extremity dose action level applies in situations where an extremity Thermoluminescent Dosimeter has measured a dose exceeding 100 mSv. All contamination events that result in a dose to the skin, irrespective of the location on the body of the exposed skin, will be recorded and reported as appropriate as a skin dose (with the associated action level being 50 mSv).
4. The ALI is defined as the activity of a radionuclide that, when taken into the body, will deliver an effective dose of 20 mSv over the next 50 years following the intake.
5. The averaging area shall never be less than 1 cm^2, even in case of hot particles. When skin is unevenly irradiated, the equivalent dose received by the skin is the average equivalent dose over the 1 cm^2 area that received the highest equivalent dose. When contamination is relatively uniform over the skin, the averaging area of 100 cm^2 may be used for operational convenience, but not if it significantly lowers the average dose.

- The NSDF design shall allow for monitoring, controlling, and recording releases of radioactive nuclear substances, such that the total releases do not exceed annual release limits listed in the LCH [4-18]. In addition, the LCH requires that the dose to the critical group, due to the sum of all radioactive releases from CRL in any period of 12 consecutive months, shall not exceed 0.3 mSv.
- Operational controls on waste placement shall ensure that wastes having the highest dose rates and wastes containing a significant inventory of long-lived radionuclides are to be placed in the lower portion of the ECM disposal cell.
- Materials and material thicknesses used in the waste placement and backfill process in the ECM, shall limit the weighted average dose rate for a routinely occupied area to 1 µSv/h. The fence line must meet Radiological Safety Zone 2 condition, 10 µSv/h dose rate at the fenced boundary.

- To allow for the effective administration of the CA, the NSDF shall be organized into radiological safety zones, based on the radiation dose rates and contamination levels. In general, the greater the level of radiological hazard, the greater the level of access control and RP measures required to ensure radiation safety and, consequently, the higher the zone number assigned. The design shall comply with CNL's RP requirements detailed in RP Consideration during Design and Modification [4-28] and ALARA Design and Review Questionnaire [4-29].
- The NSDF shall be designed in accordance with the Dose Acceptance Criteria for Accidents as shown in Table 3-4 of Section 3.5.2.
- The NSDF shall be designed in accordance with the applicable requirements from the RP Manual procedures to achieve the objectives of each referenced CNL document.

4.3.1.2 Nuclear Criticality Safety

The mass concentration of Fissionable Material in the ECM shall be limited, so that it remains subcritical during all phases of waste operations, including active waste disposal operation and post-closure periods.

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

- Maximum reactivity of the Fissionable Material present is attained.
- The most reactive credible configuration consistent with the chemical and physical form of the material (e.g. lumped source, cylindrical, sphere, dispersed, etc.).
- Optimal moderation by light water.
- Full reflection of the fissionable/fissile material system.

The criticality analysis and design shall meet all the requirements of CNSC RD-327 Nuclear Criticality Safety [4-16] and GD-327 Guidance for Nuclear Criticality Safety [4-17]. The analysis and documentation requirements for the Criticality Hazard Identification and the Criticality Safety Document (CSD) are specified in Criticality Hazards Identification Study [4-30] and Preparing a CSD or Time-Limited Amendment [4-31], respectively.

The design ensures that materials used for the NSDF, and the limits imposed on the quantities of Fissionable Material, shall comply with the CSD developed during the preparation of the Safety Case.

4.3.1.3 Environmental Protection

The NSDF Environmental Protection Plan (EPP) [4-32], has been developed to establish practices for safe and environmentally sound management of the Facility during construction, operational, and post-operational phases. The core component of the EPP is an Effluent

Verification Monitoring Program, to monitor and prevent unacceptable dispersal of radioactive materials through environmental pathways, and to support early detection of potential release of radioactivity. The EPP lists the action levels, discharge limits, and regulatory requirements and includes the Effluent Verification Monitoring Program criteria to meet the requirements of CAN/CSA N288.5-11 [4-24].

Monitoring and control plans for dust, groundwater, surface water, and air are included in the EPP for the construction, operations and closure phases. The radioactive emissions shall be monitored meeting CNL EnvP requirements.

4.3.2 Fire Protection

The design of fire protection shall meet the requirements of Fire Protection for Facilities that Process, Handle or Store Nuclear Substance [4-15] and the fire protection goals [4-33] and [4-34] include:

- Minimize the risk of radiological releases that are a result of fire.
- Protect nuclear Facility occupants from death or injury due to fire.
- Minimize business interruption resulting from fire damage to structures, equipment and inventories.
- Minimize the impact of radioactive or hazardous material on the environment as a result of fire.

4.4 Operational Aspects Relevant to Safety

Operational aspects relevant to safety include CNL functional support area programs, conduct of operations, OLCs, and criticality safety.

4.4.1 Health Safety Security Environment and Quality Programs

Canadian Nuclear Laboratories has established functional support area programs to ensure that CNL operates in full compliance with statutory and legislative requirements, while promoting and supporting performance excellence underpinned by a healthy safety culture [4-35]. Assuring safety at CNL encompasses nuclear safety, as well as the broader HSSE&Q landscape including operations, maintenance, chemistry, engineering, OPEX, human performance, RP, OSH, fire protection, EnvP, security, emergency preparedness, and decommissioning and waste management [4-35]. Combining a heathy safety culture (human behaviour), and effective safety management (processes and oversight), prevents events and assures the safety and security of people, facilities and the environment during normal and accident conditions.

The HSSE&Q, Engineering, and Environmental Remediation Management (ERM) functional support area programs are in accordance with the principles of defence-in-depth and QA, and include:

- Emergency Preparedness.
- Environmental Protection.
- Fire Protection.
- Nuclear Criticality Safety.
- Nuclear Materials and Safeguards Management.
- Occupational Safety and Health.
- Performance Assurance.
- Pressure Boundary.
- Radiation Protection.
- Security.
- Transportation of Dangerous Goods (TDG).
- Waste Management.

Note that the Pressure Boundary Program is part of the Engineering functional support area. The TDG Program and the Waste Management Program are part of the ERM functional support area. The other programs listed are within the HSSE&Q functional support area.

4.4.1.1 Emergency Preparedness

The EmP Program [4-36], provides an operational framework to implement CNL's Health and Safety and Environment Policies, with respect to necessary emergency response measures and compliance with company priorities, identified in the Strategic Emergency Management Plan [4-37]. The EmP Program focus is prevention and mitigation of, preparedness for, response to, and recovery from, emergencies [4-36]. The EmP Program requirements in the relevant legislations and regulations, are delineated as applicable company-wide and site specific requirements [4-38].

Emergency preparedness is required at all CNL business locations. A graded approach to requirements is applied based upon an assessment of the most credible events that could occur at any given location [4-36]. This program uses the following performance measures to assess site-wide compliance with program requirements:

- Emergency procedures are reviewed annually and revised as required.
- Designated personnel are trained in their emergency response duties.
- Facility or building personnel conduct and/or participate in drills and exercises, as identified in the annual exercise schedule.
- Emergency equipment is maintained in a state of readiness and quality confirmation is reported to the EmP Office.

Emergency Procedures are reviewed and revised as per program requirements and the Facility Emergency Procedures are revised every three years.

4.4.1.2 Environmental Protection

The EnvP Program description and requirements are documented in [4-39] and [4-40]. The EnvP Program implements CNL's Environment Policy [4-41], and ensures compliance with legal and other environmental obligations applicable at CNL operated sites in Canada. Under the EnvP Program, program requirements apply to operations and activities that may affect the environment in and around CNL sites. A graded approach to requirements is applied based upon environmental risks/events that could occur at any given location. The EnvP Program, also applies to all employees, as well as other personnel (contractors, consultants, attached staff, etc.) conducting work at CNL sites.

The Environmental Management System [4-22] at CNL provides an overview of the key processes, organizational structure and the responsibilities associated with the EnvP Program.

An index to EnvP Program documentation [4-42], lists the policy, requirements documents and all supporting and implementation procedural documents for EnvP. Operations and activities conducted at CNL sites in Canada are bound by environmental requirements specified in the following federal legislation, but not limited to:

- Nuclear Safety and Control Act [4-2].
- Canadian Environmental Protection Act [4-43].
- Canadian Environmental Assessment Act [4-44].
- Fisheries Act [4-45].
- Transportation of Dangerous Goods Act [4-46].
- Species at Risk Act [4-47].

4.4.1.3 Fire Protection

The Fire Protection Program description and requirements are documented in [4-33] and [4-34]. The Fire Protection Program provides an operational framework to implement CNL's OSH Program [4-48], with respect to fire protection and to ensure compliance with applicable legal and other requirements. The Fire Protection Program applies to design, operations and other activities that may affect fire protection in and around CNL sites [4-33] and [4-34].

The Fire Protection Program objectives are [4-33] and [4-34]:

- Protect life, property, environment, and provide fire safety.
- Prevent fire losses and degradation of fire protection coverage.
- Provide responsible fire protection and change control that enhances fire protection.
- Demonstrate compliance to applicable fire protection codes and standards.
- Improve fitness for purpose, with respect to fire protection.

- Provide reliable facilities from a fire protection perspective.
- Improve business performance and provide risk management using various tools such as self-assessment, code compliance reviews, fire protection screening processes (Engineering Change Control (ECC)) and Fire Hazard Analysis (FHA).

4.4.1.4 Nuclear Criticality Safety

The Nuclear Criticality Safety Program [4-49] and [4-50], provides a framework for safe operations at CRL and for the prevention of nuclear criticality accidents by conforming to all applicable regulations, company policies and procedures. The Nuclear Criticality Safety Program is responsible for all activities involving the use, process, movement and storage of Fissionable Materials, and applies to activities that may affect nuclear criticality safety (e.g. design, operations, commissioning and decommissioning activities). The focus of nuclear criticality safety at CRL is on those areas that contain equal to or greater than 0.1 kg of fissile nuclides in Special Fissionable Material (SFM) [4-49].

Nuclear criticality safety is aimed at preventing criticality accidents. The CNL Nuclear Criticality Safety Program [4-49] and [4-50], complies with the CNSC Regulatory Document RD-327 [4-16] and CNSC Guidance Document GD-327 [4-17], which provide the requirements for the prevention of criticality accidents in the handling, storage, processing and transportation of Fissionable Materials, and the long-term management of nuclear waste. Note that in 2019 February, Nuclear Criticality Safety, REGDOC-2.4.3 [4-12], replaced CNSC Regulatory Document RD-327 [4-16] and CNSC Guidance Document GD-327 [4-17].

The following are the foundation of the Nuclear Criticality Safety Program [4-49]:

- Nuclear criticality safety is part of CNL's Nuclear Safety Policy [4-51].
- An adequate margin of sub-criticality is maintained under all normal and credible abnormal conditions (events or event sequences having frequency of occurrence equal to or more than 10^{-6}/year), as demonstrated by using quantitative or semi-quantitative methods.
- Upper subcritical limits are not exceeded under both normal and credible abnormal conditions.
- The consequences of a criticality accident are mitigated to limit the on-site and off-site doses to people.
- Canadian Nuclear Laboratories is compliant with site licence requirements for criticality safety, through Nuclear Criticality Safety Program processes and procedures.

4.4.1.5 Nuclear Materials and Safeguards Management

The Nuclear Materials and Safeguards Management (NM&SM) Program [4-52] and [4-53], provides nuclear materials and safeguards management compliance and services to CNL. The NM&SM Program's primary focus is on Facilities that contain Fissionable Materials, therefore, are subject to regulatory safeguards measures and reporting requirements [4-53].

The NM&SM Program applies to all nuclear material and safeguards management activities performed at CNL Facilities. The NM&SM Program requirements [4-53], apply to all CNL Sites, CNL employees, and non-CNL Personnel that work at these sites. The NM&SM Program requirements [4-53], applies to all activities involving the procurement and receipt of radioisotopes and radiation sources, as well as the procurement, receipt, disposition, transfer, accounting, safeguards management, storage, and inventory management of nuclear material.

The following are the foundation of the NM&SM Program [4-52]:

- Compliance with the Canadian NSCA [4-3], CNL site licences and CNSC/IAEA regulations.
- All nuclear material on-site shall be accounted for.
- All IAEA safeguards inspection requests are complied with and supported.
- All required IAEA safeguards reports are submitted.
- All safeguards approaches for projects are designed in co-operation with the Facility.

4.4.1.6 Occupational Safety and Health

The OSH Program applies to all work performed by CNL employees, and to work performed by others on-site or work places controlled by CNL [4-48]. The purpose of the OSH Program is to prevent accidents and injury to health arising out of, linked with, or occurring to employees in the course of employment, and to all persons on sites or workplaces controlled by CNL [4-48].

The CNL Safety and Health corporate policy [4-54], establishes the CNL standards and expectations with respect to safety and health.

The OSH Program requirements document [4-55], establishes the requirements for the CNL OSH Program. Canadian Nuclear Laboratories is committed to providing a safe workplace and to compliance with applicable safety and health requirements. The OSH Program complies with applicable Federal and Provincial OSH legislation, regulations and standards.

4.4.1.7 Performance Assurance

Canadian Nuclear Laboratories has a responsibility to ensure safety for its employees and the public, and to protect the environment from any potential hazards associated with operating its sites and facilities. The Performance Assurance Program [4-56], responds to this obligation by implementing the following elements:

- Operating Experience (OPEX) and Corrective Action Program.
- Assessment.
- Human Performance.
- Continual Improvement.
- Performance Measures and Analysis.

Requirements listed in the Performance Assurance Program requirements document [4-57], drive the structure and content of the Performance Assurance Program.

The Performance Assurance Program [4-56], uses information from within CNL and from the nuclear industry to improve the safety of operations, improve operational performance and reduce the significance and the occurrence of unplanned events at CNL sites in Canada. The unplanned events reported to OPEX are entered into a database of OPEX that are monitored for trends and used to share any Lessons Learned (LLD).

The Performance Assurance Program, provides processes for the identification and investigation of unplanned events, determination of corrective actions, internal notification to stakeholders, and trending information sharing – both internally and with the broader nuclear industry.

4.4.1.8 Pressure Boundary

The purpose of the Pressure Boundary Program is to ensure that pressure-retaining systems and components are designed, constructed and operated in full compliance with statutory and legislative requirements, while promoting and supporting performance excellence with a strong safety culture [4-58]. The ultimate objective of the Pressure Boundary Program and its governing codes and standards, including CSA Standard N285.0 [4-59] and CSA Standard B51 [4-60] is "no pressure boundary failures" [4-61].

The Pressure Boundary Program [4-58] applies to design, procurement, fabrication, installation, examination, testing, repair, replacement, modification, construction, and maintenance of pressure retaining systems, and components at CNL [4-61].

The Pressure Boundary Program requirements document [4-61], describes the requirements to ensure that the Pressure Boundary Program is planned, implemented and maintained.

4.4.1.9 Radiation Protection

The RP Program applies to the operation and activities that affect the safety of staff and equipment, in terms of exposure to ionizing radiation at all CNL sites and applies to all employees and other personnel (visitors, contract staff, etc.) conducting work at CNL sites [4-62]. The RP Program applies to all activities conducted where CNL holds a CNSC issued licence in Canada [4-62].

The objective of the RP Program is to ensure and demonstrate compliance with applicable Regulations and Acts and maintain doses to workers ALARA, social and economic factors taken into account [4-26]. Canadian Nuclear Laboratories applies the ALARA principle in all activities involving the use of ionizing radiation. All radiation doses to personnel or members of the public must be justified, in accordance with the ALARA principle and be maintained below regulatory limits.

The RP Program Authority [4-62], has oversight responsibility to ensure Dosimetry Services directly meets or assists the RP Program in meeting the relevant requirements of the RP Program and the Radiation Protection Regulations [4-4].

The RP Program requirements are listed in the CNL RP Requirements [4-26] and include:

- Limiting radiation doses to less than the regulatory limits.
- Limiting detrimental stochastic health effects in employees and members of the public to levels ALARA, social and economic factors being taken into account (ALARA principle).
- Preventing detrimental non-stochastic (deterministic) health effects caused in employees and members of the public by radiation.

Dosimetry is a necessary component of the program, providing a quantitative measure of the effectiveness of the radiation safety program, as it applies to both the individual worker and the collective workforce. Dosimetry is a fundamental requirement for the demonstration of compliance with regulatory obligations mandated by the site licence. Dosimetry services for personnel and visitors are provided by CNL, and are managed according to the CRL Dosimetry Program [4-63] and [4-64]. These services include monitoring, assessing, recording and reporting doses of ionizing radiation received by all individuals while on-site.

4.4.1.10 Security

The Security Program implements CNL's Security Policy [4-65] within CNL operating sites in Canada and to ensure compliance with all applicable legal and corporate requirements [4-66]. The Security Program [4-66] is responsible for ensuring the protection of CNL employees, facilities and nuclear materials in accordance with the CNL Security Policy [4-65].

The Security Program applies to the operation and activities that affect the security in and around CNL sites, and applies to all employees and other personnel (visitors, contract staff, etc.) conducting work at CNL sites [4-66].

The Security Program Requirements Document [4-67], provides a summary of legal and other requirements applicable to CNL sites in Canada.

4.4.1.11 Transportation of Dangerous Goods

The TDG Program [4-68], applies to all activities involving the transportation of dangerous goods. Transport encompasses all operations associated with the movement of dangerous goods, including: classification, documentation, packaging, safety marks, security, emergency response, training, and regulatory permits and licences [4-68].

The main objectives of the TDG Program are [4-68]:

- To protect persons, property and the environment from the effects of radiation and hazardous material during transport by establishing and maintaining requirements and processes, necessary to facilitate the safe transport of dangerous goods to and from CNL sites in accordance with regulatory requirements.
- Ensure compliance with applicable regulatory and licence requirements.

The TDG Program requirements are listed in the TDG Program Requirements [4-69].

4.4.1.12 Waste Management

The Waste Management Program is responsible for documenting the activities involving the waste management lifecycle of solid and liquid wastes, including spent fuel and nuclear wastes mixed with other hazardous substances [4-70]. The program provides advice to all waste generators, to ensure that activities involving the waste management lifecycle are performed in a manner that protects the workers, the public, and the environment, and are in compliance with the licensing and associated Provincial and Federal documents and standards from the company-wide management system standards and policies [4-70]. Included within the waste management lifecycle are characterization and records, which facilitate the waste management lifecycle by clearly informing the requirements of each phase [4-70].

The Waste Management Program [4-70] implements CNL's Environment Policy [4-41] with regard to the management of both solid and liquid waste.

The Waste Management Program translates the specific waste requirements from the relevant Provincial and Federal documents and standards, into program requirements, as described in Waste Management Program Requirements [4-71].

4.4.2 Waste Management Areas Conduct of Operations

The NSDF will be operated following the WMAs conduct of operations.

The organization, responsibilities, processes, and controls for the WMA Facility are specified in Waste Management Areas Main Governing Documentation Index [4-72]. The WMA conduct of operations conforms to CNL's Quality Program [4-73]. The WMA conduct of operations is in accordance with the principles of defence-in-depth and QA. Further details regarding the WMA conduct of operations, including NSDF staff qualifications and training, are provided in Section 10.

4.4.3 Operating Limits and Conditions

To ensure that the NSDF is operated within parameters that have been shown to be safe, a set of OLCs shall be established for the Facility. The NSDF OLCs are documented in the Facility Authorization [4-74], and relate to administrative requirements and Limiting Conditions for Safe Operation. In Section 15, the Limiting Conditions for Safe Operation are outlined in detail for the NSDF.

4.4.4 Criticality Safety

Nuclear criticality safety of the NSDF and the associated operations is reviewed by the CNL Nuclear Criticality Safety Panel. Nuclear criticality safety has been analysed and the limits and control measures specified in the NSDF CSD [4-75].

The basis for nuclear criticality control is dependent on the following variables:

- The mass of the Fissionable Materials present.
- The presence/ybsence of neutron absorbers.
- The presence/ybsence of neutron moderator.
- The presence/ybsence of neutron reflection.
- Geometry for high/low neutron leakage.
- Neutron interactions with neighbouring structures.

4.5 References

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5. FACILITY DESCRIPTION – STRUCTURES, SYSTEMS AND COMPONENTS

This section provides the Facility description including a description of the SSCs. The section is a summary of the information in the NSDF Design Description [5-1].

The NSDF has four main design elements, and the location of these design elements is depicted in Figure 5-1:

- ECM for the disposal of LLW.
- WWTP for the treatment of wastewater.
- Support facilities providing services related to the operation. (Shown as "SF" and blue in Figure 5-1).
- Site infrastructure supporting the Facility operation. (Shown as "SI" and pink in Figure 5-1).

The architectural layouts for the buildings have been developed in response to the mechanical, electrical, process, and functional needs of the NSDF. Building structures have an approximate design life of 55 years [5-1], and building layouts meet NBCC code requirements [5-2]. Table 5-1 provides a summary of the NSDF buildings including size and code classification [5-1]. Table 5-2 provides a summary of other structures, including structures that do not classify as buildings, as per NBCC [5-2]. The other structures in Table 5-2 have building numbers to support maintenance activities.

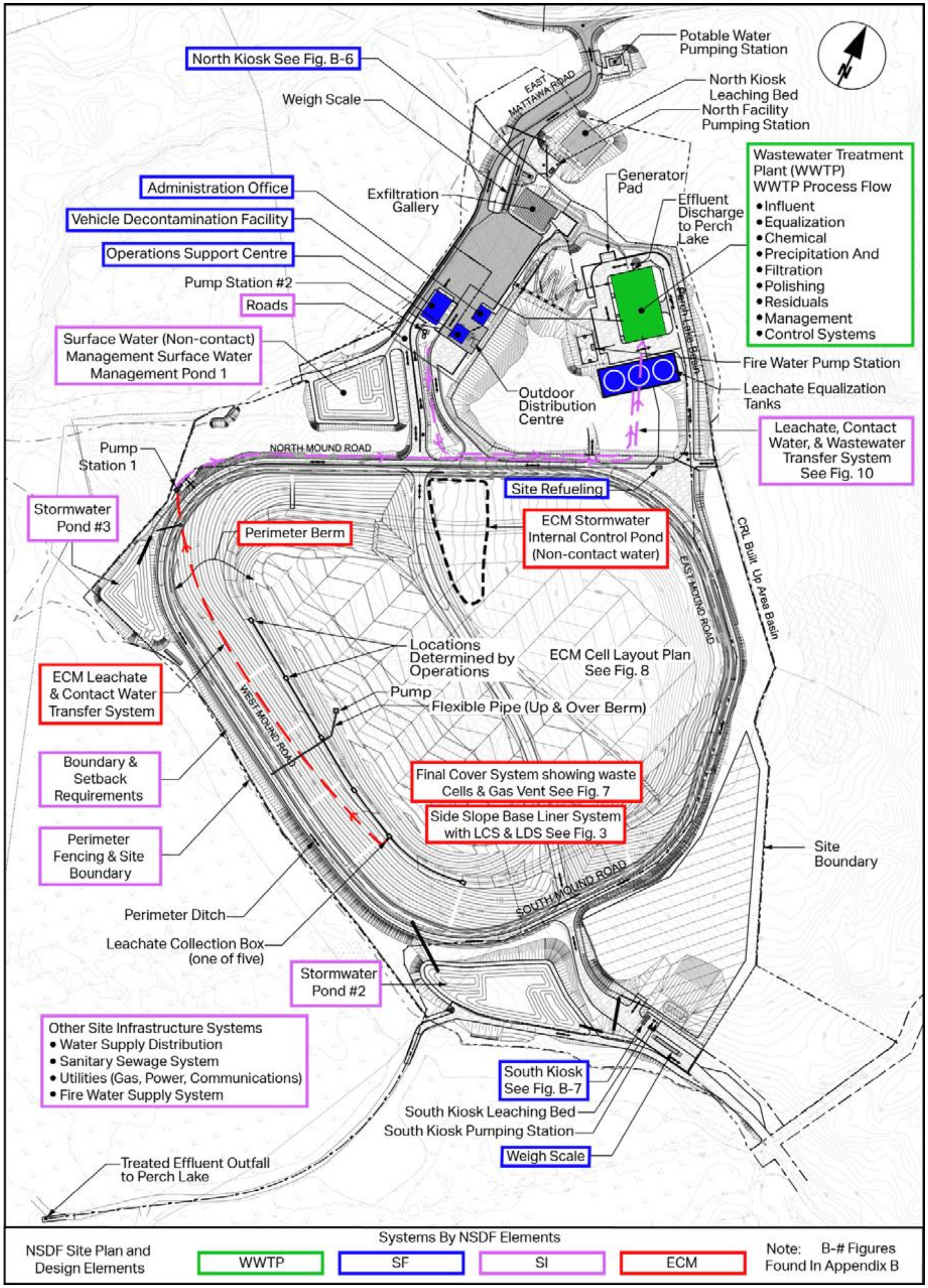

Figure 5-1 Near Surface Disposal Facility and Design Element Locations

Table 5-1
Near Surface Disposal Facility Buildings [5-1]

Building Number	Building Name	Function	Building Dimensions (m) (Length x Width)	Building Classifications
1551	WWTP	Treating wastewater arising from NSDF operations.	64.24 x 38.47	Group F, Division 3, Up to 4 stories
1552	Administration Office	Provides staff office space, lunch and meeting rooms.	15.36 x 12.53	Group D, Up to 2 stories
1553	Operations Support Centre (OSC)	Provides personnel decontamination and shower facilities.	14.34 x 13.96	Group D, Up to 2 stories
1554	Vehicle Decontamination Facility	Provides vehicle decontamination and light vehicle maintenance.	17.56 x 27.56	Group F, Division 3, Up to 2 stories
1556	North Kiosk	Monitoring and registering vehicle loads into the NSDF.	10.42 x 3.03	Group D, Up to 2 stories
1557	South Kiosk	Monitoring and registering vehicle loads into the NSDF.	10.42 x 3.03	Group D, Up to 2 stories
1561	Power Distribution Building	Houses power distribution equipment, and communication network equipment.	8.00 x 5.00	Group F, Division 3, Up to 2 stories
1562	Fire Water Pump Station (FWPS)	Houses fire water pumps and located above two underground concrete fire water tanks to provide fire water to the NSDF site hydrant system.	26.10 x 15.80	Group F, Division 3, Up to 2 stories
1563	Potable Water Pump Station (PWPS)	Stores potable water from CRL water main and supplies potable water to the NSDF site (excluding South Kiosk).	10.97 x 6.70 m	Group F, Division 3, Up to 2 stories

Table 5-2
Other Structures [5-1]

Building Number	Facility Name	Function/Description
1550	Engineering Containment Mound (ECM)	Double-lined near surface waste disposal of 1 000 000 m^3 LLW with a footprint of approximately 12 hectares. Leachate detection/collection systems. The design life is 550 years.
1555	Equalization tanks	Contains wastewater including leachate, contact water, and operational wastewater.
1558	Contact Water Pump Station 1 (CWPS #1)	Receives leachate and contact water from the ECM via pumped and gravity flow piping. Pumps leachate in redundant HDPE dual containment pipes to the Equalization Tanks.
1559	Contact Water Pump Station 2 (CWPS #2)	Receives contact and decontamination water generated by the WWTP, VDF, and OSC. Pumps wastewater in redundant HDPE dual containment pipes to the Equalization Tanks.
1560	Site Vehicle Refueling Station	Dual containment above ground storage fuel tank (4 500 L). Storage of bulk fuel for use in site vehicles.
1564	North Facility Sanitary Pumping Station	Sewage disposal system for the main NSDF facilities. Includes pump station, septic tank, and leaching bed.
1567	Natural Gas Generator Enclosure	Houses the natural gas generator.

5.1 Engineered Containment Mound

The ECM is a double-lined near surface waste disposal Facility, designed for the disposal of 1 million m^3 of LLW that meet the NSDF Waste Acceptance Criteria (WAC). A multi-layer final cover system is installed over the placed waste upon completion of disposal operations in each waste cell. The ECM located within a CA, is designed for a 550 year design life, including 50 years of operations. The volume of the airspace for the ECM is approximately 1.43 million m^3. The ECM area is approximately 12 hectares.

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

The ECM includes several SSCs that contribute to the safe and effective operation of the mound and protection of humans and the natural environment from the placed wastes. The ECM SSCs includes:

- Disposal cells.
- Base liner system including primary liner and Leachate Collection System (LCS), and secondary liner and Leak Detection System (LDS).
- Perimeter berm.
- Temporary Storage Waste Receiving and Process Area (TSWRPA).
- Leachate transfer system.
- Contact water collection, transfer and conveyance system.
- Non-contact water collection, transfer and conveyance system.
- Daily and interim cover.
- Final cover system including Landfill Gas (LFG) venting.

The base liner system, perimeter berm, and final cover system support the long-term safety, containment and isolation of the waste.

5.1.1 Disposal Cells

Figure 5-2 shows the layout of the 10 disposal cells within the ECM. The disposal cells are filled in succession as numbered starting with disposal Cell #1 and ending with disposal Cell #10. As each cell is filled to capacity, the next cell is prepared to accept waste. The average disposal cell area is 12 000 m^2 and the largest active disposal cell area is 15 000 m^2.

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

The disposal cells:

- Are oriented so that the ridges in the herringbone/shaped grading pattern can be used to contain storm water (contact or non-contact water), and convey the water to catchment areas (contact water conveyed to the contact water collection ponds; non-contact water conveyed to a temporary clean storm water catchment area, located within each cell), for removal from the ECM.

The design of the disposal cells included the following considerations:

- The area where the disposal cells could be placed was limited by the NSDF boundary and the available space for the ECM and the need to maximize the remaining NSDF site area to accommodate the design of the surface water ponds, buildings, roads, and other supporting infrastructure.

- Facilitate operations by placing waste at the lower elevation end, Disposal Cells 1 - 6, and moving the waste placement face up slope of the existing ground surface. This method of waste placement is more efficient than placing waste on the high end and working to a lower end of a disposal cell.
- Facilitate waste placement, based on the waste stream projected over the 50 years of operations.
- Maintain a disposal cell area that minimizes the volume of leachate and contact water generated by the disposal cell during operations and maintain inactive disposal cell area to generate more non-contact water versus contact water (that would require treatment by the WWTP).
- Facilitate disposal cell sizes and boundaries that provide a systematic and organized structure to fill the cells in progression. Cell sizes are not constrained to a minimum size but should have a floor area large enough to allow for equipment to place material and recognize the boundary interface between Phase 1 and Phase 2.
- The contact water and leachate volumes used in the design of the WWTP Equalization Tanks, the LCS, the contact water storage area, and the leachate/contact water transfer systems are based on a maximum active waste disposal area of 15 000 m^2 plus the temporary storage and waste receiving and processing area of 6 000 m^2, total area of 21 000 m^2.
- Accommodate a TSWRPA adjacent to, or within the active cell.

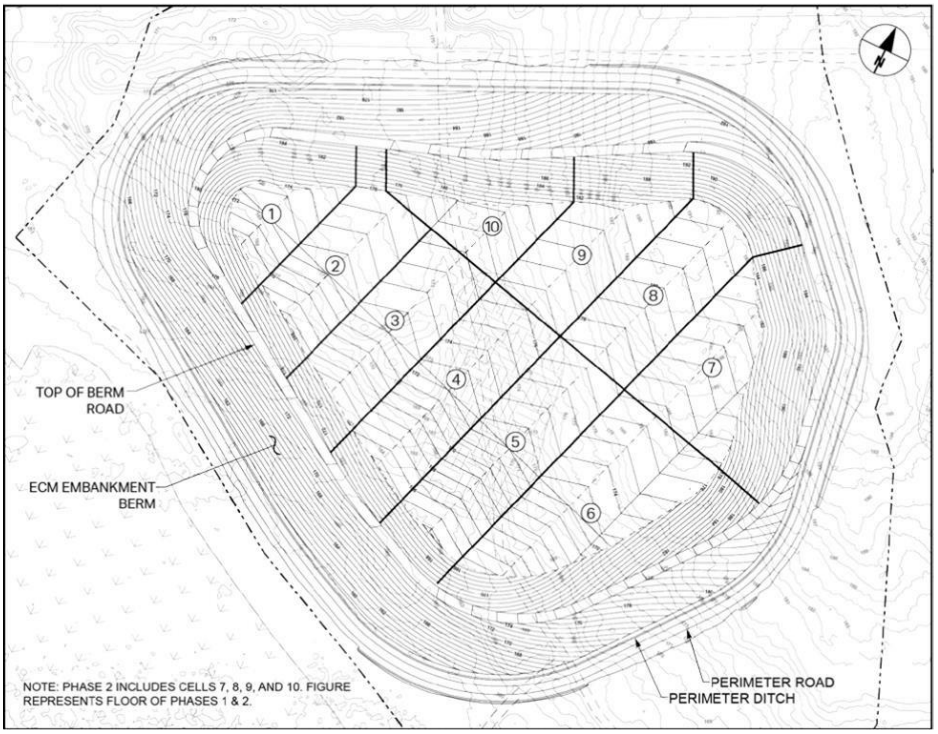

Figure 5-2 Engineered Containment Mound Disposal Cell Layout

5.1.2 Base Liner System

The base liner system is included in the design to provide waste containment and protect the environment from contaminant migration from the ECM. The base liner system is comprised of a primary liner and secondary liner, to provide redundancy in the event of primary liner failure. The base liner system has a total thickness of 2.05 m, and includes a combination of natural earthen materials and geosynthetic barrier systems. The primary function of the base liner system is to provide containment of the LLW and leachate generated during and following operation of the ECM, and to minimize the potential for impacting groundwater from a release of leachate from the ECM. The components of the base liner system are shown in Figure 5-3. The base liner system, which is integrated with the LCS and the LDS, consists of the following barriers and ancillary components, from top to bottom:

- 500 mm granular ‘A’ sacrificial cover (to be removed prior to waste placement).
- Sacrificial geomembrane (to be removed prior to waste placement).
- 300 mm granular ‘A’ filter.
- Non-woven geotextile filter.
- 300 mm layer of 19 mm clear stone.
- Woven geotextile separator.
- 200 mm thick sand cushion (liner protection).

- 2 mm textured (both sides) HDPE geomembrane liner (barrier).
- Geosynthetic clay liner (GCL) (barrier).
- 300 mm layer of 9.5 mm clear stone.
- Woven geotextile separator.
- 200 mm thick sand cushion.
- 2 mm (80-mil) textured (both sides) HDPE geomembrane liner (barrier).
- Geosynthetic clay liner (GCL) (barrier).
- 750 mm-thick compacted clay liner (CCL) (barrier).

The sacrificial geomembrane is a 1 mm textured double sided Linear Low-Density Polyethylene geomembrane with white surface on the top side. The sacrificial geomembrane is overlain by 500 mm of granular 'A' sacrificial cover, which provides frost protection.

The two sacrificial layers over the Phase 1 area and the Phase 2 area, allow operations to divert storm water to the contact water collection areas (ponds) or the non-contact water collection areas (ponds), depending on the function of the cell. Storm water falling in an active cell will drain to a contact water pond, while storm water falling in a non-active cell will drain to a non-contact water pond. The sacrificial materials associated with the disposal cell, including the sacrificial geomembrane and granular 'A' sacrificial cover are removed prior to placement of waste.

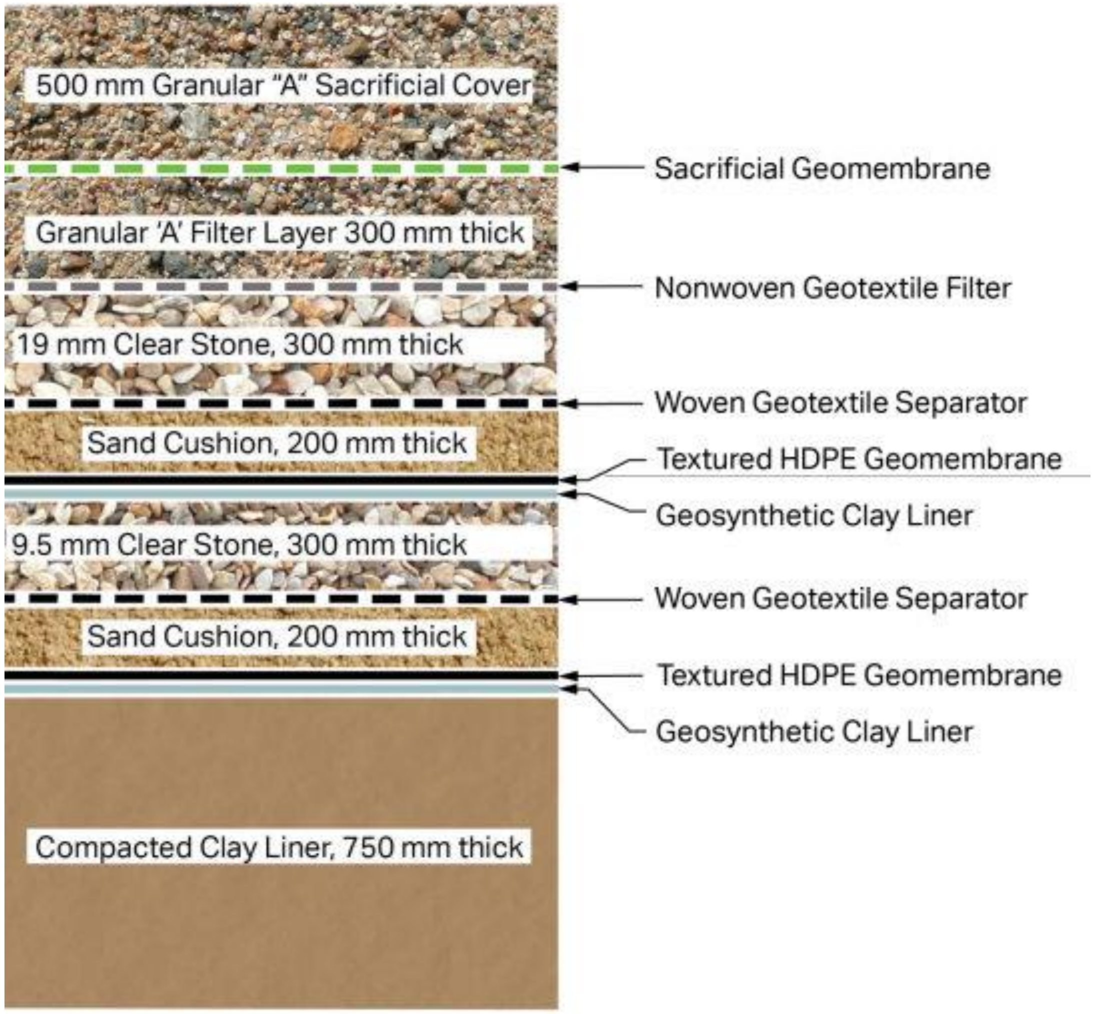

Figure 5-3 Base Liner System

Figure 5-4 shows the configuration of primary components of the base liner system at the intersection of the ECM floor and the ECM interior portion of berm. The primary liner component of the base liner system is designed to contain the waste, retain leachate generated and function as a hydraulic barrier system to restrict leakage of leachate to the underlying components of the base liner system. The secondary liner system is designed to contain any leakage that may occur through the primary liner by means of an additional HDPE geomembrane and GCL layer and minimizes the potential for leachate contamination beneath the ECM. The 750 mm CCL layer is constructed on top of the finished subgrade surface as required to provide a tertiary hydraulic barrier against the release of leachate to the environment. A compound longitudinal slope between 5% and 10% defines the top of the base liner and finished subgrade surface of the ECM. An intracellular transverse slope of 3% is provided along with the longitudinal slope to facilitate drainage of leachate to the LCS clear stone layer with perforated collection pipe within each valley.

The base liner system materials were selected based on their compatibility with the predicted leachate characteristics in the ECM arising from the WAC, and required design service life. The Base Liner and Leachate Compatibility Evaluation [5-3], includes an evaluation of the compatibility of materials used in constructing the ECM liner system with the radiological and chemical characteristics of leachate predicted to be generated within the ECM. In addition, a laboratory testing program was carried out on HDPE geomembrane products from leading manufacturers to assess their long-term performance. The program involved accelerated aging tests with leachates simulating severe operating conditions at elevated temperatures. Canadian Nuclear Laboratories assessed the results of this testing program to select the final geomembrane for use in the ECM base liner system construction. This laboratory testing program was completed during 2017 and 2018, and is summarized in the document, Near Surface Disposal Facility, Geomembrane Relative Performance Report [5-4]. A geogrid is included on the side slopes at the base as shown in Figure 5-4. The geogrid is required on the 3H:1V side slopes to minimize the potential for downslope movement (sliding) of the non-woven geotextile cushion and granular leachate drainage layer above the primary geomembrane liner. The potential for this downslope movement exists during the active waste placement period prior to final buttressing of the slope with waste fill. The cause of the downslope movement is the low frictional resistance between the geotextile cushion and geomembrane liner. The geogrid is placed between the geotextile cushion and granular drainage layer and anchored at the crest of the slope in an anchor trench. The aperture size of the geogrid was selected to allow interlocking with the drainage layer aggregate. The geogrid design is based on the tensile force acting against the gravitational sliding forces, so as to maintain a stable configuration on the slope.

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

The thickness of 0.75 m for a clay liner in a composite liner system is consistent with the standard of practice for waste containment facilities [5-5]. Furthermore, this thickness meets the requirements of Ontario Regulation 232/98 for non-hazardous waste facilities and is the same as that used for the Port Granby and Port Hope Low-Level Radioactive Waste (LLRW) facilities that are currently being constructed. For the NSDF Project, the 0.75 m thick clay liner, combined with the overlying geomembrane and GCL components of the proposed composite secondary lining system, provide an effective and redundant hydraulic barrier system to protect against long-term contaminant releases from the ECM to groundwater.

Figure 5-5 shows the intersection of the base liner side slope with the final cover and the perimeter berm.

The primary function of the LCS, is to drain leachate generated in the ECM to the LCS leachate sumps (for subsequent extraction), throughout the operations phase and during the post-closure phase. The primary functions of the LDS are to: (1) provide a means of monitoring for potential leachate leakage through the primary liner; and (2) to drain leachate and condensate that accumulates in the LDS to the LDS leachate sumps for subsequent extraction.

The LCS and LDS within the base liner system drains leachate to the leachate sumps. The LCS and the LDS leachate sumps enable the Leachate Transfer System to extract accumulated leachate, to measure the flow rates and totalized flows of the leachate extraction, and to monitor the leachate sump levels.

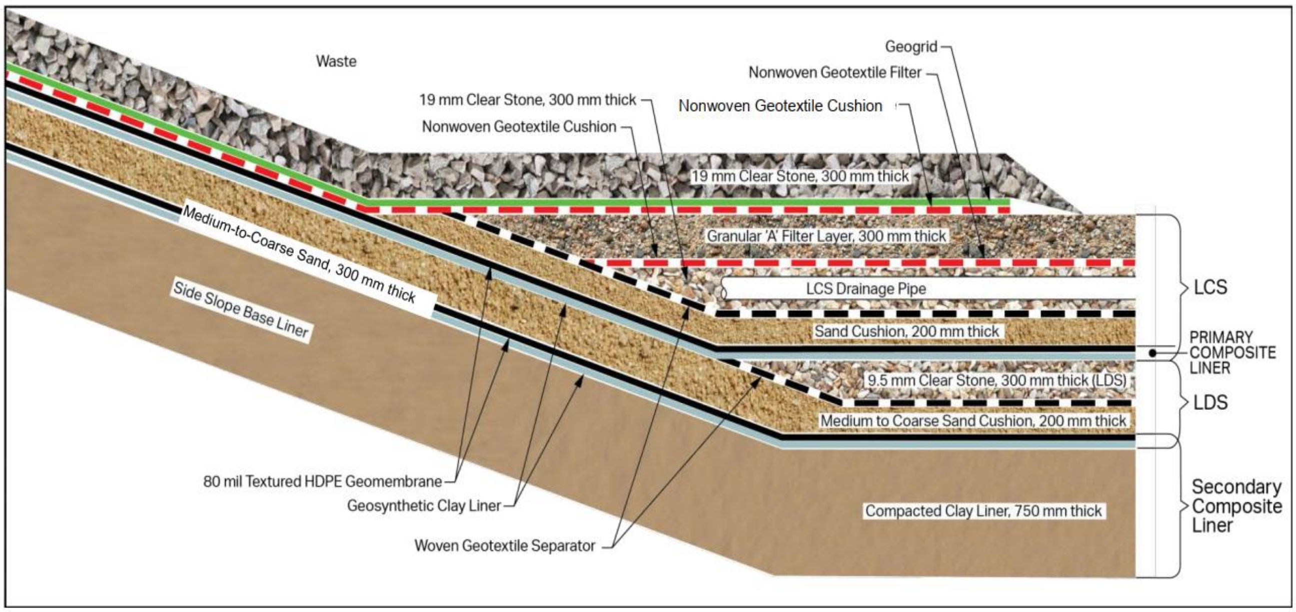

Figure 5-4 Base Liner System Intersection with the Side Slope Components

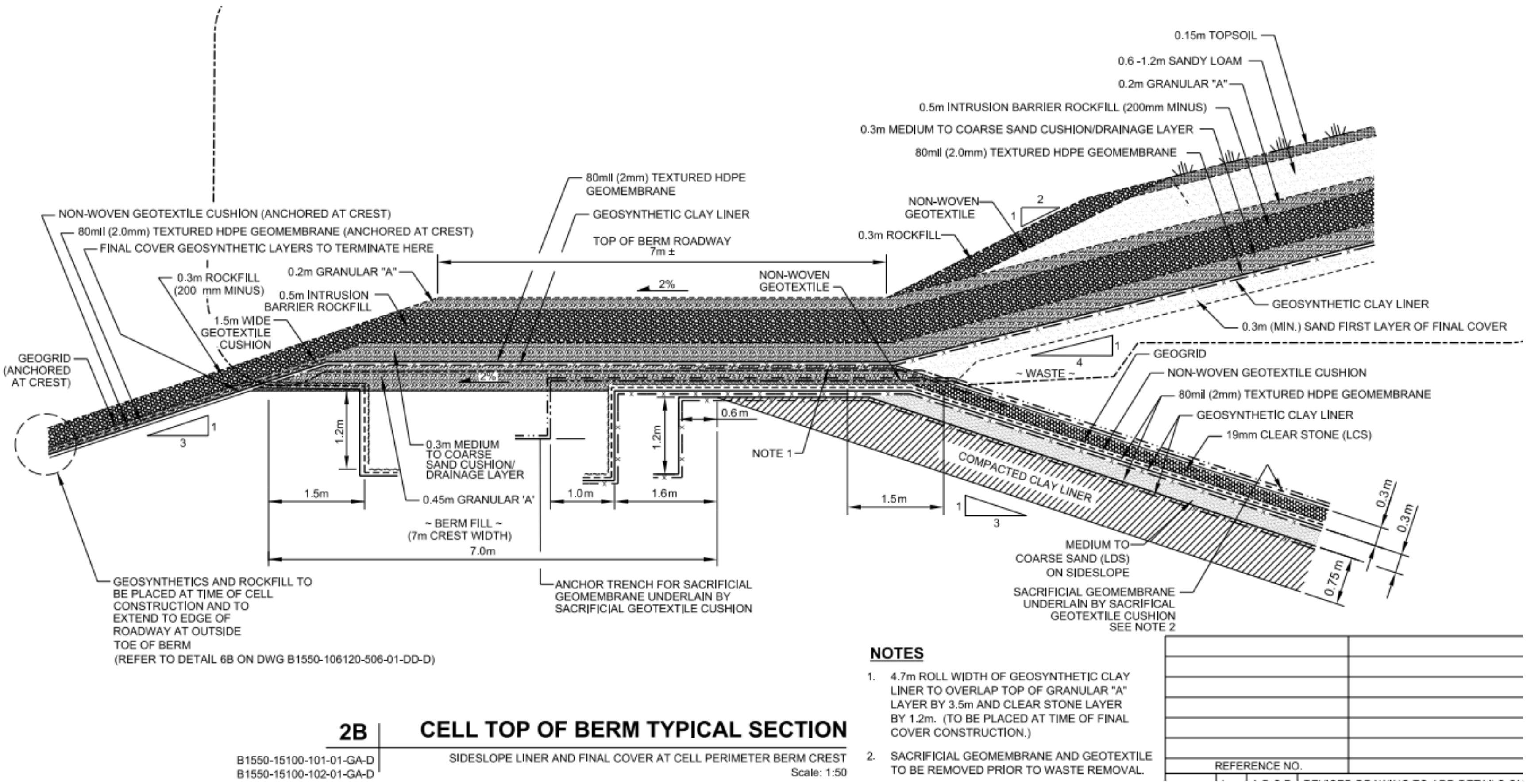

Figure 5-5 Base Liner System Side Slope Intersection with the Perimeter Berm and the Final Cover System

5.1.3 Primary Liner and Leachate Collection System

The thickness of the 19 mm clear stone layer is 300 mm throughout the ECM floor except along the full length of the valleys, where the clear stone layer thickness is increased to 0.5 m along the perforated LCS pipes.

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

- 300 mm granular 'A' filter.
- Non-woven geotextile filter.
- 300 mm layer of 19 mm clear stone with perforated leachate collection pipe.
- Woven geotextile separator.
- 200 mm thick sand cushion (liner protection).
- 2 mm textured (both sides) HDPE geomembrane liner (barrier).
- Geosynthetic clay liner (GCL) (barrier).

The LCS design includes a LCS granular drainage layer, which has a hydraulic conductivity greater than the minimum 1.0×10^{-2} cm/sec value required at the time of installation. The conveyance pipes for the LCS consist of 200 mm nominal diameter perforated HDPE Dimension Ratio (DR) 17 pipe with the perforations being 100 mm apart.

The LCS in each cell drains to an internal collection leachate sump located at the southwest end of the ECM. The ECM design includes a total of five LCS/LDS leachate sumps that are located in disposal cells 2 – 6. Figure 5-6 shows the location of the five leachate sumps, identified as Leachate Sump 2 - 6. Additional supplemental GCL layer and supplemental geomembrane layers are included above the secondary liner geomembrane (2 mm textured HDPE) component in each leachate sump, to reduce interface transmissivity and further minimize potential for leakage and to provide an additional level of protection of the secondary geomembrane. In addition, a minimum 0.1 m thick sand layer is included above the primary geomembrane, and a minimum 0.2 m thick sand layer is included above the secondary geomembrane, to provide an additional level of protection for both geomembranes.

Each leachate sump contains a LCS and LDS component. The LCS component contains a 50-mm clear stone backfill, which interfaces with the distal end of the 200 mm LCS drainage pipe, a 610 mm HDPE riser pipe, and a non-perforated cleanout riser pipe. The perforated HDPE LCS drainage pipe connects with a side slope cleanout riser pipe.

The cleanout pipes are provided to allow access to the leachate sumps and LCS drainage pipes, and to allow periodic cleaning/jetting of the LCS header pipes. Where direct access to the LCS components through the leachate extraction boxes above the leachate sumps for cleaning purposes is not possible, separate side slope riser pipe cleanout systems are provided to allow access to those LCS pipes. This is the case for Cell 1 (Valley 7) and Cell 6 (Valley 1).

The size of the HDPE header pipe segments was selected to be the same as that of each of the LCS collection pipes. All access to the LCS pipes for cleanout is gained from the top of the perimeter berm.

The LCS drains any leachate that may accumulate on the primary liner, and is intended to limit the buildup of head to 0.3 m or less during the operations and post-closure phases of the ECM.

The LCS drainage layer conveys leachate to five leachate sumps located on the south edge of the ECM in Cells 2 - 6 via a 200 mm HDPE LCS drainage pipe. From the leachate sump, leachate is pumped to a leachate extraction box located on the crest of the ECM berm, and is ultimately conveyed to the WWTP for treatment. Monitoring of leachate levels in the leachate sumps is to be performed using pressure transducers installed into the sumps.

An evaluation of the LCS drainage layer capacity and the potential for long-term chemical/biological clogging is provided in the Leachate/Wastewater Collection and LDSs Evaluation and Optimization Report [5-6].

Figure 5-7 shows the ECM leachate and contact water transfer system. Cross sections and plan views of the LCS/LDS leachate sumps are shown in Figure 5-8, Figure 5-9 and Figure 5-10.

Figure 5-6 Location of the Five Leachate Sumps

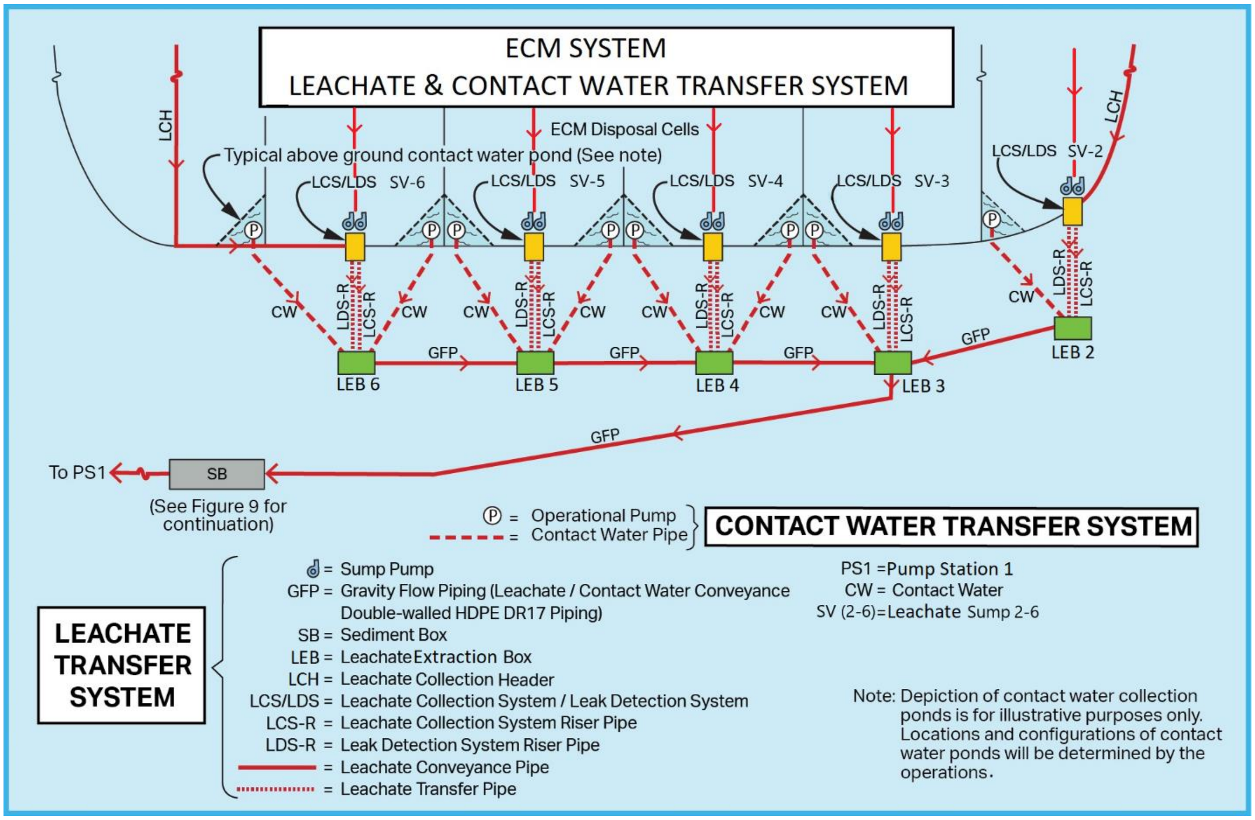

Figure 5-7 Engineered Containment Mound Leachate and Contact Water Transfer Systems

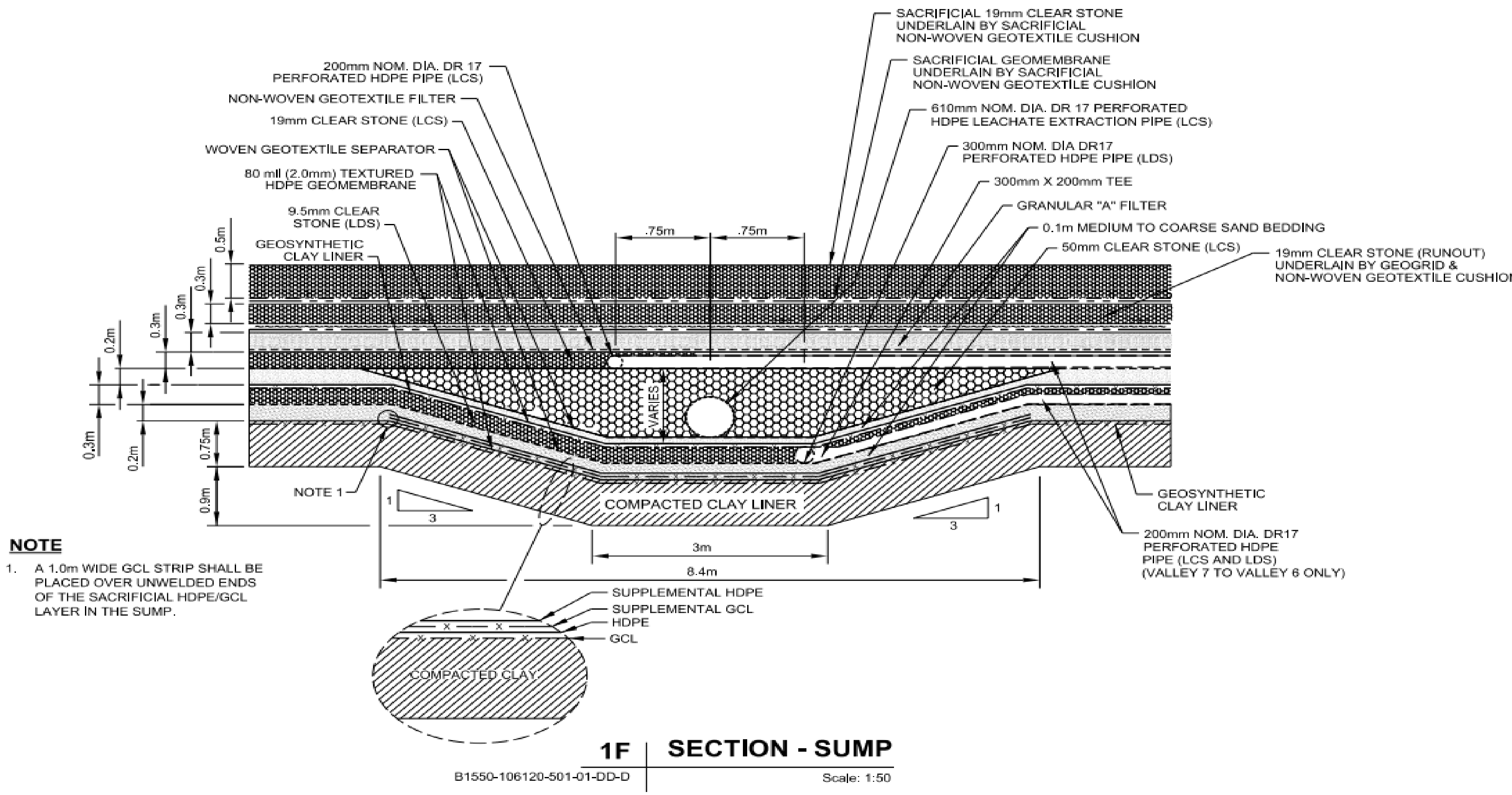

Figure 5-8 LCS/LDS System Leachate Sump Cross Section

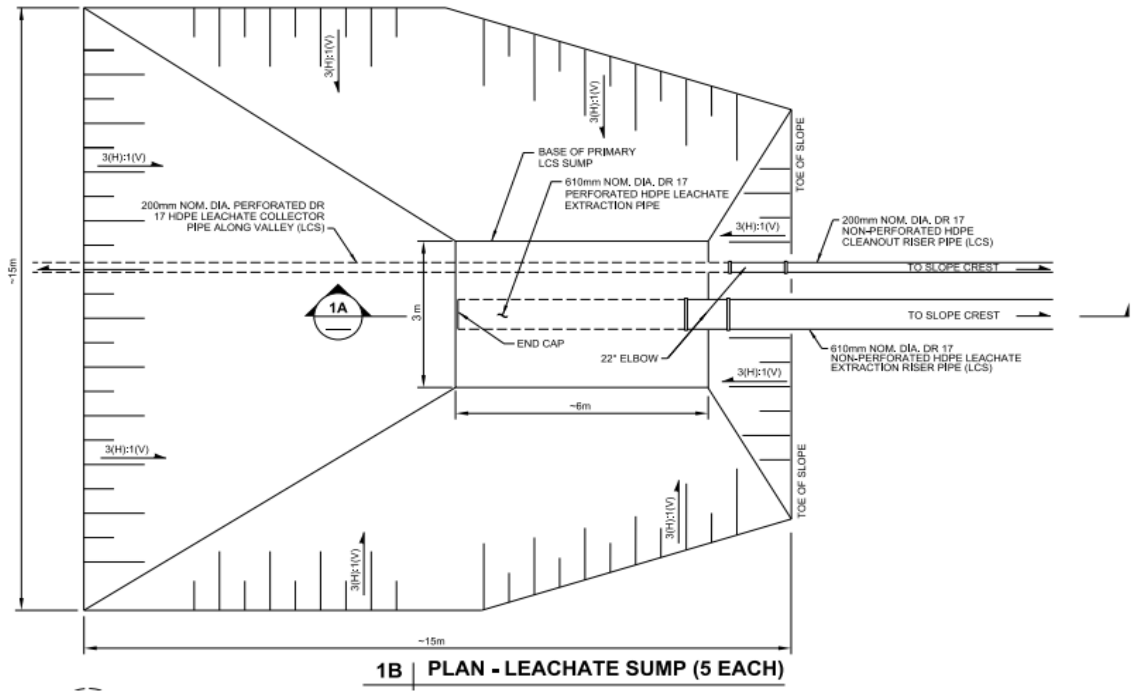

Figure 5-9 Leachate Sump Cross Section and Plan View

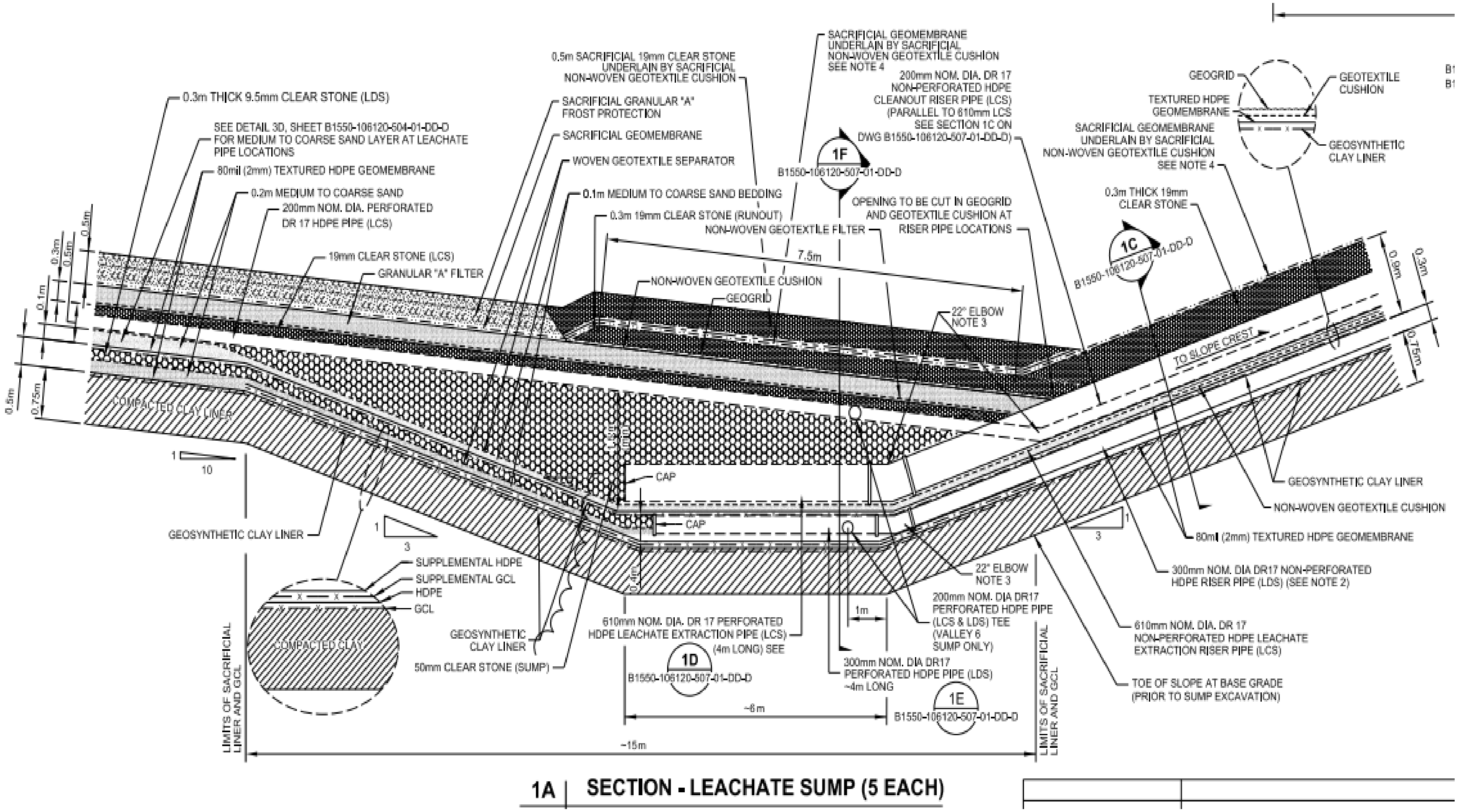

Figure 5-10 LCS/LDS Leachate Sump Cross Section and Plan View

5.1.4 Secondary Liner and Leak Detection System

A LDS is incorporated within the composite base liner system above the secondary liner. The LDS system includes the following layers/components, from top to bottom:

- 300 mm layer of 9.5 mm clear stone.
- Woven geotextile separator.
- 200 mm thick sand cushion layer.
- 2 mm (80-mil) textured (both sides) HDPE geomembrane liner (barrier).
- Geosynthetic clay liner (GCL) (barrier).

The LDS enables monitoring of any leakage flow through the primary liner and provides secondary containment for leachate that may be released through the primary liner. The LDS drains leachate and/or condensate to the LDS component of each leachate sump (for each of the five leachate sumps in the ECM). The LDS component of each leachate sump includes a 9.5 mm clear stone layer containing a section of perforated, 300 mm diameter, DR17 HDPE pipe with the perforations being 100 mm apart.

The design of the LDS does not require a perforated pipe along the valleys. The very low flows predicted for LDS can be easily conveyed by the clear stone and medium-to-coarse sand cushion layers. The piping for the LDS is restricted to the leachate sump areas and a header pipe connection Valley 7 to Valley 6.

Typical cross sections of the LCS/LDS leachate sump are shown in Figure 5-8 and Figure 5-10.

5.1.5 Perimeter Berm

The perimeter berm shown in Figure 5-11, forms the outer boundary and sidewalls comprising the perimeter of the ECM and provides containment of the wastes placed into the ECM. The primary function of the perimeter berm is to provide a means for maintaining the structural integrity of the ECM waste containment system during ECM operations and throughout the ECM design life. The perimeter berm surrounding the ECM also provides containment and isolation for the ECM waste and leachate.

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

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

The height of the perimeter berm varies from about 2 m minimum to about 15 m maximum. The lowest height of approximately 2 m is along the North West edge. The perimeter berm height is the height of the compacted free draining fill, and not the ECM perimeter sidewall height that contains the waste. Depending on the location around the ECM, the ECM perimeter sidewall consists of free draining fill (compacted), bedrock, or a combination of the two. This is due to the sloping terrain and distribution of bedrock. Figure 5-13 shows a typical section where the perimeter berm height is relatively small compared to the sidewall height. In Figure 5-13, the perimeter berm height is approximately 3.3 m and the overall height of the ECM sidewall is approximately 14.9 m. The ECM sidewall height is relatively consistent around the ECM.

The inside face of the perimeter berm is covered with the various base liner system layers, while the outer face is covered with a 300 mm rock fill barrier over an HDPE geomembrane liner, geotextile cushion, and geogrid. The top of the perimeter berm is covered with a layer of Granular 'A' material, an HDPE GMB, and a geotextile cushion. Figure 5-11 shows the perimeter berm intersection with the base liner system and the final cover system. Figure 5-12 shows the typical section of the perimeter berm outside toe.

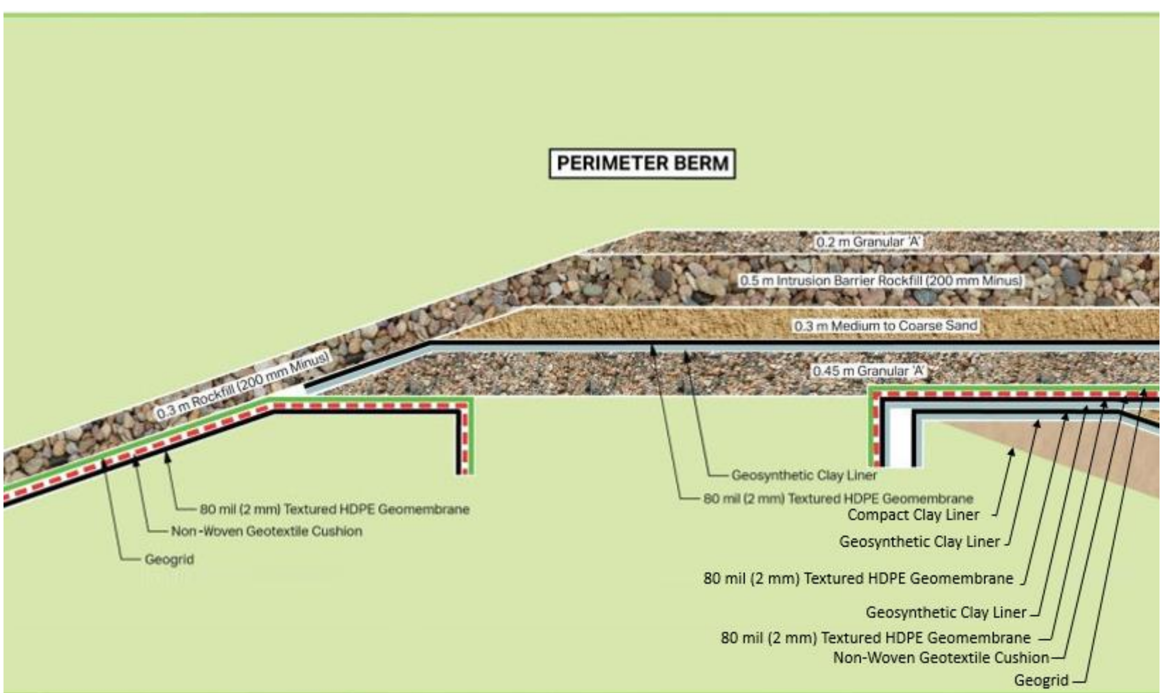

Figure 5-11 Perimeter Berm Intersection with Base Liner System and Final Cover System

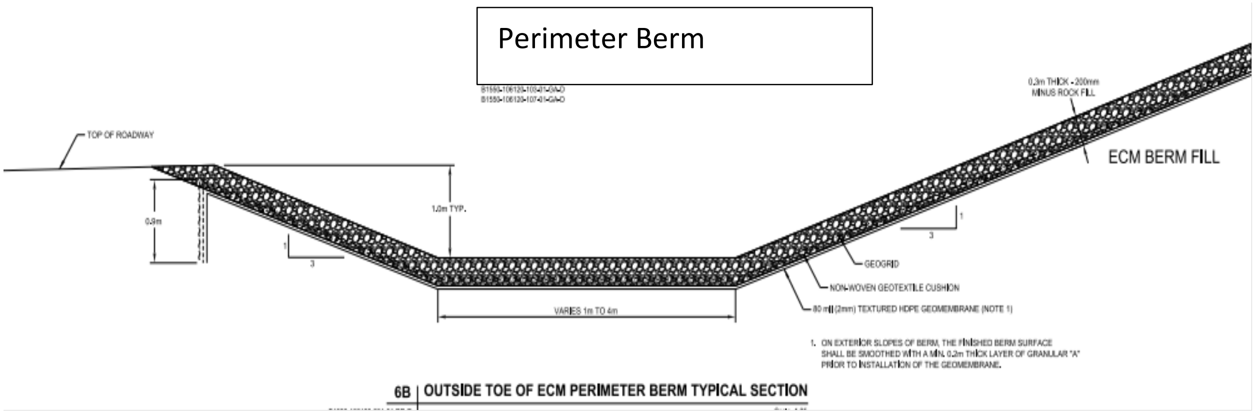

Figure 5-12 Outside Toe of Perimeter Berm (Typical Section)

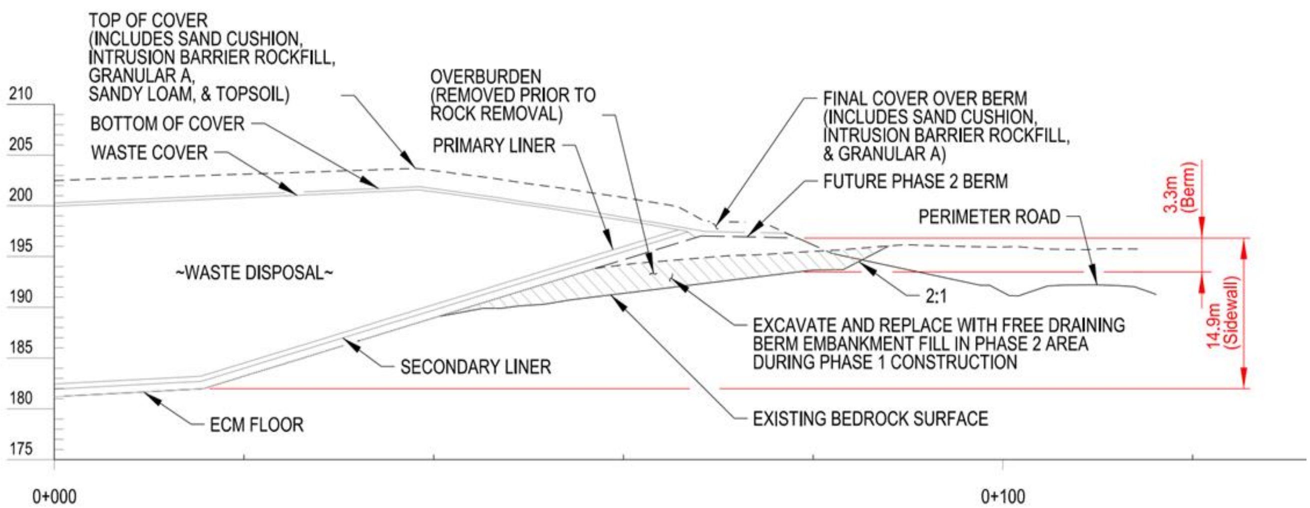

Figure 5-13 Engineered Containment Mound Perimeter Berm Typical Section

5.1.6 Temporary Storage Waste Receiving and Processing Area

The TSWRPA is constructed within the footprint of the active cell or adjacent cell, and includes the drum and waste unloading platform. The TSWRPA facilitates the safe unloading and transfer of bulk and packaged waste for storage and or processing. The TSWRPA is constructed at grade, consisting of aggregate material provided to minimize dust generation and facilitate contamination control. As the disposal cell is nearing closure, the TSWRPA will be removed and constructed within the new active disposal cell.

The TSWPRA will normally store wastes, and stored waste shall be placed in the ECM disposal cell within one year. The TSWRPA stores 800 m^3 of waste, and is sized to promote efficient unloading between the dedicated site vehicles and waste transport vehicles, to minimize handling, and to limit the potential of dust generation.

No uncontained waste is stored in the TSWRPA. All waste is either in its transportation container or disposal container, or covered with daily cover. The only processing that is performed is staging of waste or container preparation for grouting in the ECM.

5.1.7 Leachate Transfer System

The primary function of the leachate transfer system is to extract leachate and condensate from the LCS and LDS components of the leachate sumps to a leachate extraction box located at the crest of the ECM berm. From the leachate extraction boxes, the combined leachate and contact water (wastewater), enters a gravity flow system draining to CWPS #1, located at the northwest of the ECM. The gravity flow piping consists of 300 mm diameter, double-walled HDPE pipe and is buried under the surface of the exterior slope of the ECM. The gravity flow system will be sloped generally between 1.0% to 2.0% to promote self-cleaning of the pipes and minimize standing water.

Contact Water Pumping Station #2 receives water from the OSC, VDF, and the WWTP active drain. At each CWPS, water is pumped through buried force main piping to the Equalization Tanks. The force mains are constructed of 100 mm diameter, double-walled HDPE piping, and are buried at depth to provide frost protection.

Figure 5-14 shows CWPS #1 and Figure 5-15 shows CWPS #2.

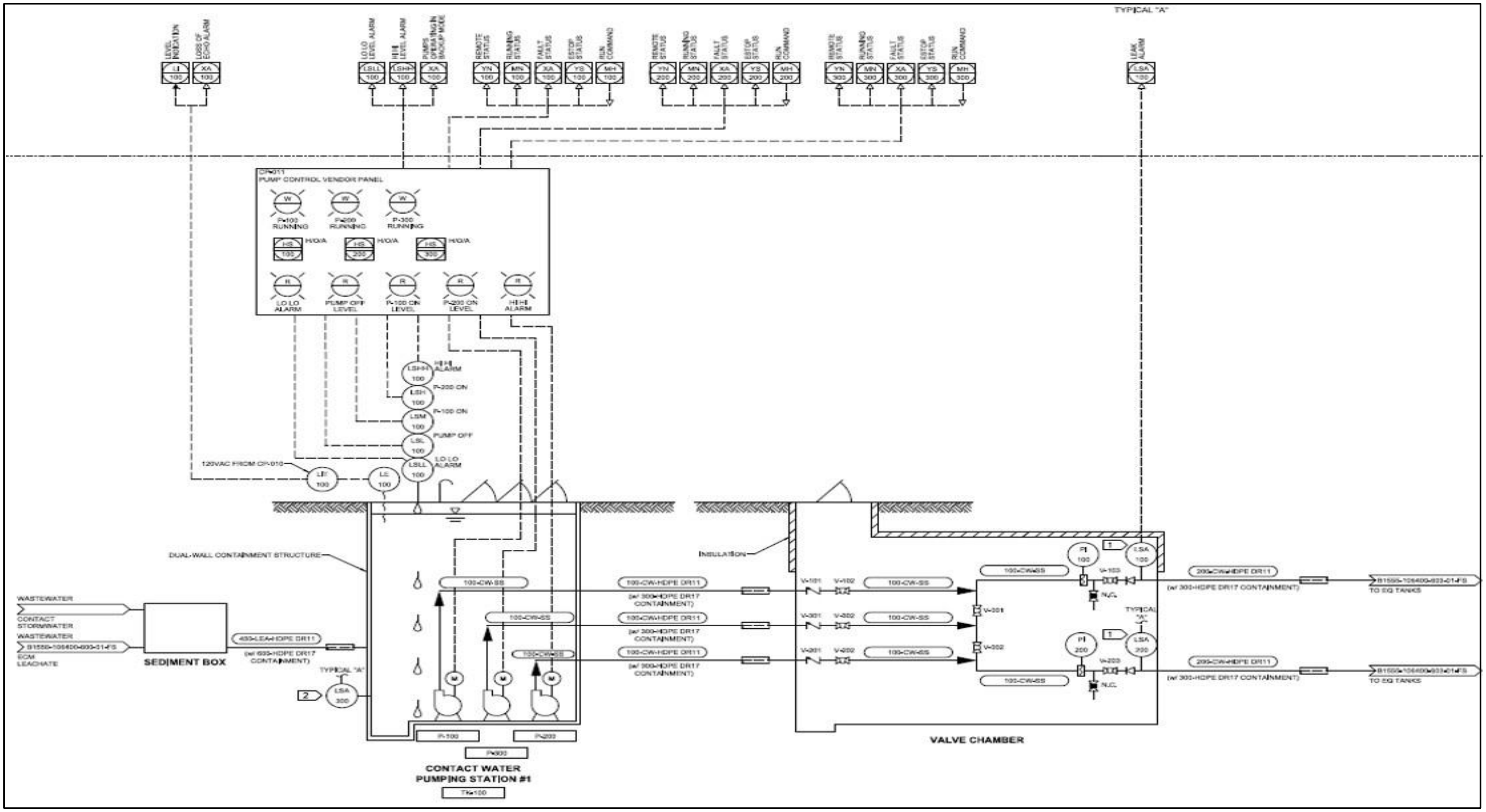

Figure 5-14 Contact Water Pumping Station #1

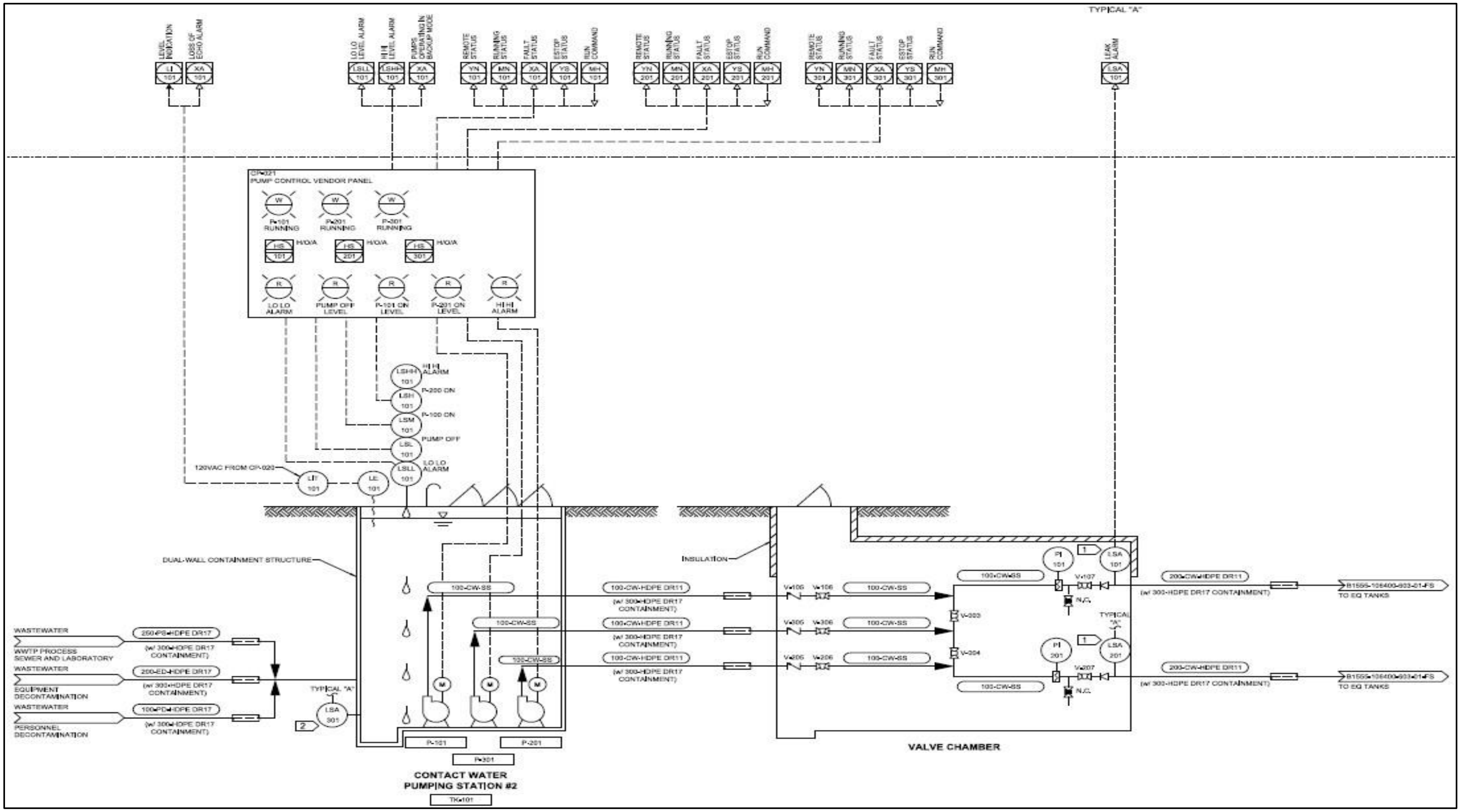

Figure 5-15 Contact Water Pumping Station #2

5.1.8 Contact Water Collection, Transfer and Conveyance System

Stormwater within the ECM is managed using engineered features and equipment such as:

- Temporary berms that segregate contact and non-contact run-off.
- Geomembranes.
- Interim Covers.
- Bladders.
- Temporary contact water storage ponds and non-contact water storage ponds.
- Contact water mobile pumps and non-contact water mobile pumps.
- Contact water pump discharge hoses that interface with the leachate extraction boxes.
- Non-contact pump discharge hoses that interface with the stormwater management system.

Contact water is managed separately from non-contact water. The primary function of the contact water collection and transfer system, is to collect and to pump contact water from the active cell to one of the leachate extraction boxes, which are located on the ECM perimeter berm crest. A mobile pump is used to transfer the collected contact water to one of the leachate extraction boxes. The pumps are sized to transfer the capacity of the contact water pond (back-to-back 100-year storm event), in a 48 hour period.

Stormwater contacting the waste is managed as contact water and collected in lined contact water ponds or structures and conveyed to the Equalization Tanks.

The ECM has been designed to allow for flexible operations and adjustment to the changing conditions related to contact and non-contact water as necessary. Contact and non-contact water are segregated through the use of erosion and sedimentation controls, including earthen berms (clean soil), sandbags, straw bales, waddles, or other management structures at the discretion of the operations staff. Routing or intermittent pumping is required to control the accumulation and transfer of both contact and non-contact water collection and management activities.

5.1.9 Non-Contact Water Collection, Transfer and Conveyance System

Precipitation that falls within the waste cells onto a waste disposal area that is covered with an interim cover, or other non-contaminated areas (e.g. inactive cell or Phase 2 area), the precipitation does not come in contact with waste and is defined as non-contact water. Non-contact water from inactive areas within the ECM is prevented from entering the active disposal cell by use of temporary berms between cells. Non-contact water is conveyed by either a pump system or a gravity based system based on the location of the non-contact water pond in the ECM and location relative to the surface water management ponds.

The primary function of the non-contact water collection and transfer system is to remove non-contact water from the ECM containment area, and convey the water to the exterior perimeter drainage channels, through which it is conveyed to the surface water management ponds located outside of the ECM. The surface water management system design considered the Probable Maximum Precipitation event, 570 mm over 12 hours [5-7]. Figure 5-1 shows elements of the non-contact water collection and transfer system.

Non-contact water is collected for all inactive cells in lined non-contact water ponds or equivalent structures located in the ECM. The non-contact water is transferred via temporary pumps into ditches located on the outside of the perimeter berm. The perimeter ditches convey the non-contact water to the surface water management ponds outside of the ECM berm. The non-contact water management system, including the perimeter drainage ditches, surface water management ponds, and the perimeter berm is designed to be capable of containing and conveying run-off from the 100-year storm event that falls in open cells, on the final closed ECM (both Phase 1 and Phase 2), and capable of safely managing run-off generated from the Probable Maximum Precipitation [5-7]. A temporary internal control pond captures non-contact water in the Phase 2 area during Phase 1 operation. The surface water is routed from this pond and through a controlled outlet for settling, attenuation and is conveyed to Surface Water Management Pond (SWMP) 3. The internal control pond provides initial Total Suspended Solids (TSS) removal to assist the design to achieve the water quality goals. To prevent storm water from entering the LCS system, a sacrificial liner for Phase 1 is provided to cover the entire floor and an interim cover is applied to the 3:1 side slope of waste disposal areas that will remain inactive for more than 30 days.

5.1.10 Daily Cover

Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face, to control the release of fugitive dust from the surface of the waste [5-1]. The Daily Cover also fulfills other functions including: minimizing erosion of placed waste, minimizing blowing litter, reducing odour, discouraging vector and vermin activity, improving equipment access to the active disposal area, and maintaining a more aesthetically pleasing site appearance [5-1].

The daily cover consists of 0.15 m layer of clean soil or an alternative daily cover material that is pre-approved for use including tarpaulin, fixative (crusting agent), or similar temporary cover system material [5-1]. The daily cover, 0.15 m layer of clean soil, provides fire protection for the placed waste, from wind-blown sparks or embers released from a fire. If a tarpaulin or fixative is used as an alternate daily cover material, the tarpaulin or fixative must be fire rated, and classified as "fire proof" [5-1]. Prior to using any fixative as an alternative daily cover material, the fixative must be verified to not adversely affect the WWTP treatment processes [5-8].

When possible, coarser-grained soil is used as daily cover, to promote the hydraulic connection between waste layers (also known as waste lifts) [5-1].

Grout, controlled low-strength material, may be used as daily cover in waste disposal areas that are using grout for void reduction, specifically for some Type 4 and Type 5 wastes [5-8]. The granular "A" sacrificial cover material on the sacrificial geomembrane, protecting the base liner system in non-active cells, when removed, can be stockpiled and re-used as daily cover [5-8].

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

At the end of each work day, the ECM worker will document that the daily cover has been applied.

5.1.11 Interim Cover

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

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

The sacrificial liner is a 1.0 mm (40 mil) thick, double-sided, textured, white-surfaced (top side only) linear low-density polyethylene (LLDPE) geomembrane that is adequately anchored to prevent uplift by wind. In addition, the sacrificial liner is to be durable, have a suitable coefficient of expansion and be resistant to ultraviolet radiation damage [5-1].

Figure 5-16 shows the interim covers on waste disposal areas (inactive 3:1 face) that will remain inactive for more than 30 days and waste disposal areas (cell 1 and cell 2) that have reached the design waste fill grade.

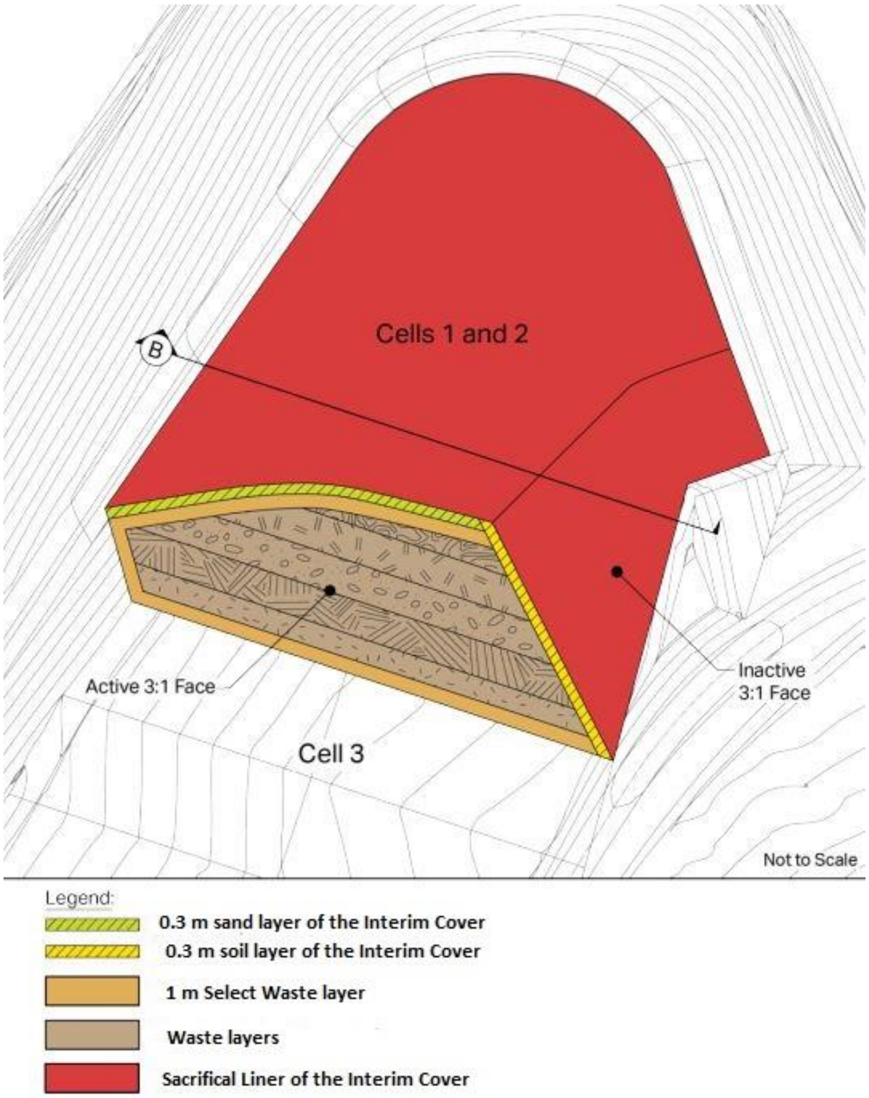

Figure 5-16 Interim Covers

5.1.11.1 Inactive Waste Disposal Areas

The interim cover consisting of 0.3 m layer of clean soil overlain by a sacrificial liner is applied to waste disposal areas that will remain inactive for more than 30 days. The interim cover, including the clean soil layer and sacrificial liner, are removed prior to the resumption of waste placement, to the extent practical, to promote hydraulic connection between waste lifts.

5.1.11.2 Waste Disposal Areas that have Reached the Design Waste Fill Grade

The interim cover consisting of 0.3 m layer of clean sand overlain by a sacrificial liner is applied to waste disposal areas that have reached the design waste fill grade, and are awaiting installation of the final cover system. The interim cover is installed on the 1 m layer of select waste. The primary function of the sacrificial liner is to protect the 0.3 m layer of clean sand, first layer of the final cover system, against erosion, promote non-contact surface water run-off, and limit precipitation infiltration into the sand layer and underlying wastes prior to the installation of the remaining layers of the final cover system [5-8].

The sacrificial liner is removed during the installation of the final cover system. The 0.3 m clean sand layer of the interim cover is not removed for the installation of the final cover system, and is regraded to eliminate low areas.

5.1.12 Final Cover System

A multi-component final cover system will be constructed over the entire surface of the completed containment mound. The primary function of the final cover is to provide containment of the disposed wastes and minimize water infiltration. The final cover system has a combined total thickness that varies, but has a minimum thickness of 2.05 m. The final cover system shown in Figure 5-17, consists of the following layers, top to bottom:

- Vegetative cover.
- Topsoil, 150 mm thick.
- Sandy loam, 600 mm to 1 200 mm thickness.
- Granular 'A' filter layer, 200 mm thick.
- Intrusion barrier rock fill, 500 mm thick.
- Medium-to-coarse sand, 300 mm thick.
- Textured (both sides) 80 mil HDPE geomembrane.
- Geosynthetic Clay Liner.
- Temporary sacrificial liner. Note: The temporary sacrificial liner is placed during operations. The temporary sacrificial liner will shed non-contact water from the disposal cell operations. The temporary sacrificial liner will be removed prior to placement of the subsequent final cover materials.
- Sand, 300 mm thick.

Additional description of each layer of the final cover, is provided below.

- **<u>Sand Layer</u>** – The first layer, sand, of the final cover, provides a smooth base and contains an appropriate subgrade moisture content for installation of the GCL. This layer also helps facilitate upward movement of LFG that may be generated in the ECM below the GCL component of the final cover into the passive system for discharge to the atmosphere.

- **Temporary Sacrificial Liner** – The temporary sacrificial liner is placed during operations. The temporary sacrificial liner sheds non-contact water from the disposal cell operations, and will be removed prior to placement of the subsequent final cover system materials.
- **Geosynthetic Clay Liner (GCL)** – The GCL functions as a lower (secondary), low permeability barrier that also limits the downward leakage through any potential defects that might exist in the overlying geomembrane liner, and provides a back-up hydraulic barrier in the unexpected event that the geomembrane experiences deterioration over the design life of the Facility. This role of the GCL requires that its hydraulic conductivity remain at a low value over the design life of the ECM. In the event of a hole or leak in the 80 mil HDPE geomembrane, the clay portion of the GCL would hydrate, forming another barrier to mitigate any potential leakage flow downward into the waste profile, thereby creating essentially a self-healing effect on the hole or leak in the HDPE liner.
- **HDPE Geomembrane** – A textured, 80-mil thick, HDPE geomembrane liner is placed directly on the GCL. The geomembrane serves as the upper (primary) barrier against infiltration through the cover into the buried wastes. It is also expected to prevent or minimize the upward migration of radon and other LFGs from the waste fill into the atmosphere.
- **Medium to Coarse Sand layer** – A sand layer is incorporated over the HDPE geomembrane liner to minimize the localized strains from resultant loads by the larger grain-sized aggregate above.
- **Intrusion Bio-barrier Rockfill** – The 0.5-m-thick intrusion barrier rock fill layer is included to deter burrowing animals and roots from potential deeper-rooted plant species reaching and possibly damaging the cover lining system, as well as penetrating into and transporting contaminants from the waste fill. This rock fill layer would also help deter inadvertent future intrusion into the buried wastes by humans. The layer also provides for some lateral drainage of water that percolates through the upper layers of the cover.
- **Granular 'A' Drainage Layer** – The principal function of the 0.2 m-thick granular filter layers above the intrusion bio-barrier layer, is to provide a natural filter layer to minimize the possibility of fines migrating downward from the sandy loam fill layer to the underlying intrusion bio-barrier, to help minimize the potential for future clogging of the bio-barrier layer. It also allows for some degree of lateral flow diversion within the cover system.
- **Sandy Loam** – The primary purpose of the 0.6 to 1.2 m-thick sandy loam layer is to provide moisture retention for plant uptake and evapotranspiration. This moisture retention is important for promoting surface plant root development, which is important for transpiration and minimizing surface erosion processes. This layer also provides additional gamma radiation shielding and additional confining stress for the final cover lining system.
- **Topsoil Layer** – A 0.15 m topsoil layer is placed on the top of the cover system. This provides a growth zone for hardy grasses.
- **Vegetative Cover** – The final cover is vegetated to provide an aesthetically pleasing surface, enhance evapotranspiration, and reduce the potential for erosion.

The final cover system is designed to protect both the human and natural environment from the waste materials and associated contamination, and ensures ambient gamma radiation at the surface close to background. The final cover system, typical section, is shown in Figure 5-18.

The final cover system is designed to mitigate the ingress of surface water. The estimated steady state leakage rate through the final cover is 0.3 mm/year after final construction. Considering a total final cover area of approximately 12 hectares for the ECM, this calculated leakage rate through the final cover corresponds to an estimated post-closure (steady state) leachate generation rate of approximately 37 m^3/year [5-9].

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

The final cover system is designed with a minimum 2% (cross slope) and a minimum 5% (drainage direction), to provide positive drainage off the ECM top deck surface, allow for accommodating potential long-term effects of localized differential settlement, if it were to occur during the post-closure period, and maintain cover stability. Details pertaining to slope stability analyses performed for the ECM are documented in the Base Liner and Final Cover Evaluation and Optimization [5-10], and Slope Stability Analysis [5-11].

Table 5-3 provides tolerance requirements for differential settlement of the final cover system after construction, to maintain positive drainage of surface water and to minimize localized tensile strains in the geomembrane liner. Minimizing local tensile strains in the geomembrane is important in preventing long-term stress cracking of the geomembrane. In this regard, a maximum allowable strain of 5% has been set for the final cover geomembrane liner as documented in Recommended Maximum Allowable Strain and Design Considerations for HDPE Geomembrane to be used in the NSDF [5-12]. For the final cover design, differential settlement and displacement under earthquake loading are the primary potential sources of geomembrane tensile strains. The tolerance requirements for the final cover settlement provided in

Table 5-3 [5-1], limit the tensile strains from differential settlement to approximately 0.1%.

Settlement monitoring is performed to verify differential settlement trends in the ECM. Settlement plates are to be installed during operations to verify settlement trends prior to placement of the complete final cover system. Settlement monitoring is to be conducted as detailed in the Closure Plan [5-13].

The final cover system is designed with a ridge and valley geometry. Cross-slope inclinations of the ridge/crest configuration consisting of the sandy loam and topsoil layers are graded at 2% slopes. Ridge crests are approximately 30 m apart. The purpose of the ridge and valley geometry is to reduce the occurrence and magnitude of concentrated flows and to maintain run-off from the cover system in a controlled manner.

The geomembrane in the final cover may experience some localized strains due to differential settlement of the waste. However, much of the differential settlement is expected to be related to differences in the compressibility of the waste under its self-weight and therefore, is expected to occur prior to construction of the final cover. Long-term differential settlement, due to differences in biodegradation rate of the waste fill, is expected to be minor due to the low content of decomposable organic matter. Localized tensile strains in the cover geomembrane, due to differential settlement, are therefore expected to be small [5-9].

Table 5-3
Tolerance Requirements for Final Cover Settlement [5-1]

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

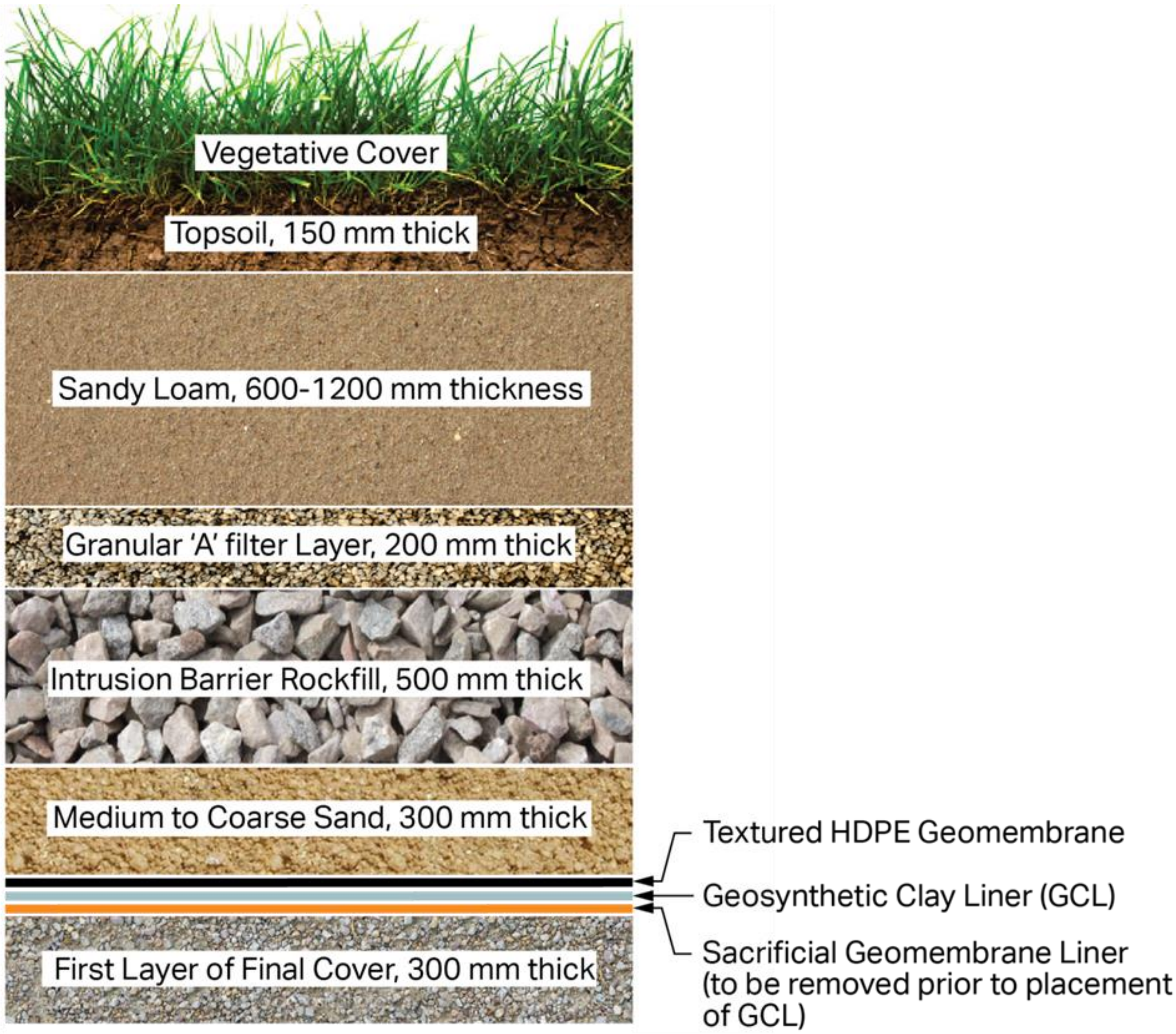

Figure 5-17 Final Cover System

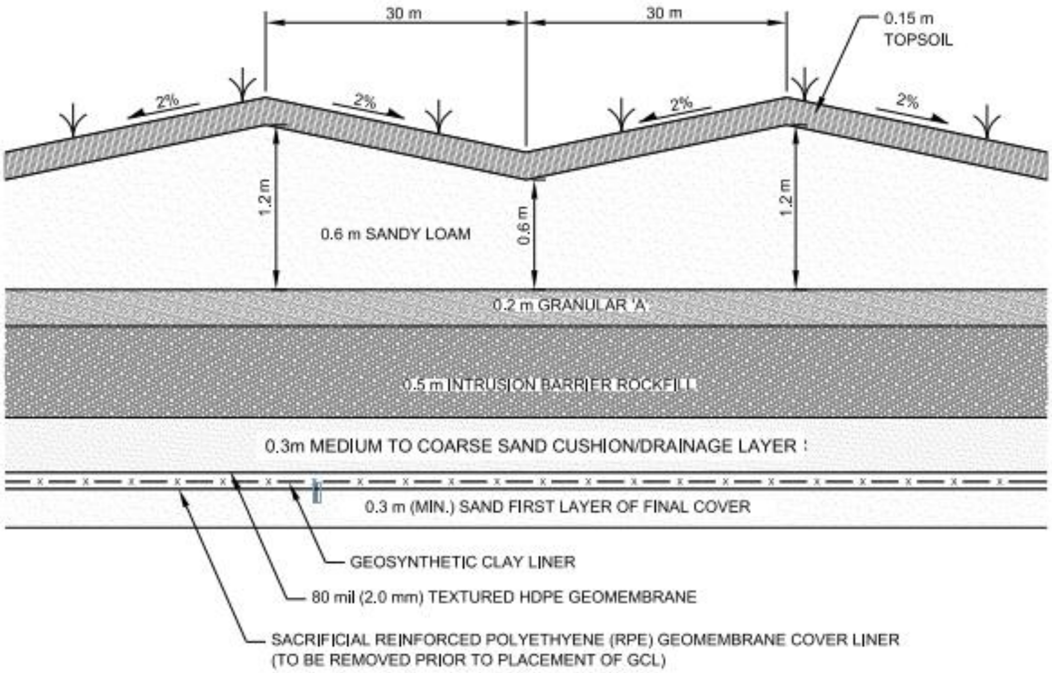

Figure 5-18 Final Cover System Typical Section

5.1.13 Landfill Gas Venting

A passive gas collection and venting system is included in the ECM design. The primary function of the gas venting system is to passively collect, control and safely dissipate gases that may be generated within the ECM following placement of the final cover system. The predicted LFG composition and generation rates are documented in Landfill Gas Management Plan [5-14]. Vertical gas vent pipes are to be placed in the final cover in specified locations in Phase 1 and specified additional locations in Phase 2, in order to minimize the potential for excessive build-up of pressures under the cover system and installed in a manner to preclude negatively impacting the integrity or stability of the cover system. Gases to be vented include gases that may be generated from biological decomposition, corrosion, and radioactive decay of the placed wastes. The passive venting system includes a sand bedding layer placed beneath the GCL and HDPE geomembrane in the cover, and a series of geovent strip drains placed atop the sand bedding layer and beneath the GCL and HDPE, connecting to the vertical vent pipes. A maximum spacing interval of approximately 186 m will be used for the LFG vents [5-14].

Landfill Gas vent pipes are constructed using 316 Stainless Steel (SS) (e.g. Schedule 10), that is resistant to long-term deterioration of the piping as a result of ultraviolet light and is resistant to long-term corrosion from adjacent soils.

Each vent pipe extends from the “sand bedding layer” to the top of the final cover, extending to a height of approximately 3 m above the final cover surface. The base of each vertical gas vent pipe will be stabilized by including a trapezoidal mound of Granular ‘A’ stone material around the base of each vent pipe and on top of the HDPE geomembrane. A similar mound of Granular ‘A’ stone material will be placed and compacted, if required, around the top portion of each vent pipe where it exits the final cover extending to a depth of 0.3 m below the top of the final cover system to further secure the vent pipes.

At the end of the Institutional Control Period (ICP); (330 years after ECM closure), the passive LFG vent pipes are backfilled with gravel from the bottom of each vent pipe to the height of the top of the final cover system and the above-ground portion of each vent pipe removed.
Land GEM modelling and Table 5-4 shows that the expected bulk LFG generation rates will be at a maximum approximately one year after closure of the ECM. After closure of the ECM and construction of the final cover, gas generation decreases as there is reduced availability of moisture and oxygen in the waste [5-15]. The gravel backfill placed in the below-grade portions of the passive vent pipes would allow for the continued future release of pressure, resulting from remaining small amounts of LFG that might be generated beyond the end of the ICP, while also preventing intruders that could be detrimental to the performance of the final cover system. A schematic of a vertical gas venting pipe is shown in Figure 5-19.

Table 5-4
Landfill Gas Generation Results from LandGem Modeling [5-15]

Year After Start-up of ECM	**LFG Generated (m^3/y)**	**Methane Generated (m^3/y)**	**Carbon Dioxide Generated (m^3/y)**
10	5.018E+04	2.509E+04	2.509E+04
20	1.062E+05	5.308E+04	5.312E+04
30	1.596E+05	7.980E+04	7.980E+04
40	2.046E+05	1.023E+05	1.023E+05
50	2.475E+05	1.237E+05	1.238E+05
51	**2.517E+05**	**1.258E+05**	**1.258E+05**
100	1.970E+05	9.849E+04	9.849E+04
150	1.534E+05	7.670E+04	7.670E+04
200	1.195E+05	5.974E+04	5.974E+04
250	9.305E+04	4.652E+04	4.652E+04
300	7.246E+04	3.623E+04	3.623E+04
350	5.644E+04	2.822E+04	2.822E+04

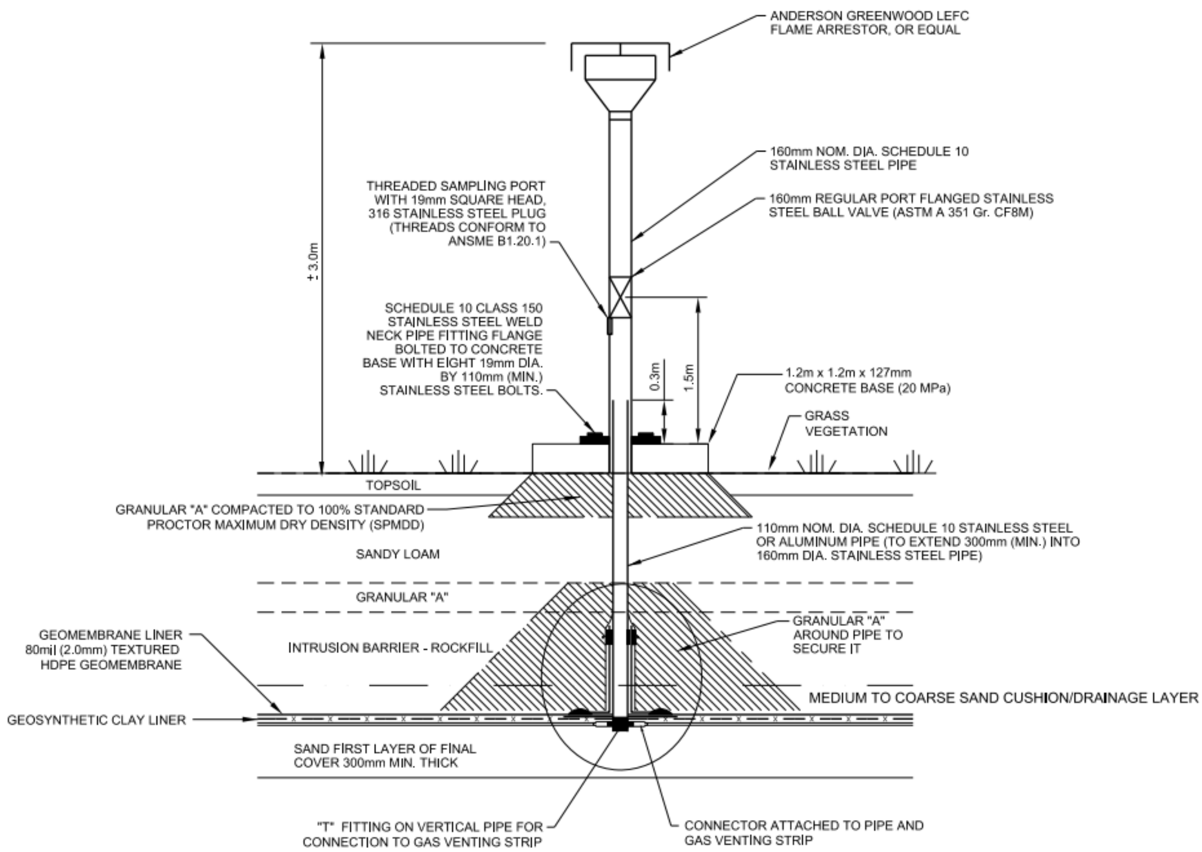

Figure 5-19 Vertical Gas Venting Pipe

5.1.14 Weather Cover Concept

Additional measures that could be taken to keep the waste dry during waste handling, placement and storage (operation), and minimize precipitation infiltration into the active disposal cell are being considered including assessing the feasibility of using a conceptual weather cover structure over the open disposal cell to minimize contact water and precipitation infiltration [5-16]. Minimizing precipitation infiltration into the active disposal cell will reduce the volume of leachate and contact water generated in the ECM. However, this concept will increase the volume of water that is managed as non-contact water within the surface water management system [5-16]. The NSDF Project considers the Weather Cover Structure to be an optimization of the current design, and that the ECM can be operated effectively without the Weather Cover Structure [5-16].

The weather cover concept [5-16] that is being developed could be implemented at many points in the operational life cycle of the ECM (e.g. before Cell #2 opens, half way through filling

Cell #3 etc.). Note that the weather cover concept requires a rectangular geometry thus, the concept may not be applicable for use on Cell #1 or will not fully cover other cells due to the shape constraints. Figure 5-20 and Figure 5-21 show preliminary figures of the weather cover structure concept.

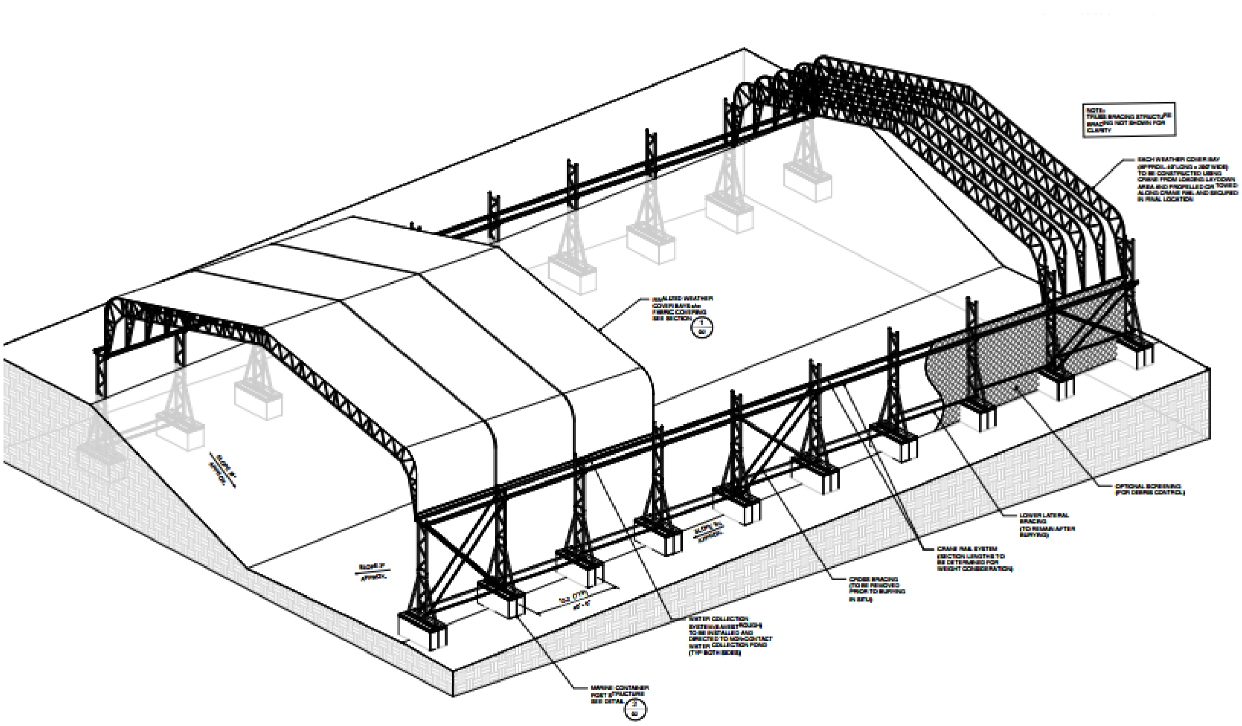

Figure 5-20 Weather Cover Structure Concept

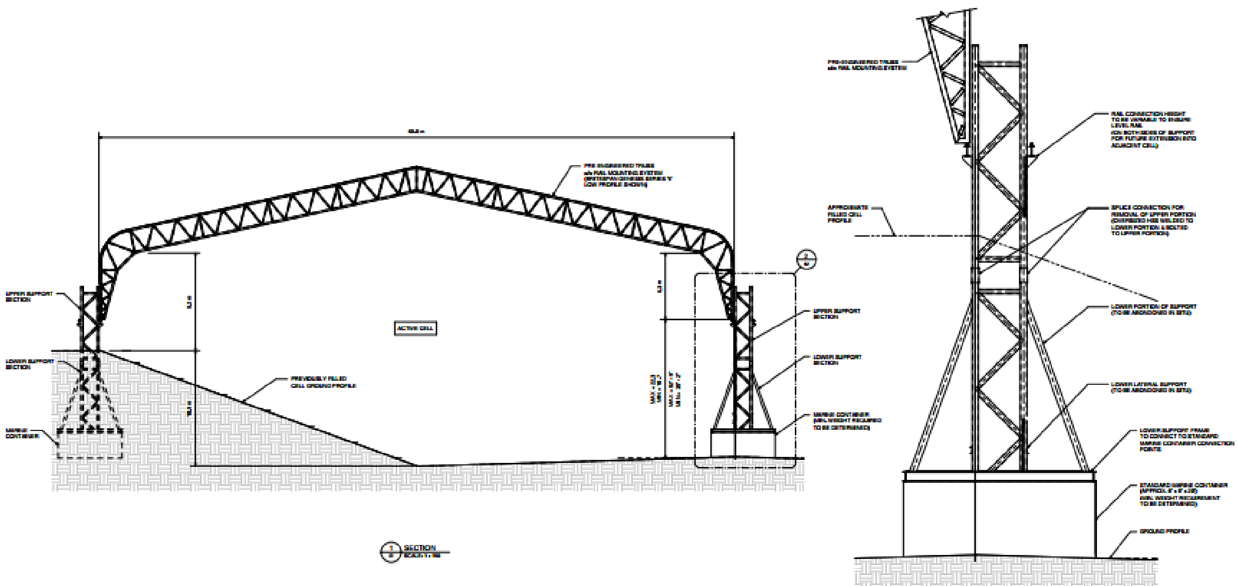

Figure 5-21 Weather Cover Structure Concept

5.2 Waste Water Treatment Plant

The WWTP building houses the wastewater treatment process equipment, support equipment, and areas for administration and services. The WWTP building area is approximately 2 489 m^2, and the building dimensions are approximately 39 m width, 64 m length and 13.5 m height with a lower height of 10 m. The building has a mezzanine floor that is approximately 5 m high. The WWTP structure has an approximate design life of 55 years [5-1]. The WWTP is designed for a 50 year operational life, but may be operated for a period beyond 50 years, if proper maintenance and equipment replacement are provided [5-1].

The WWTP treats NSDF wastewater and the wastewater sources include:

- ECM leachate.
- ECM contact water.
- Decontamination water from VDF.
- Laboratory wastewater.
- Wastewater generated during WWTP operations including recycle flow.

Process treatment technologies, were selected based on a determination of Best Demonstrated Available Technology Economically Achievable, as provided in Design Concept Decision (Optioneering Study) for the WWTP [5-17]. The WWTP consists of the following systems:

- Equalization Tanks (influent flow equalization).
- Wastewater transfer system (from Equalization Tanks to WWTP).

- Chemical Precipitation Membrane Filtration.
- pH adjustment.
- Polishing treatment system.
  - Granular Activated Carbon (GAC) polishing.
  - Ion Exchange (IX) resin polishing (Zeolite and strong acid cation).
- Final effluent storage and sampling.
- Residuals management area - storage and filter press.
  - Spent IX resin, spent GAC media.
- Chemical storage and metering.
- Process control systems.
  - Supervisory Control and Data Acquisition (SCADA) System.
  - Building Automation System (BAS).
- Hardwired trips, interlocks, or alarms that are important to safety.
- Effluent conveyance and discharge.
- Compressed air system.

A simplified process flow diagram is provided in Figure 5-22. Influent Equalization Tanks are located outside of the WWTP building. The layout of the WWTP process area is separated into:

- Chemical storage Rooms 1 & 2.
- Chemical precipitation and filtration area.
- Polishing treatment area.
- Residue management area.
- Personnel decontamination area.

The chemical precipitation and filtration area, has a concrete floor mezzanine level to house the microfiltration systems and chemical precipitation systems, as well as closed mechanical rooms containing the air compressors, and chemical room air handling equipment. Below the mezzanine a pipe gallery links the systems to one another. Metal service platforms and stairs provide service access to all equipment. There is a 5-tonne overhead bridge crane in the chemical precipitation and filtration area.

The polishing treatment area contains the pH adjustment tanks (permeate and final), polishing system feed tank, GAC vessels, IX resin vessels, the final effluent storage tanks. The polishing treatment system is designed for removal of radionuclides, metals, and organic constituents that remain in the wastewater after the chemical precipitation and filtration system.

The residues management area has an elevated platform for the filter press, below a dewatered solids bin. Connected to the side of the residuals management area are equipment and personnel decontamination rooms. Within the residuals management area, a modular steel box contamination control enclosure is erected around the filter press and residuals bin, which creates an enclosed ventilated Radiological Safety Zone 3 space. There are two 2-tonne monorail hoists in the residue management area.

The finished floor of the entire process area is depressed by 150 mm to provide containment for firewater and leakage from tanks and other process systems. The finished floor is sloped towards various active drains which collect to a single point at the boundary of the WWTP building, then draining into a gravity sewer to Contact Water Pump Station #2.

The chemical feed tanks are surrounded by trenches sloped to a dry sump with grating flush to the finished floor.

The WWTP key support areas include:

- A WWTP control room housing workstations for the SCADA and BAS, wraparound console and hardwired alarm annunciation panel.
- Communications HUB room with three Information Technology racks for various systems requiring data connections.
- Laboratory for on-site wastewater system performance testing.
- Mechanical room housing supply and exhaust air handling equipment for the building.
- Electrical room housing the Motor Control Centre and I&C panels.
- Compressor room.
- Mechanical Room #2 (houses rainwater harvesting system).

The WWTP includes a dual-train treatment system for treating NSDF-generated wastewater. The WWTP process was designed based on consideration of the outcome of the Leachate and Wastewater Treatability Assessment [5-18]. The peak flow rate of the treated effluent from the WWTP is determined by the WWTP's treatment capacity. The WWTP has two treatment trains each, with a treatment capacity of 3.155 L/s in a continuous final effluent discharge scenario. A batched final effluent discharge scenario is also available to confirm the final effluent quality before releasing. The WWTP's treated effluent conveyance system is sized to convey the WWTP's peak discharge capacity of 12.5 L/s (45 m^3/h) based on batch discharge. Based on a six hour production cycle, the WWTP can process 540 m^3/day.

The building has been designed with fire rated walls. All relevant service rooms within the building will be separated by 1-hour rated walls in accordance with NBCC. Chemical rooms and radiological areas are separated from non-radiological areas by two-hour rated walls in accordance with CSA N393. A clean agent gas suppression fire protection system is provided for the HUB room and designed in accordance with NFPA 2001.

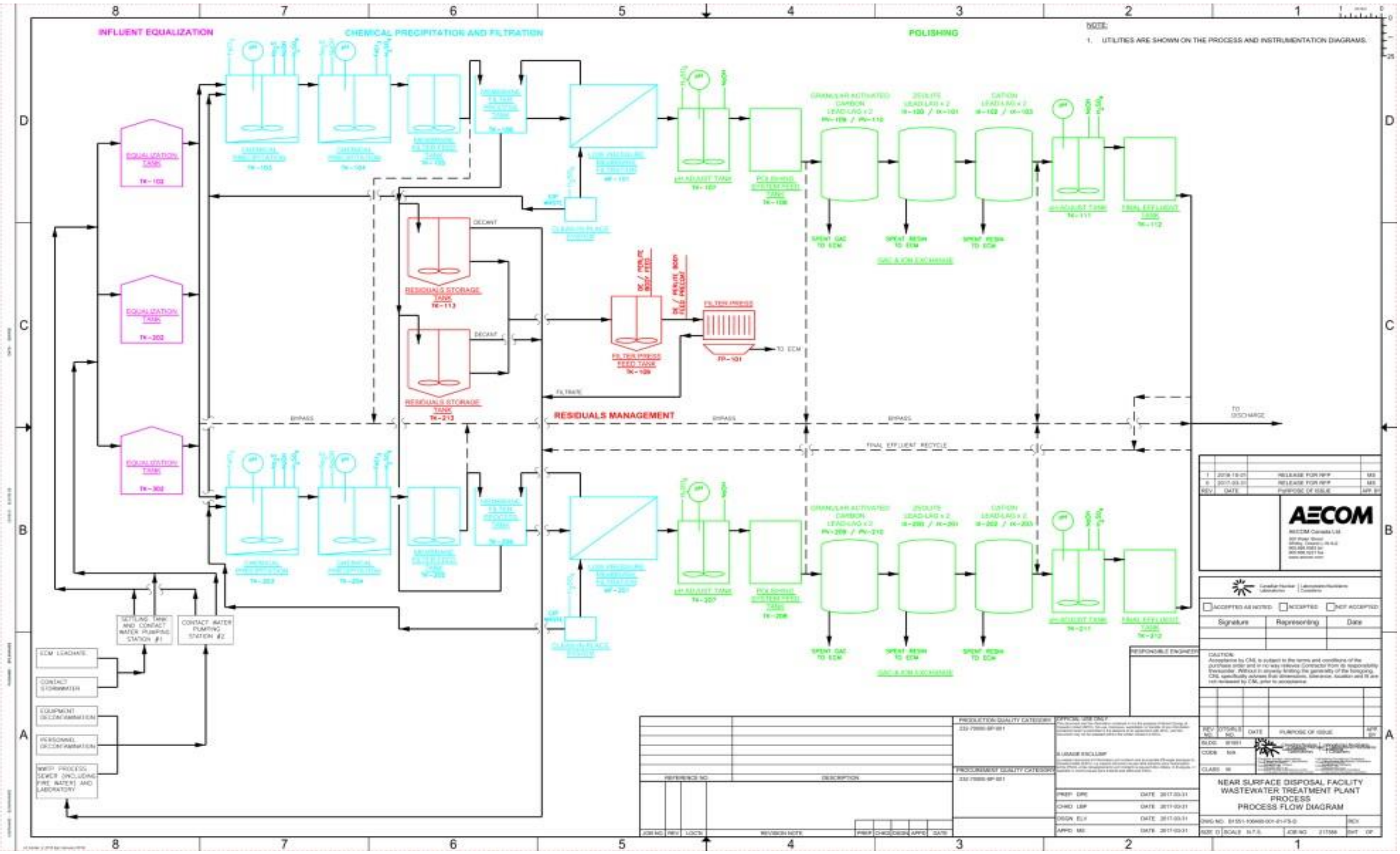

Figure 5-22 Waste Water Treatment Plant Process Flow Diagram

5.2.1 Equalization Tanks (Influent Flow Equalization)

The influent equalization system is designed to store and equalize wastewater generated at the NSDF including:

- ECM leachate.
- ECM contact water.
- Equipment and personnel decontamination water.
- Laboratory wastewater.
- Recycle flows (including fire water) from the WWTP active drain.

The influent equalization system is designed to contain 4 710 m^3 of contact water that would be produced from the largest cell of the ECM during back-to-back 100 year, 24-hour storm events. Three above-grade, covered tanks, constructed of SS, each with a capacity of 1 900 m^3, will provide the required equalization volume. The equalization volume was selected to contain the worst-case contact water flow, as well as provide adequate buffer capacity for ongoing WWTP operations.

Three Equalization Tanks, provide worker flexibility to process wastewater from one tank, divert less concentrated wastewater (contact water) to a second tank, and allow one tank to be taken out of service for cleaning and maintenance during dry weather conditions.

Wastewater is transferred to the Equalization Tanks from two pumping stations (CWPS #1 & 2). Double-walled piping, equipped with leak detection, is used for transfer of wastewater to and from the Equalization Tanks for all below-grade transfer piping installed outside of the Equalization Tanks containment area and WWTP building.

The Equalization Tanks are installed within a concrete secondary containment area designed to contain 110% of the volume of a single tank, in accordance with Ontario Ministry of Environment and Climate Change guidelines. The secondary containment volume is sufficient to contain the volume of a single tank, plus the volume of precipitation in the secondary containment area equivalent to a 100 year, 24-hour storm event. The concrete floor of the secondary containment area slopes to a collection sump equipped with a level instrument. Water collected in the secondary containment sump is sampled and analyzed to determine if it is an accumulation from precipitation or from a leak in the Equalization Tanks or piping. Spills or leaks from the Equalization Tanks are directed to the secondary containment sump and pumped back to the Equalization Tanks for treatment. Precipitation should be removed from the containment area soon after precipitation events, to prevent the accumulation of stormwater in the area.

Each Equalization Tank is equipped with level instruments and includes piping and valves to allow the worker to direct influent wastewater to and from the selected tank. Freeze protection is provided for each of the Equalization Tanks. The freeze-protected Equalization Tanks are equipped with immersion heaters to maintain wastewater temperature above freezing, and are insulated and clad to minimize loss of heat. The immersion heaters are inserted within an enclosed pipe housing from the sidewall of the tank near the bottom, and can be removed from the housing for service. The heaters do not directly contact the wastewater. All exposed wastewater piping installed outside of the WWTP building is heat traced and insulated.

In the event that the duty Equalization Tank reaches its maximum capacity (and wastewater influent flow has not been switched to another Equalization Tanks), all leachate extraction pumps and contact water pumps are automatically shutdown to prevent Equalization Tank overflow; the system is restarted by operating personnel when Equalization Tank capacity becomes available.

5.2.2 Wastewater Transfer System (from Equalization Tanks to WWTP)

Three pumps (two duty, one standby), equipped with variable frequency drives, are installed within the WWTP building and transfer wastewater from the Equalization Tanks to Train 1 and/or Train 2 of the treatment system. Flow meters measure and totalize the rate of wastewater flow transferred to each treatment train. Each pump has a wastewater transfer capacity of up to 11.36 m^3/hour, allowing a full equalization system to be emptied in 21 days of continuous operation using a single treatment train, or 10.4 days with both treatment trains online.

5.2.3 Chemical Precipitation

The chemical precipitation is designed for removal of metals and radionuclides that can be chemically precipitated from the wastewater.

Each treatment train includes two chemical precipitation tanks operated in series (four tanks in total). Two chemical precipitation tanks provide capability to add different chemicals at different locations, or to provide rough pH adjustment in the first stage and fine pH adjustment in the second stage, to optimize treatment performance and increase the overall reliability of the system. The chemical precipitation tanks are sized to provide a minimum of 20 minutes of hydraulic detention time at the design flow rate of 11.36 m^3/hour. The detention time was selected based on the detention time provided in the pilot scale test (approximately 15 to 17 minutes), plus a margin of safety to accommodate lower wastewater temperatures than those used during the pilot scale test. Lower wastewater temperatures are not expected to significantly impact the rate of chemical precipitation; however, the detention time can be further increased, if needed, by adjusting the speed of the Equalization Tanks wastewater transfer pumps to lower the flow rate through the chemical precipitation process.

Each tank is equipped with a variable speed mixer to combine the influent wastewater with desired chemicals to convert soluble metals and radionuclides to insoluble precipitates. The tanks are constructed of 316 L SS, with closed tops, nozzles and hatches to facilitate access to equipment, and sloped bottoms to enhance tank draining and cleaning for inspection. The tanks are vented to the outside of the building. The tanks are equipped with level instruments for monitoring purposes. The chemical precipitation tanks are fitted with a pH probe to automatically control chemical feed pumps to maintain a set-point pH in the tank. A sampling port is provided on the side of each tank to collect samples of the tank contents for analysis, and to visually observe the effectiveness of the chemical precipitation process.

Based on the results of the laboratory and pilot scale tests, the following chemical storage and feed systems are provided to deliver chemicals to the chemical precipitation tank:

- Ferric chloride.
- Sodium sulphide.
- Sodium hydroxide.
- Sulphuric acid.

The chemicals used in the chemical precipitation are based on the expected wastewater composition and the chemical precipitation chemicals may change based on the observed wastewater composition. Changes to the chemical precipitation chemicals and process will follow ECC [5-19].

During normal operation, ferric chloride is expected to be dosed to the first chemical precipitation tank, and both sodium hydroxide and sodium sulfide will be dosed to the second chemical precipitation tank. Sulphuric acid is not typically required for chemical precipitation, but is available in the event sodium hydroxide is inadvertently overdosed, or if the influent wastewater pH is higher than needed for effective chemical precipitation.

Control interlocks are provided to prevent the feeding of chemicals when the chemical reaction tank mixers are not in operation. Interlocks are also provided to prevent the con-current dosing of sulphuric acid and sodium hydroxide, to avoid exothermic neutralization reaction during control to a pH set-point.

Since the combination sodium sulphide with sulphuric acid can result in the formation of toxic hydrogen sulphide gas, hardwired interlocks are provided to prevent the addition of both chemicals to the same chemical precipitation tank at the same time, and adding sodium sulphide to a tank where the pH is below a low-level set-point (approximately pH 8.5). Hydrogen sulphide gas monitors will also be provided in the headspace of the chemical precipitation tanks to alert the worker if hydrogen sulphide gas is present.

Chemicals are stored in segregated rooms based on chemical compatibility, and to avoid the mixing of incompatible chemicals in the event of a spill. Chemical metering pumps, transfer piping, and controls are provided to allow each chemical to be dosed to either or both of the two chemical precipitation tanks in each train.

5.2.4 Membrane Filtration

The membrane filtration system is designed for removal of heavy metals and radionuclides that can be filtered from the wastewater.

Membrane filtration provides nearly complete removal of suspended solids from the chemically-pretreated wastewater, and effectively eliminates the presence of suspended solids in the filtered effluent. The membrane filtration system is specified to achieve an effluent suspended solids concentration less than 5 mg/L. The tubular membrane filtration process was demonstrated during the pilot scale test to easily accommodate the expected concentration of suspended solids produced by the chemical precipitation process.

In combination with chemical precipitation, the membrane filtration process was demonstrated during the pilot scale test to achieve the effluent discharge targets for heavy metals. In addition, the combined processes achieved high removal efficiencies for barium, calcium, and magnesium, which is important to reduce the load to the downstream polishing treatment processes. The radionuclide surrogate for strontium was also removed at a high efficiency.

Each membrane filtration treatment train includes a membrane filter feed tank, membrane filter process tank, membrane filtration skid, and Clean-in-Place (CIP) system. The membrane filter feed tanks provide equalization of chemically-precipitated wastewater, and are sized to provide eight hours of hydraulic retention time at a flow rate of 11.36 m^3/hour.

Membrane filtration systems are available as packaged systems installed on skids. The packaged system is equipped with a manufacturer-provided Programmable Logic Controller (PLC) to automatically control the functions of the membrane filtration system.

Membrane filter process tanks receive membrane recycle flows containing concentrated solids from the membrane filtration skid, and are sized to provide adequate capacity based on the selected membrane filtration system. The membrane filter feed tanks and process tanks are closed top, flat bottom vertical cylindrical tanks constructed of 316 SS and are vented to the outside of the building. Other materials may be used for the process tanks, if provided as part of a standard manufacturer's membrane filtration package. Each tank is equipped with a level instrument to start and stop pumps, control process pumping rates, and maintain set-point elevations of wastewater in the tanks. A dedicated level switch is provided to shut down pumps and prevent tank overflows at a designated high-high elevation. A variable-speed mixer is provided in each membrane filter feed tank to maintain solids in suspension.

Three membrane filter transfer pumps (two duty, one standby), are included to transfer chemically pretreated wastewater from the membrane filter feed tanks to the process tanks. The pumps are controlled to maintain a set-point level in the process tanks as wastewater is processed through the membrane filtration system.

Two duty transfer pumps circulate chemically precipitated wastewater from the process tanks to the membrane filtration systems where precipitated and suspended solids are filtered from the wastewater. A flow meter measures and totalizes the flow of wastewater to each membrane filtration system. Concentrated solids removed by the membrane filters are returned to the process tanks. An air-operated diaphragm pump dedicated to each membrane filtration system, operates on a timer to periodically transfer concentrated solids from the process tanks to the residuals storage tanks.

Permeate that passes through the membrane filters is transferred under low pressure through a pH adjustment tank to the polishing treatment process. Permeate is occasionally back pulsed through the membranes to loosen solids that may accumulate on the membranes over time.

The membrane filtration system includes pressure gauges to monitor pressure drop across the membrane filters and a flow meter to monitor flow rate. Increasing pressure drop and decreasing flow rate provide an indication of membrane fouling, and when pressure drop increases and/or flow rate decreases to an unacceptable level, the system must be taken offline for cleaning. Turbidity monitors are installed in the permeate discharge piping to alert the worker of turbidity levels that may signify the breach of a membrane module.

A dedicated CIP system serves each membrane filtration system to provide chemical mixing and re-circulation of cleaning chemicals through the membrane filters on a periodic basis. The CIP system is specific to each manufacturer's design, but is expected to include a chemical mix tank equipped with a mixer. A chemical cleaning solution is prepared in the chemical mix tank, and circulated through the membranes for a period of several hours. The duration is dependent on the extent of membrane cleaning that is required. After cleaning, water from the flush tank is circulated through the membranes to flush any residual cleaning chemicals from the membranes, prior to placing the system back in service.

Typical cleaning frequency for this type of wastewater is approximately once per week. Based on the pilot scale test, a 10% solution of sulphuric acid was demonstrated to be effective for membrane cleaning. A metering pump is provided to deliver sulphuric acid from the chemical storage tanks to the CIP tank for preparation of the cleaning solution. It is estimated that 150 L of 93% sulphuric acid will be required for each 1.5 m^3 batch of membrane cleaning solution. The sulphuric acid cleaning solution can be re-used approximately two to four times.

Occasionally, an alternate cleaning solution containing 5% to 10% sodium hypochlorite and 0.5% to 1% sodium hydroxide may be required for control of biological fouling and removal of organic material. This cleaning solution could also be recycled for use during subsequent cleaning cycles, or discharged for re-processing through the WWTP. Since residual chlorine from the sodium hypochlorite chemical may result in higher chemical (sodium sulphide) requirements in the chemical precipitation tanks, it may be desirable to pre-treat the spent sodium hypochlorite cleaning solution to remove residual chlorine prior to discharge to the Equalization Tanks. A chemical transfer system is provided for addition of sodium bisulphite to the chemical mix tank to remove residual chlorine. An oxidation-reduction potential instrument is used to ensure that residual chlorine has been removed prior to discharge to the Equalization Tanks for processing through the WWTP.

Spent cleaning solution is discharged to one of two spent CIP solution tanks for storage prior to processing through the WWTP. One spent CIP solution storage tank is designated for acidic CIP solution, and one tank is designated for caustic CIP solution. The spent CIP solution storage tanks have sufficient volume to contain a minimum of two CIP discharges, or approximately 3 m^3. The spent CIP solution storage tank is double-walled HDPE, with interstitial leak detection and a level instrument to prevent discharge of spent CIP solution to the tank when insufficient capacity exists. Two duty metering pumps for each spent CIP solution storage tank (four pumps in total), convey spent CIP solution to the first-stage chemical precipitation tank in each treatment train for processing through the WWTP. The rate of spent CIP solution is limited to one percent of the WWTP flow rate, and can be controlled by the worker at the desired set-point. The membrane rinse water is discharged to the chemical precipitation tanks.

5.2.5 pH Adjustment

The pH adjustment process includes permeate, and final.

5.2.5.1 Permeate pH Adjustment

The pH of permeate from the microfiltration process is expected to be elevated, and may need to be reduced prior to subsequent polishing treatment processes. Each treatment train includes a pH adjustment tank and feed tank for the downstream processes.

The pH adjustment tanks are closed top, flat bottom, vertical cylindrical tanks constructed of 316 SS and vented to the outside of the building. Filtered water enters each pH adjustment tank and chemicals are added to adjust the wastewater pH, if necessary, to optimize the effectiveness of the downstream processes. Each pH adjustment tank is sized to provide 20 minutes of hydraulic detention time at the design flow rate of 11.36 m^3/hour. Each pH adjustment tank is equipped with a mixer, pH probe and controller, and level instrument. The pH controller is used to automatically control chemical feed pumps to maintain a selected set-point pH.

Filtered wastewater is transferred by gravity from the pH adjustment tanks to the polishing process feed tanks, each sized to provide eight hours of hydraulic detention time at the design flow rate of 11.36 m^3/hour. The polishing process feed tanks are closed top, flat bottom, vertical cylindrical tanks constructed of 316 SS, vented to the outside of the building, and equipped with level instruments. Three feed pumps (two duty, one standby), transfer wastewater from the polishing process feed tanks to the polishing process vessels. Flow meters measure and totalize the feed flow rate to each polishing process system.

5.2.5.2 Final pH Adjustment

Effluent from the IX vessels is conveyed by residual pressure to the final pH adjustment tanks. The tanks are closed top, flat bottom, vertical cylindrical tanks constructed of 316 SS and vented to the outside of the building. Chemicals are metered into the tanks to adjust the final effluent pH to within a range of pH 6.5 to 9 for discharge. The final pH adjustment tanks are sized to provide 20 minutes of hydraulic detention time at the design flow rate of 11.36 m^3/hour. The final pH adjustment tank are equipped with a mixer, pH probe and controller, and level instruments. The pH controller is used to automatically control chemical feed pumps to maintain a selected set-point pH within the required effluent discharge pH range.

5.2.6 Granular Activated Carbon Polishing

Granular activated carbon adsorption is used for removal of organic Contaminants of Potential Concern (COPC) that may be present in the NSDF wastewater. Granular Activated Carbon is widely recognized as best available technology by numerous regulatory agencies for removal of a broad range of organic chemicals by adsorption on the GAC media.

Two GAC vessels are operated in a lead-lag fashion to provide removal of organic chemicals that may be present in the NSDF wastewater. The GAC vessels are constructed of 316 SS, and contain approximately 860 kg of GAC for adsorption of COPC. When the GAC in the lead vessel reaches its capacity to adsorb contaminants, the GAC will be replaced with fresh media, or the entire GAC vessel is exchanged for a new vessel containing fresh media. The vessel with fresh GAC is placed in the lag position, and the former lag vessel is placed in the lead position. The GAC vessels contain a minimum of 1.93 m^3 of GAC and provide 1.3 m of GAC depth with an empty bed contact time of more than 10 minutes. Pressure gauges are provided to monitor the pressure drop across the GAC vessel.

5.2.7 Ion Exchange Resin Polishing

The IX process provides polishing treatment for removal of low concentrations of metals and radionuclides that remain after chemical precipitation and membrane filtration. Ion exchange is considered to be best available technology by the United States Environmental Protection Agency. The results of the pilot scale test illustrate that Strong Acid Cation (SAC) exchange resin can remove heavy metals and radionuclide surrogates such as strontium to very low concentrations, in many cases below detection limit. Zeolite was demonstrated to be effective for removal of cesium. The pilot scale test demonstrated that effluent discharge targets established for the WWTP can be achieved using IX technology.

Resin capacity was demonstrated during the pilot scale test to be 712 bed volumes to breakthrough of strontium from SAC resin, and 792 bed volumes to breakthrough for cesium removal on zeolite resin. It should be noted that concentrations of strontium and cesium in the pilot scale test wastewater simulant are several orders of magnitude higher than that expected in the WWTP wastewater.

The IX treatment trains include a series of IX vessels in a lead-lag arrangement to remove the range of constituents expected to be present in the NSDF wastewater. When the IX resin in the lead vessel reaches its capacity to adsorb contaminants, the resin is replaced with fresh resin, or the entire IX vessel is exchanged for a new vessel containing fresh resin. The vessel with fresh resin is placed in the lag position, and the former lag vessel is placed in the lead position.

The IX vessels contain resins specific to the contaminants to be removed from the wastewater. The design includes two vessels in a lead-lag arrangement for the following resins:

- Zeolite (cesium removal).
- Strong acid cation (heavy metals and cationic radionuclides removal).

The design has the capability and the flexibility to accommodate future changes in wastewater chemistry and the IX resins can be changed to mitigate unforeseen influent wastewater characteristics. In addition, a future third set of IX vessels can be added if required for future process optimization. Once operational data is available, IX resin selection can be optimized for efficiency and reduced secondary waste.

Although anionic radionuclides are not projected to be present in the NSDF wastewater at concentrations that exceed discharge requirements, anion resin vessels can also be operated in the IX treatment trains, if required to reduce the concentrations of anionic radionuclides during the operating period of the ECM.

The IX vessels are constructed of 316 SS, and contain 1.93 m^3 of zeolite per vessel, and 2.55 m^3 of SAC resin per vessel. The IX vessels provide 1.3 m of resin depth and an empty bed contact time of more than 10 minutes. Pressure gauges are used to monitor the pressure drop across each IX vessel.

Samples of the effluent from each GAC and IX vessel are taken on a periodic basis, depending on the frequency and duration of WWTP operation, to confirm treatment effectiveness and determine when breakthrough of the target contaminants from the lead vessel occurs. Breakthrough in the lead vessel will signify a need to replace the resin.

Due to changes in the updated waste inventory, cesium concentrations in the NSDF wastewater are expected to be below the effluent release target, and operation of the zeolite vessels may not be required.

5.2.8 Final Effluent Storage and Sampling

Treated effluent from the final pH adjustment tanks, is conveyed by gravity to the final effluent storage tanks, each sized for eight hours of hydraulic detention time at the design flow rate of 11.36 m^3/hour. The final effluent storage tanks provide storage of final effluent for sampling, prior to discharge. The tanks are closed top, flat bottom, vertical cylindrical tanks constructed of SS. The tanks are equipped with a level instrument to measure and monitor the elevation of final effluent in the tank.

Effluent samplers are provided for automatic collection of composite effluent samples. Flow meters measure and totalize the final effluent that is discharged from the WWTP. The discharge flow rate from the final effluent storage tanks can be manually adjusted with a valve on the discharge line. Final effluent is discharged to the exfiltration gallery or to Perch Lake. The effluent released shall meet the NSDF Effluent Discharge Targets [5-20].

5.2.9 Residuals Management – Storage and Filter Press

The residuals management system is designed for handling and de-watering of residuals generated as a by-product of wastewater treatment process.

Two pumps (one duty pump for each train), periodically transfer residuals from the membrane filtration system process tanks to the residuals storage tanks. The residuals storage tanks are closed top, vertical cylindrical with cone bottom, and constructed of 316 SS with a capacity of approximately 80 m^3. The tanks are equipped with a mixer, level instruments, and decant ports. The mixers are used to blend the residuals, as required. Decant ports are provided to decant supernatant from the tanks, if additional settling of solids occurs in the tanks.

The residuals generated by the WWTP, are dewatered residuals from the chemical precipitation process, and spent media from the GAC and IX polishing processes. Based upon the projected wastewater quantity and characteristics, and results of laboratory and pilot scale tests, the annual quantity of dewatered residuals is expected to be approximately 42 m^3/year, and the annual quantity of spent GAC and IX resin is expected to be approximately 17 m^3/year and 30 m^3/year, respectively.

Based on the projected wastewater quantity and characteristics, and results of pilot scale tests, an average of approximately 1 to 2 m^3/day of liquid residuals is estimated to be generated from the chemical precipitation and membrane filtration process, with a solids concentration ranging from 15 000 to 50 000 mg/L. The estimated dry mass of residuals is 35 kg/day, prior to addition of body feed and pre-coat chemicals.

When the residuals storage tank contains an adequate volume of residuals for de-watering, any clear supernatant which has formed at the surface of the tank will be decanted to active drain. The workers will open a decant port and observe the decant quality as it exits the decant line and enters the active drain. When the decanted liquid becomes visibly cloudy and/or dark-colored, this provides an indication that the solids layer has been reached, and the decanting will be stopped. Removal of supernatant from the residuals storage tanks will result in higher residuals concentrations and improved de-waterability. Supernatant is directed to the influent Equalization Tanks, via the active drain system and Contact Water Pumping Station #2.

5.2.9.1 Filter Press

Two feed pumps (one duty, one standby), transfer residuals from the residuals storage tanks to a filter press feed tank. The filter press feed tank is equipped with a mixer and used to blend body feed chemical with the thickened residuals prior to de-watering. The filter press feed tank is closed top, vertical cylindrical with cone bottom, and constructed of 316 SS with a capacity of 9.5 m^3. Results of the pilot scale test indicate that a body feed dosage of 25% of the dry solids in the residuals was effective in enhancing de-waterability characteristics, including higher cake solids concentration and more effective release of the dewatered cake from the filter cloths.

A bag feed system is provided for dosing body feed chemical to the residuals contained in the filter press feed tank. The use of body feed is determined by the worker based on OPEX. It is expected that body feed will be used initially at the recommended concentration of 25% of the dry solids contained in the residuals, and may be increased or decreased for subsequent de-watering campaigns based on filter press performance.

Two filter press feed pumps (one duty, one standby), periodically transfer residuals from the filter press feed tank to a recessed chamber filter press for de-watering. The filter press is located on the first floor in the residuals management area of the WWTP building. The recessed chamber filter press is a packaged system that includes a manufacturer-supplied programmable logic controller to automatically control the functions of the filter press. The filter press de-watering operation is a batch process, consisting of filling the press with residuals for de-watering, building pressure to complete the de-watering process, and opening the press to allow dewatered residuals to be removed. The filter press is equipped with a pre-coat system to apply a thin layer of diatomaceous earth or Perlite to the filter press cloths prior to filling the press with residuals. A make-down system is used to prepare a slurry. The slurry is transferred to the filter press using one duty and one standby filter press pre-coat pumps. The estimated pre-coat requirement is 43 kg/m^3 of filter press volume.

After applying the pre-coat that enhances residuals de-waterability, the filter press is filled with residuals from the filter press feed tank, gradually building the pressure in the filter press to approximately 690 kPa. When the rate of filtrate drops below the desired level, the filter press operation is stopped, and any residuals that remain in the feed line are pneumatically discharged back into the residuals storage tank.

The filter press plates are opened to allow dewatered residuals that have formed between the filter press plates and cloths, to drop into a transport container located below the filter press. Optional styles of transport containers are compatible with the filter press operation, including a B25 box, or a soft-sided container. The soft-sided container is positioned in a collapsible frame located beneath the filter press during de-watering and discharge of dewatered filter cake. De-watered residuals are transported to the ECM for disposal.

Based on the results of the pilot scale test, it is expected that the dewatered residuals will have a solids content in excess of 30%, with a density of 1 390 kg/m^3. The filter press is specified to achieve minimum dewatered cake solids of 30%.

5.2.9.2 Spent Polishing Media

Spent media from GAC and IX vessels are sluiced from the vessel into a disposal container. The vessel is isolated from the process flow by closing valves on the inlet and discharge of the vessel. A connection is made between the vessel and disposal container, and the vessel's sluice valve is opened. Service water is applied to the vessel through the effluent internals to slightly fluidize the media bed. When the media has become fluidized, compressed air is applied to the vessel influent valve from the plant air system. The compressed air pressure is throttled to maintain an even flow of media from the vessel to the disposal container, and additional service water is applied as necessary to maintain a slurry. After all spent media has been removed from the vessel, application of service water and compressed air is alternated to completely clean the vessel of spent media. Compressed air is applied at the end of the spent media transfer operation to remove any remaining water.

Fresh media is transferred to the vessel after removal of spent media. The media change-out can be performed with the vessel in-place, or the vessel can be moved to another location in the polishing treatment area for the media change-out. Moving the vessel to a different area would allow the vessel to be immediately replaced with a standby vessel, such that treatment can continue with minimal interruption. De-watering liquid and water used to wet and prepare the fresh media, is discharged to the trench drain located in the polishing treatment area.

After slurrying, the spent resin or GAC into the container, most of the free liquid is pumped from the container using an air operated diaphragm pump. The pump removes liquid through de-watering laterals equipped with fine strainers to keep the media within the container. After removal of the bulk fluid, a high velocity vacuum is applied to the container to remove remaining free liquid to less than 1%. The high velocity vacuum operation can be repeated if the container is stored for a longer period and additional removal of free liquid is required. After de-watering, any remaining void space in the container would be grouted prior to disposal in the ECM.

5.2.10 Chemical Storage and Metering

The chemical storage and metering systems support several of the individual WWTP processes. Chemicals are stored in a dedicated area of the WWTP within containment areas suitable for each particular chemical. Acid chemicals are stored in Chemical Storage Room #1 and caustic chemicals in Chemical Storage Room #2, to avoid the mixing of incompatible chemicals in the event of a spill. Liquid chemicals are transferred from totes or drums to chemical feed tanks for metering to each chemical dosing location.

Two chemical feed tanks, each with a volume of 600 L, are provided for the chemicals:

- Sodium sulphide, 15% solution as Na_2S.
- Sulphuric acid, 93% solution as H_2SO_4.

Two chemical feed tanks, each with a volume of 1 000 L, are provided for the chemicals:

- Ferric chloride, 38% solution as $FeCl_3$.
- Sodium hydroxide, 50% solution as NaOH.

One installed, duty chemical metering pump is provided for each chemical dosing location. In addition, one spare pump is provided for each pump type and size to allow for quick replacement of any pump, if necessary. The metering pumps are variable speed, and pumping rates will be controlled to achieve the selected set-point pH or chemical dose that is based on the flow of metered wastewater. An isolation valve and ball check valve are provided at each chemical dosing point of application. The ball check valve provides positive shutoff when the pump stops and prevents the chemical line from draining and adding unwanted chemical into the process. Since sulphuric acid is not expected to be normally required at the chemical precipitation tanks, the sulphuric acid feed lines are equipped with lockable valves as an added safety measure to prevent the inadvertent addition of sulphuric acid and sodium sulphide at the same time, which could result in the formation of toxic hydrogen sulphide gas. Pressure relief valves in the chemical feed systems relieve system pressure in the event the chemical feed pump operates against a closed valve either at the chemical precipitation tank or elsewhere in the pump discharge.

Chemical spills in Chemical Rooms 1 & 2 are not directed to floor drain, but contained in trenches and dry sumps around the chemical feed tanks.

5.2.11 Process Control Systems

A process control system is used to monitor and automatically control the WWTP processes, the ECM, and the CWPSs. The process control system provides the process information and alarms required to make operational decisions in a timely manner.

The complete process control system consists of field instruments, Local Control Panels, Chemical Unloading Panels, PLC Control Panels, PLCs, SCADA system, vendor package PLCs, and Operator Interface Terminals. The process control system is designed for 24/7 availability and utilizes components with a level of reliability suitable to the operating requirements. Field equipment and instruments feedback information to the PLCs which control the WWTP process and the CWPSs. The SCADA system enables remote operation and monitoring of the processes.

5.2.11.1 Supervisory Control and Data Acquisition System

A SCADA system is located in the Control Room. The SCADA system provides monitoring and supervisory control of the WWTP processes, the CWPSs, and the Leachate Transfer System (LCS and LDS), to allow the workers to monitor and control the process equipment. The design of the SCADA system is described in the SCADA Program and Design Report [5-21].

The SCADA system logs all the alarms, historical data from field instruments and equipment status, and events (events are worker-initiated events such as set-point changes). Data logged by the SCADA system are available for diagnostic and troubleshooting purposes, to provide the workers with incident management capability.

The SCADA system alerts the WWTP staff via alarms when critical process parameters are outside of the operating limits, and when worker attention is required to investigate and address these alarm conditions. Where bypass options are provided in the process design, provisions are made to monitor bypass status in SCADA.

The SCADA system platform is Rockwell FactoryTalk View SE (Site Edition). The SCADA system consists of a SCADA server/database computer and two SCADA workstations for worker control and monitoring. There is a provision for web-based remote monitoring of plant SCADA (with security provisions), via a separate SCADA View node. Once logged into the SCADA View node with appropriate security credentials, the worker is able to monitor plant status and alarm information remotely.

The SCADA server/database computer communicates with the PLCs and gathers all the Input/Output data from field devices, in addition to logging real-time data from field instruments, equipment status, alarms, and events information, which can be accessed by the plant O&M team for diagnostics and reporting purposes.

The SCADA software will be developed using a modular approach, such that there will be a template pop-up screen developed for different types of devices such as analog motor, discrete motor, analog valve, discrete valve, analog instruments, gas analyzers, digital input, etc. The template screen will be reused in the SCADA application as a standard device pop-up window to monitor status and diagnostics information and to control the device operation in Remote-Manual mode of operation.

Each SCADA workstation is equipped with a separate UPS, sized such that it can supply power for one hour in case of power failure.

5.2.11.2 Building Automation System

The WWTP BAS, consists of a networked array of controllers and field devices capable of providing Building Automation and Control Network compatible Direct Digital Control and/or monitoring of all connected building Heating, Ventilation, and Air Conditioning (HVAC) systems.

The NSDF BAS is networked to CNL's existing Siemens site wide BAS network, and is available via an existing Operator Work Station (OWS) within Building 700 Central Monitoring Room. The OWS provides CNL with a remote access and control capability of the NSDF site from Building 700.

The major components comprising the BAS include:

- An OWS complete with a Graphical User Interface and printer.
- Network Automation Engines.
- Application Specific Controllers.
- Field sensors and control components.
- Operating, application and energy management software.

Workers shall be able to access BAS system information and effect control parameter changes via an OWS located in the WWTP Control Room. The OWS shall consist of a large format LCD display screen, keyboard, personal computer, and printer. This allows operations personnel to interact with the BAS via graphic representations of the HVAC systems and display real time operating data.

Building Automation System components, required to maintain the flow of information from key building components and system alarms annunciated at the main alarm panel, are supplied with Class II Power. All other controllers are supplied by Class IV Power.

5.2.12 Compressed Air System

The air compressor room is located on the second floor of the WWTP and includes dual air compressors and filters to ensure continuity of compressed air supply. The compressed air system feeds air operated process equipment (membrane filter, filter press, de-watering system) and the breathing air system. Two breathing air station stations are provided for the filter press enclosure (lower and upper levels). The breathing air system includes five stages of air filtration in accordance with CSA Z180.1 for air quality. The compressed air system is provided with Class III electrical power in the event of a Class IV Power outage.

5.2.13 Effluent Discharge System

Treated effluent produced by the WWTP is discharged to the Perch Lake watershed either through an exfiltration gallery and/or by pumping to Perch Lake. The treated effluent conveyance system has been designed to transfer the peak flow generated by the WWTP. The two discharge paths for the treated effluent are:

- Gravity piping to the exfiltration gallery.
- Force main and gravity piping system to Perch Lake.

5.2.13.1 Exfiltration Gallery

The exfiltration gallery is sized to accommodate the peak discharge rate of 6.3 L/s based on native soil hydraulic conductivity parameters. The exfiltration gallery discharge is located adjacent to the WWTP within the Perch Lake Watershed. The location and footprint of the exfiltration gallery is maximized to approximately 1 000 m^2. The exfiltration gallery makes use of underground storage chambers surrounded with crushed stone at a total storage depth of approximately 1 m. The discharge flow rate to the exfiltration gallery will be limited, depending on the elevation of the groundwater table. Three monitoring wells are provided for monitoring the groundwater elevations.

The treated effluent system utilizes a buried 200 mm diameter Polyvinyl Chloride (PVC) piping to convey the treated effluent from the WWTP to the exfiltration gallery. The exfiltration gallery is designed to yield a mean flow velocity of not less than 0.6 m/s when flowing at full capacity. The piping were laid out in straight runs with maintenance holes at each bend. The system’s outlet utilizes a header pipe which discharges to a buried chamber storage system for the purposes of spreading incoming treated effluent across the footprint of the exfiltration gallery.

Provisions are made for sampling at the point of discharge. The sampling station utilizes a 1 200 mm maintenance hole with a raised inlet for obtaining samples.

For discharge to the exfiltration gallery, the effluent flow path is via groundwater to East Swamp Stream, the nearest surface water body providing aquatic habitat. A dilution factor of approximately seven is estimated for this discharge pathway. The dilution factor of seven is based on the ratio of the estimated annual effluent discharge flow rate of 11 230 m^3/year to the average flow rate of the receiving water body, East Swamp Stream, of approximately 73 000 m^3/year.

The design of the exfiltration gallery meets the following key performance requirements:

- Minimize soil erosion and deposits in East Swamp.
- Effluent water shall not negatively impact the water quality and the species at risk in East Swamp wetlands.
- The average effluent flow rate shall not exceed 10% - 20% the average flow rate from East Swamp.
- The water level in East Swamp shall not vary significantly from the current levels.
- There shall be no overland flow from the exfiltration gallery.

5.2.13.2 Perch Lake Discharge

In the event of high groundwater elevations, treated effluent which cannot be directed to the exfiltration gallery, will be conveyed directly to Perch Lake. Centrifugal pumps (three pump system) located within the WWTP, will be used to convey effluent through dual containment HDPE piping routed along WWTP Access Road, East Mound Road, South Mound Road and ultimately along the Access Road to Perch Lake. A submerged diffuser in Perch Lake will be used to disperse the effluent.

The key design characteristic of this portion of the system is to convey the treated effluent from the WWTP to Perch Lake. One dual containment 150 mm buried HDPE pressure main exits the WWTP and enters the nearby valve chamber. The 150 mm pressure main is installed in a 250 mm HDPE containment pipe with casing spacers placed in the annular space between the pipe walls. The pressure main is sloped, such that a leak in the 150 mm force main would be conveyed back to the valve chamber. Leak detection stations are provided at 100 m spacing to allow for inspection of the pipeline at various locations. The leak detection stations allow for inspection as well as allow for by-pass pumping operations if maintenance or replacement is required. The pipeline is installed at a depth below the anticipated maximum frost penetration depth.

A gravity drain portion, is utilized downstream of an effluent manhole chamber at the highest point within the treated effluent system to Perch Lake. The manhole chamber is used to interface between the pressure main portion and gravity drain portion of the system as well as provide air release via a vent pipe. The gravity sewer exits the effluent manhole chamber and enters the valve chamber near Perch Lake. The gravity sewer utilizes the same pipe in a pipe approach to provide dual containment, leak detection stations, and by-pass configuration as mentioned above. The gravity drain is also installed at a depth below the anticipated maximum frost penetration depth to allow for discharge year round, including during winter months.

5.3 Support Facilities

The NSDF support facilities include:

- Vehicle Decontamination Facility.
- Operations Support Centre.
- Administration Office.
- North and South Kiosks.
- Weigh scales.
- Site vehicle refueling station.

5.3.1 Vehicle Decontamination Facility

The VDF is a pre-engineered building with equipment necessary for vehicle/equipment decontamination and light site vehicle maintenance activities (oil/hydraulic fluid replacement, filter changes, tire change, etc.). The VDF building area is approximately 484 m^2 and the building dimensions are approximately 18 m width, 28 m length and 7 m height.

The building has been designed with fire rated walls. All relevant service rooms (mechanical and electrical rooms, records room and janitor's room) within the building will be separated by a 1 hour rated wall as per NBCC. The building has a fire detection system.

The largest space in this building is the vehicle decontamination hall with a clear height of seven metres. Two large overhead doors on either side of the hall provide access to and from the decontamination area with additional man doors providing access of personnel to the outside.

Equipment designed for vehicle decontamination is located in this hall. Trench drains along the base of the overhead doors and the middle of the hall are designed to collect run-off liquids from the decontamination process. The maintenance shop is used for light maintenance on the vehicles working in the site.

5.3.2 Operations Support Centre

The OSC building houses the necessary spaces required for the decontamination of the personnel working on-site and shower facilities. The OSC building area is approximately 200 m^2, and the building dimensions are approximately 14 m width, 14 m length and 3.7 m height. The building has a fire detection system.

5.3.3 Administration Office

The Administration Office is a 15.36 m x 12.53 m prefabricated building that provides space for site administration staff that are responsible for the day-to-day operations of the site. The building is designed as a prefabricated structure consisting of pre-manufactured modules built off-site and transported to site and erected. The main entrance of the building, which also serves as the fire department access point, is environmentally separated from the exterior by means of a vestibule. The building has a fire detection system.

5.3.4 North and South Kiosks

The NSDF site has two entrance kiosks, one on the north and one on the south as shown in Figure 5-1. The North Kiosk building area is approximately 31.6 m^2, and the building dimensions are approximately 3 m width, 10.4 m length and 3 m height. The South Kiosk building area is approximately 20 m^2, and the building dimensions are approximately 3 m width, 6.4 m length and 3 m height. The buildings have a fire detection system.

The kiosks have adjacent vehicle weight scales. The weigh scale office contains a display and control systems for monitoring and registering vehicles loads into the site.

5.3.5 Weigh Scales

Vehicle weigh scales are located at the north and south NSDF site entrances adjacent to the kiosks. The scales are of sufficient size to weigh road legal semi-trucks, tandem, and tri-axle dump trucks.

5.3.6 Site Vehicle Refueling Station

Located on North Mound Road at the WWTP Access Road, the site vehicle refueling station stores bulk diesel in an above ground tank for use in ECM heavy equipment. The refueling station has an automated fueling pump capable of metering fuel and logging volume transferred. The aboveground double walled fuel storage tank is 4 500 L, and complies with ULC-S601. The storage tank is equipped with vacuum-monitored leak detection of the interstitial space between the inner and outer tank, level monitoring system, overfill protection, pressure/vacuum vent (terminating 3.6 m above grade), emergency relief vent and grounding cable. The secondary containment provides a minimum 360^o containment of the primary storage tank. The overfill protection is a high level audible/visual alarm at 90% level.

In addition, the fuel storage tank is a packaged unit designed for use in a heavy equipment environment, provided with an integral vehicle impact barrier to prevent damage from accidental vehicle impacts.

5.4 Infrastructure

The infrastructure supporting the Facility includes:

- Potable water pump station.
- Fire water pump station.
- Perimeter fencing.
- Roads.
- Surface water management ponds.

- Aggregate Stockpile/Laydown Area.
- Power distribution building.
- Sanitary Sewage Disposal Systems.

5.4.1 Potable Water Pump Station

The PWPS building area is approximately 77 m^2, and the building dimensions are approximately 7.2 m width, 10.7 m length and 6.7 m height. The PWPS is located to the north of the North Kiosk.

Potable water is required within the WWTP, VDF and other support buildings for various uses, which include but are not limited to; showers, toilets, eyewash stations, faucets, floor/equipment wash down, and VDF wash water reclaim system makeup. All of the buildings and facilities are provided with potable water service; with exception to the South Kiosk which will be serviced by a stand-alone potable water storage tank.

5.4.2 Fire Water Pump Station

The FWPS building is located near the south-west corner of the WWTP. The FWPS building dimensions are approximately 3.7 m width, 5.8 m length and 3.2 m height. The building area is approximately 21.3 m^2. The FWPS is ventilated, heated, and located on top of the fire water storage tanks.

The fire water storage system consists of two independent cast-in-place buried concrete tanks (TK-101 and TK-102). The fire water storage tanks have a working volume of 403 m^3, an access hatch, fill connection, combination vent/visual level gauge, and level instruments for monitoring purposes.

The FWPS consists of two fire water pumps, two jockey pumps and their associated support systems. The fire water pump draws water from the fire water storage tank and fire water is sent to the NSDF site fire hydrant network, as needed. The fire water pumps consist of two vertical turbine electrically driven pumps configured in a duty/standby mode. The jockey pumps, used for system pressure control, consist of two multi-staged electrically driven pumps again configured in a duty/standby mode. The pumps are controlled by independent control panels. Each panel is connected to the site wide fire alarm system, which provides remote monitoring of run and fault signals. The pumps are sized to deliver 63.1 L/s at 896 kPa. The system includes an auto transfer switch (provides Class III back-up power in the case of Class IV power failure), fire pump flow test meter, and fill water supply lines and level controls.

The storage tank fill controllers (one per tank), provide level control and high/low level monitoring/ylarms. Alarm signals from each controller are connected to the site wide fire alarm system, and each controller is connected to a make-up water valve. When the water level drops to a predetermined level, the fill controllers open make-up water valves to add water into the storage tanks.

5.4.3 Perimeter Fence

A 2.4-m-high perimeter chain-link fence is provided, typically offset 1.0 m inside the NSDF boundary. A swing gates area is provided at secondary access points (i.e. connections to maintenance roadways and/or hydro-transmission corridors), and automated gates are provided at primary access points. A supplemental 1.0 m high fabric is affixed to the exterior of the perimeter fencing in areas adjacent to existing wetlands to function as a barrier for turtle migration into the site. The perimeter fencing is located typically 1.0 m inside of the defined NSDF boundary. Tree clearing is to be conducted 4 m beyond the NSDF boundary. As such, a 5 m setback from NSDF above grade structures (i.e. buildings, trees, etc.) is achieved. The limits of site regrading, account for the 30 m setback requirement from the adjacent wetland areas.

5.4.4 Roads

The NSDF site transportation network consists of primary and secondary access roads. Primary access roads facilitate two-way traffic to the site. Secondary access roads facilitate both one- and two-way traffic on the site. There are two primary access roads to the site, depicted on the Figure 5-23.

The primary waste shipment access roadway is from the ER-3 Road/EMR intersection north-west to the NSDF site boundary. This road is comprised of a granular pavement structure. This roadway is to be utilized for waste shipments arriving to the NSDF site as well as transport vehicles leaving the NSDF site, providing that vehicle decontamination is not warranted.

The second primary access route to the NSDF site is from Plant Road to the site boundary. This roadway is proposed to be comprised of an asphalt pavement structure from Plant Road to the site boundary, to minimize dust generation in the vicinity of Plant Road, the primary access roadway into the CRL campus. A right-turn/deceleration lane is proposed at the intersection with Plant Road, to allow for slower moving vehicles to turn into the site without impeding eastbound traffic to the CRL campus. The second primary access roadway is utilized for occasional waste deliveries to the site, but is primarily dedicated for employee access to the Support Facility buildings, as well as material and equipment deliveries to the NSDF site.

Secondary site access roadways generally consist of perimeter roads around the ECM as well as the WWTP. The secondary roadways are comprised of granular pavement structures and are sized to facilitate two-way vehicular traffic around the site.

The road linking the ECM to the VDF (Decontamination Road), is an asphalt single lane granular pavement roadway and is utilized by waste shipment vehicles or equipment that require decontamination.

Portable traffic barriers are proposed for the operational phase of the ECM, to limit the interaction of potentially contaminated vehicles with routes designated for uncontaminated vehicles and pedestrians.

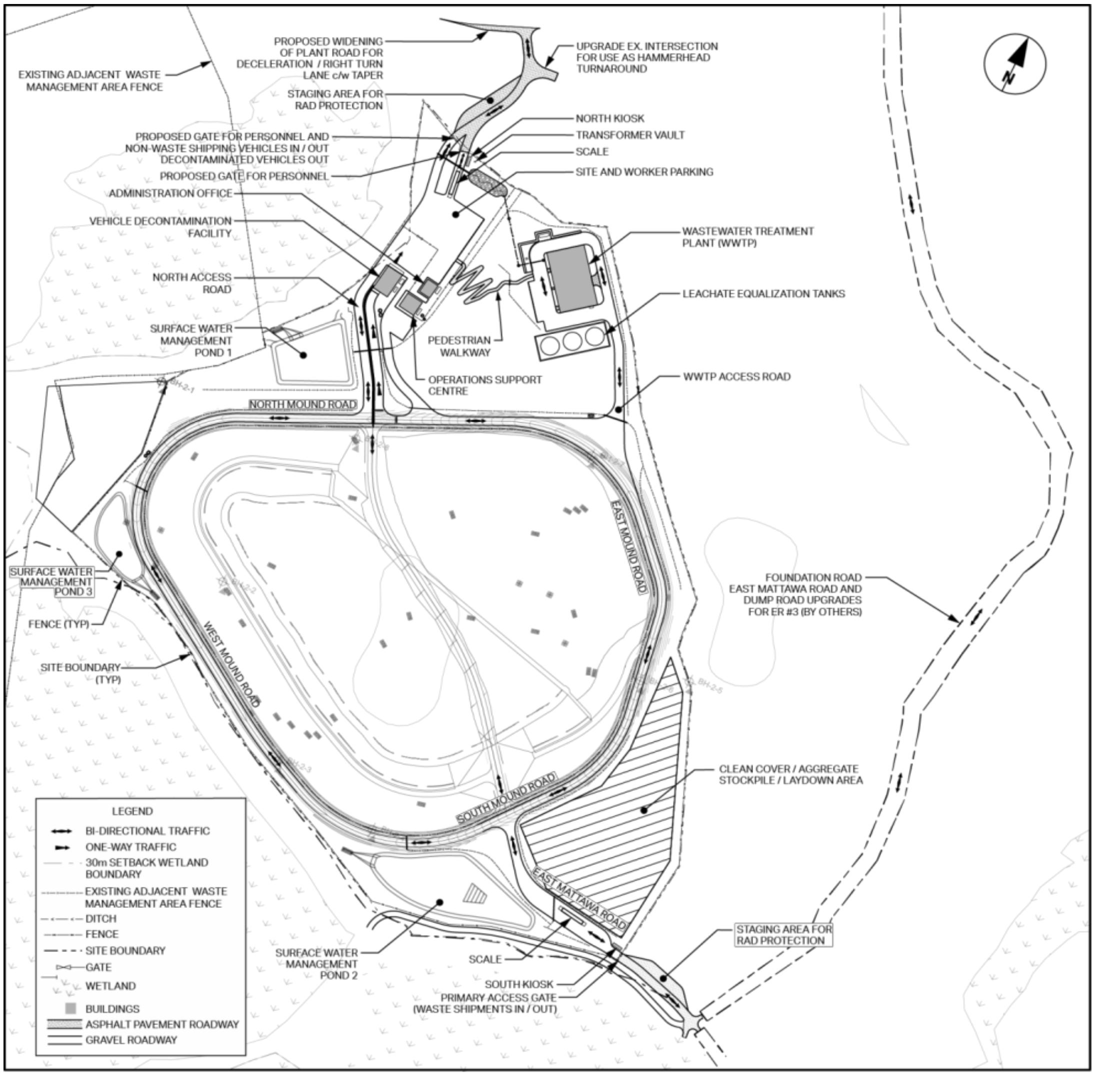

Figure 5-23 Site Layout

5.4.5 Surface Water Management Ponds

The surface water management system for the NSDF is designed to control non-contact surface water (water that has not come into contact with waste placed in the ECM), including preventing surface water from uncontaminated areas discharging into contaminated areas. Contact surface water that is collected from within the ECM, ultimately is conveyed to the WWTP for treatment.

The surface water management system consists of four main elements, collection (i.e. site grading), conveyance (i.e. internal ditches, sewers, culverts and external flow diversion ditches), treatment (i.e. settling/detention ponds), and discharge (i.e. outlet sewers, emergency overland flow routes).

Three SWMP are included in the ECM layout design for managing/treating non-contact water before discharging the water to wetlands connected to Perch Lake, Perch Creek and, ultimately, the Ottawa River. The design includes the contributing drainage ditches, culverts and related site grading, which convey non-contact surface water to these facilities. The ponds are sized for an ultimate condition that includes handling non-contact run-off water draining from the ECM interim and final covers, roadways, buildings, parking lots and clean cover/yggregate stockpile areas. The three SWMPs and conveyance structures are designed to attenuate flows produced by a 100 year rainfall event (with snowmelt and climate change considered) [5-7].

The surface water management system for the NSDF has been designed to meet the following objectives:

- Mitigate erosion and intercept sediment during construction from transport into the receiving wetland area during wet weather events.
- Control the quantity of surface water discharge from the proposed NSDF site to pre-development rates.
- Provide quality treatment of surface water from the proposed NSDF to meet the requirements of the Ontario Ministry of the Environment and Climate Change Stormwater Management Planning and Design Manual, 2003, settling suspended sediment ultimately protecting receiving watercourses/waterbodies.
- The design intent shall be to maximize TSS removal efficiency at each SWMP location and to provide supplemental TSS removal as part of the open-channel (i.e. ditch and channel) non-contact water conveyance systems employed on the site to route non-contact surface water to the designated outlets.

Surface Water Management Pond 1, is located at the north end of the site and receives drainage from the WWTP, support facilities, parking lots and roadways; SWMP 2 is located at the south end of the site and receives drainage from stockpile areas to the east and the ECM cover to the north; and SWMP 3 is located at the west side of the site and receives drainage from the ECM cover to the east.

Precipitation falling within the active cell that makes contact with the waste is considered contact water, and is conveyed to catchment areas within the active cell or an adjacent lined cell. Surface water collected within these catchment areas, is pumped to the leachate extraction boxes at the top of the berm and transferred to the WWTP. Precipitation falling in cells with final cover, completed with temporary sacrificial cover (interim cover), or inactive cells, is considered non-contact water, and is conveyed to the SWMPs.

During normal operation, the effluent flow from the three SWMPs is through a bottom draw, perforated pipe outlet. The outlet is connected to a dual-basin manhole structure which controls pond elevation, after which the effluent (2-year through 100-year flow) is conveyed by gravity to a flow spreader (consisting of a concrete curb and rip-rap covered swale). The spreader distributes flow from the piped outlet to a natural overland flow path from the spreader to the downstream wetland.

During periods of extreme flows (i.e. greater than the 100-year storm event with snowmelt, peak monthly rainfall and projected increases due to climate change considered), effluent discharges via a concrete weir structure, as part of the SWMP berm, and is further conveyed in a rap-rap lined channel to the site footprint limit where a natural overland flow path conveys flow to the adjacent wetland.

5.4.6 Aggregate Stockpile/Laydown Area

A stockpile area for daily cover/interim cover clean soil, interim cover clean sand, and aggregates is located at the southeast end of the NSDF site adjacent to the South Kiosk.

5.4.7 Power Distribution Building

The Power Distribution Building is located on the east side of the OSC and houses power distribution equipment for the Facility.

5.4.8 Sanitary Sewage Disposal Systems

The NSDF sanitary sewage conveyance system routes sewage to the primary Private Sewage Disposal System constructed for the NSDF, located at the north entrance to the NSDF site east of EMR. A second Private Sewage Disposal System is provided adjacent to the South Kiosk to support only the South Kiosk.

The NSDF's primary sanitary system utilizes a network of 100 mm to 150 mm diameter PVC gravity sewers, to convey septage from the VDF, the OSC, the Administration Office, the North Kiosk, and the WWTP to a Private Sewage Disposal System. The sanitary sewer discharges through a septic tank that separates most solids from liquid effluent. The septic tank discharges into a sanitary pump station, which in turn, lifts liquid effluent to the nearby septic tile field. The sanitary pump station consists of a 1.8 m diameter cylindrical concrete structure which houses twin submersible solids handling pumps.

Sewage discharges from the South Kiosk through a septic tank. Liquid effluent from the tank is pumped via a submersible pump within the septic tank to a septic tile field near the South Kiosk.

5.5 References

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[5-7] AECOM, *Surface Water Management Plan*, 232-508600-PLA-002, Revision 1, 2019 February.

[5-8] AECOM, *Waste Placement and Compaction Plan*, B1550-508600-PLA-001, Revision 2, 2019 October.

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[5-17] AECOM, *Design Concept Decision (Optioneering Study) for WWTP*, 232-503212-DCD-002, Revision 0, 2017 March.

[5-18] AECOM, *Leachate and Wastewater Treatability Assessment (WWTP)*, 232-106400-ASD-001, Revision 1, 2018 October.

[5-19] *Engineering Change Control*, 900-508130-MCP-001, Revision 2, 2019 July.

[5-20] *Near Surface Disposal Facility Effluent Discharge Targets*, 232-106499-REPT-002, Revision 0, 2019 October.

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6. DESIGN BASIS

The design basis is the range of conditions and events taken explicitly into account in the design of a nuclear Facility, according to established criteria, such that the Facility can withstand this range without exceeding authorized limits. The NSDF design has been driven by the requirement to safely dispose of LLW and ensure protection of the workers, the public and the environment. To achieve this safely, the characteristics of the LLW and environmental conditions have been incorporated into the design.

6.1 States of the Facility Considered

The states of the Facility considered are normal operation, AOOs, DBAs and BDBAs including DECs.

6.1.1 Normal Operation

Normal operation of the Facility is when the Facility is operating within the safe operating envelope. Operating limits for safe operation are derived based on key safety important operating variables. The NSDF OLCs are defined in Section 15.

6.1.2 Anticipated Operational Occurrences

Anticipated operational occurrences are those events that deviate from normal operations and are expected to occur once or several times during the operating lifetime of the Facility. An AOO does not result in significant damage to items important to safety, nor leads to accident conditions. These include events with frequencies of occurrence greater than or equal to 10^{-2} events per year.

6.1.3 Design Basis Accidents

Design basis accidents are those accident conditions that the Facility is designed against according to the established design criteria. These include all events with frequencies of occurrence equal to or greater than 10^{-5} per year, but less than 10^{-2} per year. Table 6-1 presents the NSDF DBAs with references to the design basis and alignment of the DBA with IAEA requirements of SSR-5 [6-1].

The DBAs that the NSDF is designed to are:

- Design Basis Earthquake (DBE) with a rate of return of 10 000 years. The basis of the DBE is documented in Seismic Analysis [6-2], and Design Requirements, Section 6.3.1 [6-3].
- Operating Basis Earthquake (OBE) with a return period of 2 500 years. The basis of the OBE is documented in Seismic Analysis [6-2], and Design Requirements Section 6.3.1 [6-3].
- Design Basis Tornado (DBT). The basis for the NSDF DBT is the CRL DBT documented in CRL Site Characteristics [6-4], and Design Requirements Section 6.3.2.2 [6-3]. Based on the Canadian definition of an EF2, however, the DBT for the CRL site is an upper EF2 Tornado

with maximum wind speed of 220 km/h [6-4]. The Equalization Tanks are designed to the DBT [6-5].

- Back to back 100 year rainfall events. The basis of the design basis rainfall event, back to back 100 year 24 hour storm event, is documented in Design Requirements, Section 6.2.2 [6-3].

Table 6-1
Design Basis of NSDF Design Basis Accidents

Applicable SSCs	Design Basis Accident	Event Return Rate and Probability of Exceedance	Design Basis Reference	Design Basis Standard	Alignment with SSR-5 Requirements [6-1]
ECM - final cover system, base liner system, and perimeter berm.	Design Basis Earthquake (DBE)	1 in 10 000 years. 5.4% in 550 years.	Seismic Analysis [6-2], Design Requirements, Section 6.3.1 [6-3].	CSA N289.1 [6-6]	Requirement 5: passive means for safety of the disposal facility. Requirement 8: containment of radioactive waste.
	Operating Basis Earthquake (OBE)	1 in 2 500 years. 2% in 50 years.	Seismic Analysis [6-2], Design Requirements, Section 6.3.1 [6-3].	CSA N289.1 [6-6]	Requirement 5: passive means for safety of the disposal facility. Requirement 8: containment of radioactive waste.
Buildings (WWTP, VDF) and support structures	Operating Basis Earthquake (OBE)	1 in 2 500 years. 2% in 50 years.	Seismic Analysis [6-2].	NBCC 2015 [6-7]	Requirement 8: containment of radioactive waste. Requirement 16: design of a disposal facility.
Equalization tanks	Design Basis Tornado (DBT)	10^{-5}/year.	CRL Site Characteristics [6-4], Design Requirements, Section 6.3.2.2 [6-3].	ANSI/ANS-2.3-2011 [6-8].	Requirement 8: containment of radioactive waste. Requirement 16: design of a disposal facility.
Surface water management ponds, and non-contact collection and conveyance	100 year, 24 hour storm event	1 in 100 years. 1% in 100 years.	Design Requirements Sections 3.2.8, 3.2.9, 3.3.2 [6-3], Surface Water Modelling and	Design Guidelines for Sewage Works [6-11], Stormwater Management	Requirement 15: site characterization for a disposal facility. Requirement 16: design of a disposal facility.

system within the ECM			Evaluation [6-9], Surface Water Management Plan [6-10].	Planning and Design Manual [6-12], Erosion and Sediment Control Guideline for Urban Construction [6-13], Ontario Provincial Standards for Roads & Public Works [6-14], Technical Guide – River and Stream Systems: Flooding Hazard Limit [6-15].	
Contact water collection ponds	Back to back 100 year 24 hour storm event	1 in 10,000 years. 0.01% in 100 years.	Design Requirements Sections 3.2.8, 3.2.9, and 3.3.2 [6-3], Surface Water Modelling and Evaluation [6-9], Surface Water Management Plan [6-10].		Requirement 8: containment of radioactive waste. Requirement 16: design of a disposal facility.
Equalization tanks	Back to back 100 year 24 hour storm event plus peak monthly precipitation and snowmelt	1 in 10,000 years. 0.01% in 100 years.	Design Requirements, Section 3.3.2 [6-3] Surface Water Modelling and Evaluation [6-9], Surface Water Management Plan [6-10].		Requirement 8: containment of radioactive waste. Requirement 16: design of a disposal facility.

6.1.3.1 Rainfall Event

The DBA rainfall event is the back to back 100 year 24 hour storm event, which is applicable to the contact water collection ponds and the Equalization Tanks. The volume of contact water generated by the DBA rainfall event is 4 710 m^3 including peak monthly rain and accumulated snowmelt, leachate from closed cells (maximum of 0.37 m^3/day when nine cells are closed with final cover in place), and impacted wastewater produced from on-going site operations (0.27 m^3/day) [6-16].

The Equalization Tanks, influent equalization system, are designed and sized to contain the leachate and contact water flow at the maximum 48 hour routed condition, that would be produced from the largest cell of the ECM during the back-to-back 100 year, 24-hour storm events, including peak monthly rain and accumulated snowmelt (volume of 4 710 m^3) [6-16] and [6-9].

The Equalization Tanks are 1 900 m^3 each with a total working capacity of 5 700 m^3. The Equalization Tanks capacity for operations is 990 m^3, based on a total working capacity of 5 700 m^3 and the DBA rainfall event volume is 4 710 m^3 [6-9].

6.1.4 Beyond Design Basis Accidents

Beyond design basis accidents including DECs, are those accident conditions that fall outside the design envelope of the Facility's safety systems (accident conditions more severe than those of a DBA). These include events with frequencies of occurrence less than 10^{-5} per year.

6.2 Chalk River Laboratories Site Design Basis

The CRL site characteristics and site design basis are documented in CRL Site Characteristics [6-4]. The CRL site design basis in [6-4], applies to the NSDF design.

The Design Basis Flood level for the CRL site, for both precipitation events and for complex events involving random (or seismically related), failure of both the upstream dams (and of the control works at the exit from Lake Temiskaming), is 122 mASL, which includes a margin of 2 m [6-4].

The DBT for the CRL site is an upper Enhanced Fijita 2 (EF2) tornado with maximum wind speed of 220 km/h, based on the Canadian definition of an EF 2 tornado [6-4].

6.3 Engineered Containment Mound

The total area of the ECM is approximately 17 hectares including the perimeter berm. The ECM area without the berm is approximately 12 hectares including the inner side slopes of the berm. The ECM has the capacity to contain 1 000 000 m^3 of LLW in 10 disposal cells. The ECM has a 550 year design life that includes 50 years of operations. The ECM design life of 550 years has been established to meet the required time period to allow for radiologic decay of the waste inventory. Details on the ECM SSCs are documented in Section 5.1.

The placed waste thickness is approximately 15 m in the center of the disposal cell, and the average waste density is assumed to be 1.5 g/cm^3.

Only one cell with a maximum area of 15 000 m^2 shall be open for the placement and disposal of waste. An adjacent cell may be open for supporting activities including TSWRPA and contact water management.

Within the ECM, the TSWRPA is a 6 000 m^2 temporary waste storage pad for staging waste. The storage pad is a gravel area that may be used to stage both bulk and packaged waste awaiting disposal in the open cell. Precipitation that falls on the temporary storage pad will be treated as contact water. No uncontained waste is stored in the TSWRPA. All waste is either in its transportation container or disposal container, or covered with daily cover. The only processing that is performed in the TSWRPA is the staging of waste or container preparation for grouting.

The contact water transfer system from the ECM to the pump station, is sized to handle an active waste disposal cell area of 15 000 m^2 plus 6 000 m^2 (TSWRPA area) for a combined area of 21 000 m^2 in-cell waste area for waste operations [6-16]. This assumption is based on an average ECM disposal cell configuration during the 50 years of operations [6-16].

In the event, that the WWTP was to experience a prolonged outage of greater than 30 days, waste placements in the ECM would be halted, and an interim cover would be installed over the open waste surfaces in the ECM.

6.3.1 Partition Coefficients

The K_d, partitioning factors are documented in Reference Distribution Coefficient and Calculation of the Effective Distribution Coefficient for the NSDF Engineered Containment Mound (K_d) [6-17] and [6-18]. This document [6-17] and [6-18], contains mass-weighted average K_d values, based on the proportions of various waste materials in the ECM, each with its own K_d value. These K_d partitioning factors conservatively estimate the leachate characteristics with the intention to avoid underestimating release rates and leachate concentrations.

6.3.2 Waste Package Failure

Waste compaction is assumed to result in the immediate failure of 5% of the waste packages [6-16] and [6-19]. As time progresses, waste containers are assumed to fail at a rate of 1% per year due to corrosion [6-16] and [6-19]. As more packages fail, more waste is available to contact infiltrating water and influence the leachate characteristics. The 1% annual failure rate is based on measured corrosion rates of metal buried in moist soil [6-16] and [6-19].

6.4 Buildings

The design basis for all buildings is the NBCC 2015 [6-7]. For the building structures, the design basis criteria are based on NBCC having a DBE with a rate of return of 2 475 years [6-5]. All building structures, including the WWTP, VDF, and other support buildings, are expected to remain functional or seismically qualified when undergoing a seismic event with a rate of return of 2 475 years [6-5].

6.5 Design Loads

Design criteria and assessment related to the seismic design, bearing capacity, and slope stability of the ECM, are documented in the Bearing Capacity, Settlement, and Lateral Earth Pressure Analysis [6-20]; Seismic Analysis [6-2]; and Slope Stability Analysis [6-21]. The subsurface data, use of this data in the design of the NSDF, and identification of required field investigations are documented in the NSDF Geotechnical Report [6-22].

Seismic design criteria apply to the various SSCs and are divided into two categories:

1. Building Structures (WWTP, VDF, and other supporting structures).
2. Engineered Containment Mound (mound, LCS, liner system and related components, and perimeter berm).

The seismic design building structures including WWTP, VDF, and other supporting structures, is based on NBCC 2015 seismic design parameters [6-7]. The Seismic Analysis [6-2], was performed based on the NBCC 2015 seismic design parameters and are listed in Table 6-2.

Table 6-2
NBCC 2015 Seismic Design Parameters [6-7]

Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)	PGA
0.389	0.208	0.104	0.049	0.25 g

For the ECM, the seismic design basis is based on the site-specific having a DBE with a rate of return of 10 000 years, and an OBE with a return period of 2 500 years. For the DBE, the ECM shall be able to withstand the 10 000 year ground motions, while maintaining containment of waste and leachate [6-5]. For the OBE, all ECM components including the containment berm, the ECM mound, the liner system and components, and LCS, are expected to not incur damage that requires emergency response or that impedes operation of the ECM, and containment of waste and leachate must be maintained [6-5].

The ECM is designed for a 1 in 10 000 year earthquake and the primary seismic design criteria for the ECM are:

- The ECM must be able to withstand the 10 000 year ground motions as defined in CSA N289.1 [6-6], while maintaining containment of waste and leachate [6-2].

Likewise, seismic deformations under the 2 500 year earthquake, must not result in damage that requires emergency response or that impedes operation of the ECM, and containment of leachate and waste must be maintained [6-2]. The design seismic performance criteria for the ECM are shown in Table 6-3.

Table 6-3
Design Seismic Performance Criteria for Engineered Containment Mound [6-2]

Seismic Loading Criteria	Design Analysis or Parameter	Performance Criteria
Design Basis Earthquake (DBE) (10 000 year event)	Design Peak Ground Acceleration	0.55 g
	Maximum Seismic Displacement of Base Liner **	<30 cm
	Cover and liner axial strain	<3% *
	Post-Earthquake Factor of Safety	Factor of Safety >1.2
	Other: No slope reversal for both cover and liner system.	
Operating Basis Earthquake (OBE) (2 500 year event)	Design Peak Ground Acceleration	0.25 g
	Maximum Seismic Displacement of Base Liner**	<15 cm
	Cover displacement	<30 cm
	Seismic (Pseudostatic) Factor of Safety	Factor of Safety >1.0
Note: * Strain includes both locked-in static strains due to vertical settlement, and strains induced by seismic deformation. ** The base liner system includes the leachate collection piping and the CCL.		

6.6 Containment

The NSDF design and operation will provide containment during the operations phase through preventing and controlling the release of nuclear and/or hazardous substances.

The NSDF Project has considered measures to contain and isolate waste during emplacement, specifically to minimize/prevent contact water and radionuclide migration. The principles of isolation and containment [6-1], are satisfied in the inventory management, design features and planned operational practices. Further, the NSDF Project is assessing additional measures to minimize contact water that are considered an optimization to the current proposed NSDF design and safety basis.

Inventory Management

The inventory proposed for the NSDF is solid LLW, which will be controlled through the NSDF WAC [6-23]. The WAC [6-23] applies a graded approach to control leachate radionuclide concentrations during placement of waste. There will be a small portion of waste, which will be required to utilize robust packaging to isolate the waste from precipitation and prevent the spread of contamination. Specifically, leachate controlled waste packages are intended to provide short-term barriers for wastes with higher radionuclides concentrations during the time the disposal cell is not covered with the final cover system (approximately 5-10 years). Thus, more mobile radionuclides, such as tritium, are kept isolated from the environment to minimize liquid effluent releases during the operations phase.

Design Features and Planned Operational Practices

Containment of the disposed LLW in the NSDF is controlled through engineered barriers including the ECM base liner system, ECM perimeter berm and the final cover system that are designed to perform multiple safety functions for at least 550 years.

The NSDF includes a number of design features to minimize the generation of wastewater (including contact water) including:

- Limiting the active cell area to 21 000 m^2.
- The separate management of contact water, and non-contact water within the ECM.
- The use of interim covers over waste areas that will be inactive for greater than 30 days.

These design features are discussed in Sections 5.1.1, Section 5.1.8, Section 5.1.9, Section 5.1.10, Section 6.3, and Section 7.

During waste placement operations, all efforts are made to minimize the contact of precipitation with the contaminated waste thus, minimizing contact water and leachate generation. The operation of the NSDF is limited to one open cell at a time to limit the surface area of waste that is exposed to the environment (i.e. precipitation) at any given time. As a cell is constructed, interim covers are placed over the waste to limit infiltration of precipitation and promote non-contact surface water run-off. As each disposal cell is completed, the final cover system is installed over the filled disposal cell. Other operational practices to limit contact with precipitation include grading and compaction of the waste fill to promote surface water run-off.

During the operations phase, sacrificial liners are used on top of the waste (as part of the interim cover) and the base liner system to divert storm water into the non-contact water collection areas (ponds). A sacrificial liner for Phase 1 is provided to cover the entire ECM floor. An interim cover is applied to 3:1 side-slope areas to prevent storm water from entering the LCS system at non-active cells. The waste is also covered with an interim cover composed of a 0.3 m layer of soil or sand overlain with a sacrificial liner that minimizes precipitation infiltration into the waste matrix, and promotes non-contact water runoff. The temporary sacrificial liners on the ECM floor and as part of the interim cover will be removed, cell by cell, prior to placement of the waste and final cover system materials.

Non-contact water in the ECM is managed and contained using the non-contact water ponds. Non-contact water that is analyzed to be free of contamination is pumped out of the ECM and released through the surface water management ponds.

Containment of contact water in the ECM is managed and contained using contact water ponds and sacrificial liners. Contact water is transferred to the Equalization Tanks and then to the WWTP for processing.

Furthermore, containment of any contact water generated is managed using the ECM LCS, ECM LDS, Equalization Tanks and the WWTP. Any water run-off that makes contact with (or is suspect of contacting) the contaminated waste, will be diverted to a contact water pond and conveyed to the WWTP for treatment to remove contaminants prior to controlled release into the environment. Treated effluent discharge targets [6-24], are established to be protective of human and non-human biota health.

Additional Measures:

Additional measures that could be taken to keep the waste dry during waste handling, emplacement and storage (operation), and are being considered including assessing the feasibility of using a conceptual weather cover structure [6-25] over the open disposal cell to minimize contact water. The NSDF Project considers the weather cover structure to be an optimization of the current design and that the ECM can be operated effectively without the weather cover structure [6-25].

6.7 Structural Analysis

This section discusses the supporting structural analysis.

6.7.1 Slope Stability

Results of the modelling for global stability, indicated that shallow surficial soils, less than approximately 1.0 m depth, are susceptible to liquefaction triggering and will be treated during the construction of the ECM to prevent post-liquefaction strength loss following a DBE. The areas requiring treatment are identified in Slope Stability Analysis [6-21].

For the southwest side of the ECM, (chiefly under the footprint of the containment berm), it is anticipated that the overburden soils (approximate overburden thickness less than 5 m), will liquefy during the design seismic event [6-21]. The overburden soils must be treated beneath the containment berm. The Excavate and Replace method is now considered to be the optimal mitigation method. Dynamic Compaction could also be used in conjunction with Excavate and Replace, in select areas of the site where the existing grade is relatively flat and in the limited areas where proximity of the existing wetlands would require the use of sheet piling or other temporary excavation support [6-21]. At a minimum, the treated zone should consist of all overburden soils and extend horizontally from beneath the containment berm to a distance at which the containment berm slopes (3H:1V) intersect the rock surface. The construction contractor must determine the actual extents of treated soil [6-21].

Limit-equilibrium analysis indicates acceptable factors of safety for the critical sections of the ECM under static and seismic cases [6-21]. Seismic cases include the pseudostatic and post-earthquake analysis using OBE and DBE ground accelerations, respectively.

Deformation analysis using three Newmark-type methods, typically calculated very small displacements ranging from less than 1 cm to 2.6 cm of the embankment under OBE loading condition. Therefore, the OBE deformation criteria is met and the ECM earthen structure is expected to remain functional when subjected to ground motions of magnitude equal to or less than the OBE. Similarly, the calculated deformations under the DBE calculated using the three Newmark-type methods were relatively small. Maximum displacement predicted by the three methodologies ranged from about 1 cm to about 5 cm under the DBE. The results are well below the DBE deformation criteria of 30 cm, and therefore, the ECM is not anticipated to experience loss of containment as a result of the DBE [6-21].

With respect to veneer stability, the calculated Factor of Safety against sliding between liner and cover components, meets or exceeds the required minimum factor of safety [6-21]. The calculated factor of safety for resistance to pull-out of liner components from anchor trenches, also exceeded the minimum factor of safety, indicating pull-out will not occur [6-21].

6.7.2 Seismic Analysis

The seismic analysis of the NSDF is documented in the Seismic Analysis [6-2], and the following is a summary.

Non-linear dynamic analysis of the ECM was performed using the computer numeric modelling software FLAC. Analysis results indicate maximum shear displacements along the base and cover liner systems are less than 2 cm and 5 cm, respectively. These calculated shear displacements are well below the acceptable displacement of 30 cm specified in the seismic performance criteria. The calculated maximum seismically induced axial strain in the base and cover liners is less than 0.9% and 0.2%, respectively.

The maximum displacements calculated in the berm and cover system are 26 cm and 22 cm, respectively. Although calculated maximum displacement up to 55 cm occurs at the convex nose at the south end of the ECM in the 3D model, the pattern of this displacement suggests that it corresponds to shallow and localized movements near the ground surface. Furthermore, results of the post-earthquake limit equilibrium slope stability analyses presented in the Slope Stability Analysis [6-21], indicate that the factors of safety are well above the target performance criterion of 1.2. The predicted behavior of the ECM, in both the deformation analyses and the limit equilibrium analyses is comparable, and the results indicate that global failure with loss of containment is very unlikely [6-2].

The seismic analysis results of the WWTP structure was found to be satisfactory [6-2]. The demand on the structural elements and foundations was found less than the resistance of these elements. As well, the lateral deflection of the structural system is well below the acceptable deflection limit.

6.7.3 Bear Capacity, Settlement and Lateral Earth Pressure

The bearing capacity, settlement and lateral earth pressure for the ECM is documented in Bearing Capacity, Settlement, and Lateral Earth Pressure Analysis [6-20].

Differential settlement of the ECM foundation liner is not expected to significantly affect leachate drainage over the base of the ECM. The slope of the ECM floor will maintain positive drainage after experiencing maximum differential settlement. Differential settlement of the ECM foundation is not expected to cause tensile cracking of the CCL component of the base liner system.

6.7.4 Liquefaction Mitigation

The ECM liquefaction mitigation options are documented in Chalk River ECM Ground Improvement Options for Liquefaction Mitigation [6-26]. The classical definition of liquefaction is a significant loss of strength and stiffness as a result of shear loading [6-26].

The project seismic design criteria, states that full liquefaction condition is to be considered if the factor of safety against liquefaction is less than 1.2 [6-26]. This assumption implies that factor of safety against liquefaction of 1.2 or greater is required for the improved ground [6-26].

Liquefiable soil under the ECM, chiefly under the footprint of the perimeter berm must be treated to mitigate the risk of liquefaction. Recommended treatment consists of excavation of the weak soil and replacement with non-liquefiable engineering fill. Dynamic compaction could also be used in conjunction with Excavate and Replace in select areas of the site where the existing grade is relatively flat, and also in the limited areas where proximity of the existing wetlands would require the use of sheet piling or other temporary excavation support [6-26]. At a minimum, the treated zone should consist of all overburden soils and extend horizontally from beneath the containment berm to a distance at which the containment berm slopes

(3H:1V) intersect the rock surface. The construction contractor will determine the actual extents of excavation and replacement for treated soil.

6.8 Construction

The CNL Construction Process provides the framework for external contractors performing construction and installation activities at CNL sites, to ensure they are being adequately controlled and documented within approved safety margins and regulatory/statutory requirements [6-27]. The Construction Process [6-27] work, conducted at CNL is controlled by various procedures, which provide the necessary guidelines to ensure that construction work is compliant with Management System Requirements for Nuclear Power Plants [6-28].

The QA procedures and monitoring requirements in the Construction Quality Assurance Plan [6-29], will be followed for the site preparation and construction activities. The mitigation measures and best management practices in the Environmental Protection Plan [6-30] will be followed to ensure protection of the environment.

Environmental measures captured in the EIS [6-31] that will be in place during the NSDF construction phase to mitigate impacts include:

General

- Workers on the NSDF site, shall complete the CRL generic contractor orientation and awareness training and the NSDF Project specific environmental awareness training [6-30].
- The posted speed limit for vehicles on haul roads is 20 km/h [6-30].
- All wastes that arise as a result of the construction will be safely managed and in accordance with CNL's Waste Management Program.
- Road grading and levelling activities will not be completed during the turtle nesting season (May 15 to June 30).
- Attractants (e.g. collection and storage in appropriate wildlife-resistant containers) will be managed to limit interactions between people and wildlife.
- As per CNL's Management of Land, Habitat and Wildlife procedure, [6-32] feeding of wildlife is prohibited to minimize habituation.

Erosion and Sediment Control

- Erosion and sediment control measures will be in place to mitigate the effects of sediment transport. The measures will include the use of erosion control blankets, as needed on steep slopes, check dams in ditches and swales.

Surface Water and Wetlands

- Temporary silt fencing (e.g. sheeting, fencing, hay-bales), adjacent to wetlands, shall be installed prior to May 1 around the construction footprint in areas located in potential critical habitat to prevent the turtle's entry during construction. Inspection of silt fencing and turtle fencing shall be conducted periodically (e.g. weekly) and particularly after heavy rainfalls. No work using heavy equipment activities disturbing the ground within the 30 m wetland setback is authorized during the turtle active season (between May 1 and September 30).
- A 30 m buffer area has been established along all identified wetlands near the NSDF site and no new construction is permitted within this 30 m buffer zone to protect the wetland.
- The three SWMPs will be temporarily configured for construction for sediment control. The flood control orifice will be smaller than the one required for normal operation to extend the retention time in the pond. The inlet elevation to the flood control inlet will also need to be increased using temporary sandbags to provide the necessary storage volumes and drawdown times. Once construction is completed, the temporary orifices and inlets will be replaced with the necessary structures required for normal operations.
- Monitoring of water levels and sediment build up in the SWMPs.
- Monitoring of wetland water elevations and surface water flows to verify changes from the presence of the ECM.
- Where practical, natural drainage patterns will be used to reduce the use of ditches and diversion berms.
- Culverts will be installed or upgraded along site access roads, as necessary, to maintain drainage; all drainage features will be designed to safely convey the flows associated with the Probable Maximum Precipitation event.
- Migratory bird exclusion measures will be implemented at the SWMPs.
- Any runoff in contact with blasting residues at the site study area will be managed according to the Surface Water Management Plan (e.g. directed to surface water management ponds and associated systems) during the construction phase.

Tree-Line Buffer

- A 5 m tree-line buffer will be established from the NSDF Project site to limit disturbance to vegetation and large tree roots at the tree-line. Buildings and structures will not be located within 5 m of this buffer zone to provide access for equipment around structures. A buffer zone will also be maintained between the ECM and the boundary of the NSDF Project site. This zone provides sufficient area surrounding the facility operations to allow environmental monitoring to be performed, to facilitate maintenance, and to allow implementation of contingency measures during an emergency.

Vegetation and Tree Clearing

- Vegetation clearing and grubbing in the majority of the site study area, and particularly in complex forested habitat, will occur before April 8 or after August 31 to avoid effects on nesting birds and bat maternity roosts.
- A risk assessment checklist is used to determine if an area qualifies as a simple habitat, qualifying for nest searches and clearing in the absence of nests during the breeding season. The checklist has a series of risk factors and the total score provides whether the area qualifies.
- If vegetation clearing in small areas with simple habitat (i.e. that can be effectively searched for nests) cannot be conducted outside the breeding bird nesting period (April 8 to August 28), or bat maternity roosting period (May 1 to August 31), pre-clearing bird and bat surveys will be completed to confirm no active nests/roosts are present in trees to be felled. Pre-clearing bird and bat surveys will be completed by CNL's Environmental Protection team to confirm no active nests/roosts are present in trees to be felled. This work must be approved by Environmental Protection prior to execution and can be denied if the risk to birds or bats is considered high.
- Species-specific buffers will be put in place around active nests/roosts to avoid disturbance to wildlife caused by noise and other sensory disturbance caused by site preparation activities.
- Implementation of a comprehensive Sustainable Forest Management Plan to ensure the long-term retention of trees serving as maternity roosts for the bat species.
- Trees will not be felled until the nests/roosts are confirmed inactive and no longer occupied.
- If vegetation clearing is scheduled in open habitat between late May and October, the habitat will be searched in advance of construction for the presence of milkweed. Areas of the footprint that contain milkweed will be cleared outside of late May to October to avoid effects on monarch butterflies.

Air Quality and Dust Management

- Work activities will be restricted or shut down during sustained wind speeds of 40 km/h as registered by the on-site wind gauge, or if visible dust plumes are observed on site [6-30].
- Road misting and fixative application to mitigate fugitive dust emissions.
- Site inspection during periods of high dust susceptibility, regular inspections will be carried out to monitor the efficacy of dust mitigation and any potential concerns with regards to fugitive dust, and if required implementation of mitigation will be recommended. Environmental conditions will be recorded.

- Use wind fencing around work areas.
- Covering stockpiles and exposed areas prior to high wind or dry conditions where standard dust suppressants may be inadequate in preventing dust generation caused by wind erosion.
- Revegetating affected areas or adding mulch to completed cells and excavated areas as soon as practicable.
- Dampening soil in dry areas prior to commencing truck/machinery activities in the area.
- Particulate monitoring – suspended particulate matter (SPM) using a high volume sampler.
- Application of aggregate to unpaved roads – a record will be kept of the date of each application of aggregate to unpaved roads.
- Fuel Usage – a record will be kept of the fuel usage related to the NSDF Project and will be used to estimate greenhouse gas emissions
- On-site vehicles and equipment engines will meet Tier 2 emission standards and be maintained in good working order.
- Limit idling of vehicles on-site.

Groundwater

- Sampling to confirm groundwater quality.
- Groundwater elevation measurements to determine groundwater flow direction and gradients.

Terrestrial Environment

- Visual monitoring of bat boxes is conducted weekly every year during the pre-construction phase and will continue through construction and for three years after start of operations.
- Wildlife-vehicle collision monitoring will be conducted in the site study area - Vehicle-caused Blanding's turtle mortality will be reported and data will be compiled in a database that can be used to inform adaptive management for the site.
- Road mortality surveys to be conducted weekly during pre-construction and operations within the NSDF Project site. During construction mortality survey to be conducted daily during the Eastern Milksnake species active period (April 15 to September 30).
- As part of the Species at Risk Act permitting process for the removal of critical habitat, critical habitat will be assessed annually to ensure no significant loss at CRL and to highlight compensation measures initiated at CRL or elsewhere. Monitoring will be integrated into CNL's existing Species at Risk Program.
- Reptile exclusion fencing will be installed around the perimeter of the site study area prior to initiating activities during the construction phase and prior to the active Blanding's turtle season (i.e. prior to April).

- Temporary exclusion fencing will be installed around the NSDF EMR footprint during construction of the NSDF Project. This temporary exclusion fencing will be replaced by permanent fencing by the end of construction of the NSDF Project.
- Exclusion fencing will be inspected annually for integrity.
- Following approval of the NSDF Project, additional permanent exclusion fencing will be installed in reptile hotspots along Plant Road.
- After replacement, culverts will have appropriate permanent fencing installed for 200 m on either side of the culvert to guide turtles through the tunnel.
- Culverts will be inspected weekly for barriers to turtle movements, during the active season for Blanding's turtle (April 15 to October 15).
- Nesting mounds will be inspected weekly for suitability and mounds will be maintained by removing vegetation as needed, during the nesting season for Blanding's turtle (May 15 to June 30).
- Nest cages will be inspected weekly for integrity during the nesting and hatchling emergence season for Blanding's turtle (May 15 to October 15).
- Cameras will be installed at culverts and will record photographs on a time-lapse basis, continuously during the active season for Blanding's turtle (April 15 to October 15) every year for the next five years. Photographs will be reviewed and data compiled.
- An Invasive Species Management Plan in keeping with best management practices such as the Ontario Ministry of Natural Resources and Forestry, Forest Management Guide for Conserving Biodiversity at the Stand and Site Scales [6-33] will be implemented to limit effects of noxious and invasive plants on natural vegetation.

<u>Noise</u>

- Activities with highest levels of noise and habitat disturbance will be avoided during most sensitive life history phase (i.e. breeding and nesting for birds, maternity roosting for bats) by conducting vegetation clearing and grubbing before April 8, or after August 31 to avoid effects on nesting birds, bat maternity roosts and the active Blanding's turtle season, and to minimize effects on monarch butterfly and milksnake.
- Activities with a high noise level (e.g. rock crushing) will be completed during day light conditions.
- Work inside closed buildings may take place during non-daylight conditions.

<u>Construction of transfer line from WTTP to Perch Lake</u>

- High-pressure directional drilling will be used.
- Minimization of vegetation removal beyond previously disturbed areas.

- Machine operation will take place on land above the high water mark of Perch Lake. Drilling machinery will kept be clean and leak free. Service, washing or refuel and storage of these substances for the machinery will be away from surface water features. Emergency spill kits will be kept on site in the event of a fluid leak or spill.
- Where possible, drilling will occur during daylight hours, which will increase the probability of visually identifying a frac-out (i.e. a condition where drilling mud from a directional drilling operation is released through fractured bedrock and travels to the surface through surrounding porous materials).
- Drilling mud, cuttings and all waste will be disposed of at appropriate disposal facility. All waste materials will be contained in a dugout or holding basin away from wetlands or other surface water features, or storm drains, to avoid entering natural surface water features, until the waste can be transported for disposal.
- Erosion and sediment control practices (e.g. silt fences, run-off management) applicable to the region and already in place at the CRL site will be used during construction of the transfer line to Perch Lake as the exit point for drilling will be within the Perch Lake riparian area.
- On-going monitoring will be in effect during all phases of drilling works to assess fluid pressure (by drillers) and changes in turbidity in local surface water features (by environmental monitors) that would indicate surface migration (frac-out) of drilling mud.
- All material and equipment required to contain and clean up a frac-out event will be available on site.
- Full-time environmental monitoring during all phases of transfer line works within the Perch Lake Swamp to evaluate adherence to environmental protection measures and make observations on signs of surface frac-out of drilling mud.
- Evidence of frac-out will trigger implementation of the Frac-out Response Plan.

Site preparation involves activities required to prepare the NSDF Project site for construction. This includes vegetation clearing (e.g. removal of trees), mobilization of the necessary construction equipment and completing large-scale earth moving activities (e.g. excavation, blasting, hauling of materials, and grading) using conventional earth-moving equipment such as bulldozers and excavators. The site preparation activities include:

- Implementing the NSDF site is delineated as a dedicated construction area.
- Mobilization of equipment and workers to the job site.
- Implementing EnvP measures as per the NSDF EIS [6-31], including silt and erosion fencing, dust monitoring, and fuel and lubricants management.
- Establishing exclusion and buffer zones (e.g. marking areas, such as wetlands, where activities are not permitted to occur).

- Set-up activities include tree clearing and grubbing of vegetation, establishing designated material and equipment lay-down areas, installing construction office and lunchroom trailers, installing temporary access control measures (fencing) and installing temporary utilities to the site.
- Excavating, removing and stockpiling of topsoil and overburden for use as clean fill and ECM final cover system. The total volume of topsoil and overburden material to be removed and stockpiled is approximately 50 400 m^3 and 407 500 m^3, respectively [6-34].
- Blasting and excavation for the ECM.
- Prior to rock blasting, horizontal drains are drilled in the rock mass to lower the expected groundwater table (per 2017 January data logged), below the floor of the bench. The horizontal drains are expected to drain groundwater from the rock mass in approximately two to three days.
- A blasting plan is required, which includes a test blast protocol [6-30] and [6-35]. Rock blasting occurs on the southeast portion of the ECM area (see Figure 6-1). Blasting operations are expected to last approximately two weeks. Blasting will open additional fractures in the floor of the bench, which is expected to further depress the water table and prevent recharge. Blast depth is approximately 1 m – 8 m in highly competent rock, approximately 1% fractured, and is performed in three phases. The first bench contains approximately 20 000 tonnes of rock. The estimated volume from all blasting activities will generate approximately 256 000 m^3 of blasted rock [6-34]. Run-off water in contact with blasting residues will be managed to ensure protection of the environment [6-30].
- Removal and/or stockpiling of waste rock. After the blasted rock is removed from the rock floor, a sacrificial liner is placed to seal the area and prevent ground water from recharging the area.
- Excavation of drainage ditches and SWMPs.
- Grading of the NSDF site, including access roads, WWTP, laydown and stockpile areas, and various other building locations.

Construction activities are expected to take approximately two years to complete, and the construction season is expected to have a duration of approximately nine months per year. The main construction activities include:

- Construction of the ECM base liner system and perimeter berm.
- Construction of the surface water management infrastructure.
- Management of surface water.
- Management of construction wastes.
- Construction of on-site roads.

- Construction and commissioning of the WWTP, including construction of WWTP treated effluent transfer and discharge system, including the exfiltration gallery and transfer line to Perch Lake.
- Construction of support facilities.
- Construction of site infrastructure.

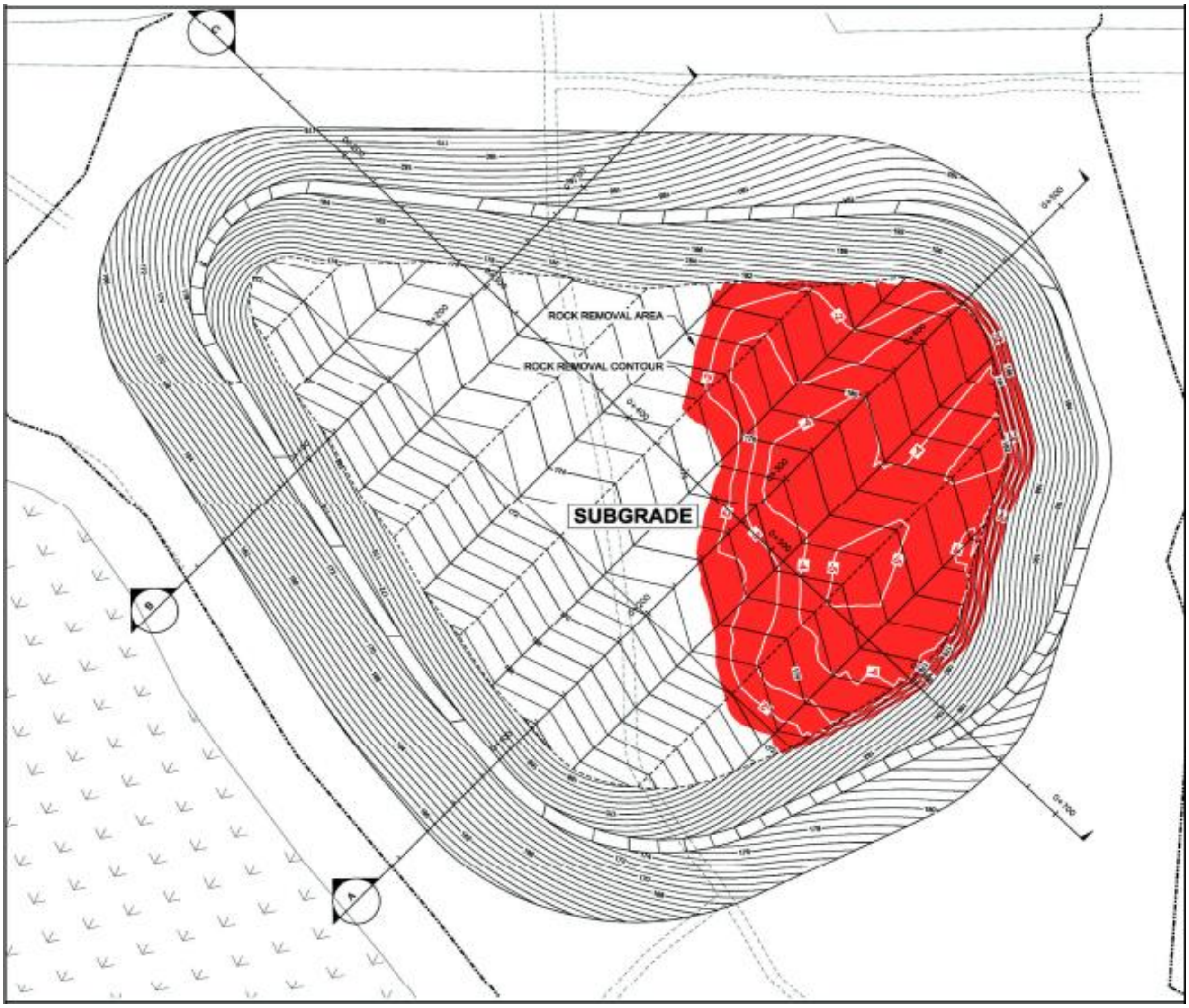

Figure 6-1 Rock Blasting Area at the ECM

6.8.1 Aggregate Materials for ECM Construction

The approximate quantities of topsoil, clay and aggregate materials required for the ECM construction is provided in Table 6-4 [6-34]. This table includes liquefaction mitigation aggregate materials for excavate and replace under the ECM perimeter berm. The potential sources of the NSDF aggregate construction materials are documented in Materials Source Evaluation [6-34].

Table 6-5 provides the design parameters/specifications for the ECM base liner system component interfaces, and the ECM base liner components are presented from the top layer to the bottom layer. Table 6-6 provides the design parameters/specifications for the ECM final cover system component interfaces.

Table 6-4
Approximate Quantities of Topsoil, Clay and Aggregate Materials Required for the ECM [6-34]

Type of Material	Application	Approximate Net Placed/Compacted Volume (m^3)				
		Phase 1		Phase 2		Total
		Construction	Operation	Construction	Operation	
Clay	Clay (for CCL at bottom)	56 700	-	31 200	-	87 900
Fine material	ECM base liner system	62 600	-	0	-	62 600
Granular, free draining	Perimeter berm, free draining gravel	481 700	-	76 000	-	557 700
Clear stone 9.5 mm	ECM base liner system (LCS and LDS)	16 500	-	10 000	-	26 500
Clear stone 19 mm	ECM base liner system	35 200	-	20 100	-	55 300
Clear stone 50 mm	LCS layer leachate sumps	300	-	0	-	300
Granular fill	Perimeter berm, intermediate gravel	160 800	-	39 400	-	200 200
Medium to coarse sand	ECM base liner system	28 500	-	5 500	-	34 000
Stone	Clean cover/yggregate stockpile/laydown area; blasted rock stockpile.	17 000	-	-	-	17 000
Granular 'A'	Layers in cover, in ECM base liner system and fill at designated locations (including perimeter berm and trenches for piping). Phase 1 sacrificial layer (24 700 m^3), Phase 2 laydown area (13 200 m^3)	57 900	10 100	12 000	27 300	107 300
Rock fill	Intrusion barrier, and 300 mm thick upper perimeter berm fill layer on outside and toe of final cover	14 300	28 400	3 100	32 600	78 400

Type of Material	Application	Approximate Net Placed/Compacted Volume (m^3)				
		Phase 1		Phase 2		Total
		Construction	Operation	Construction	Operation	
Sand	Clean material for use in Interim cover	-	15 000	-	17 800	32 800
Sandy Loam	Final cover layer (0.6 m)	-	45 000	-	58 500	103 500
Topsoil	Upper cover layer (0.15 m)	-	7 600	-	8 900	16 500

Table 6-5
Design Parameters/Specifications for ECM Base Liner Layer and LCS and LDS Component Interfaces

Interfacing Layers / Components	Interfacing Components	Design Parameters / Specifications for Layer/Component Interfaces
Primary Liner (with LCS) and Secondary Liner (with LDS) – ECM Floor Area (See Figure 5-3)		
Granular 'A' sacrificial cover	Sacrificial geomembrane.	The sacrificial geomembrane is to be durable, have a suitable coefficient of expansion, and be resistant to ultraviolet radiation damage. The sacrificial geomembrane is to be adequately anchored to prevent uplift by wind during period of use and to minimize infiltration/recharge through the liner into the rough-prepared subgrade throughout its period of use. The sacrificial geomembrane and granular 'A' sacrificial cover are to be removed prior to placement of Select Waste layer.
Sacrificial geomembrane	Granular 'A' sacrificial cover. Granular 'A' filter.	
Granular 'A' filter	Sacrificial geomembrane. Non-woven geotextile filter.	Interfaces between Select Waste layer (after removal of the sacrificial geomembrane and granular cover), granular 'A' filter layer and non-woven geotextile filter to have filter compatibility.
Non-woven geotextile filter	Granular 'A' filter. 19 mm clear stone.	Geotextile is to have filter compatibility with granular 'A' filter layer material. Geotextile has sufficient mass/unit area to prevent physical disruption of 19 mm clear stone layer during placement of granular 'A' filter layer.
19 mm clear stone granular drainage layer with LCS drainage piping	Non-woven geotextile filter. Woven geotextile separator.	Interfaces between 19 mm clear stone and geotextiles to have filter compatibility.
Woven geotextile separator	19 mm clear stone. Sand cushion(upper)	Geotextile is to provide a physical barrier over the 19 mm stone layer to prevent mixing of the stone layer with the finer-grained sand cushion.
Sand cushion (upper)	Woven geotextile separator. Primary HDPE geomembrane.	Interface to have filter compatibility between sand cushion layer materials and woven geotextile separator. Particle sizes in sand cushion layer material are to be small enough to prevent localized stress (dimpling/protrusions) on the primary geomembrane.

Interfacing Layers / Components	Interfacing Components	Design Parameters / Specifications for Layer/Component Interfaces
Primary HDPE geomembrane	Sand cushion (upper). GCL (upper).	Finished upper surface of HDPE geomembrane liner is to be free from standing water, snow, stones or other debris at the time of deployment of the sand cushion. Finished upper and lower surfaces of HDPE geomembrane is to meet the specified respective minimum interface friction requirements.
GCL (upper)	Primary HDPE geomembrane. 9.5 mm clear stone.	Upper surface of GCL is to be free of standing water, ice, snow, debris and loose stones, wrinkles, folds or "fish-mouths. The GCL shall not be in a saturated condition at the time of the HDPE geomembrane installation. The HDPE geomembrane is to be installed as soon as possible after placement of GCL. The GCL is to be placed under dry weather conditions and after removing temporary sacrificial liner. Pre-maturely hydrated GCL may need to be removed/replaced at direction of the Engineer.
9.5 mm clear stone	GCL (upper). Woven geotextile separator.	Clear stone layer and layer surface to consist of hard, durable rock particles free of organic matter (i.e. roots, leaves, wood, etc.), concrete, metals, construction debris and clay or shale partings.
Woven geotextile separator	9.5 mm clear stone layer. Sand cushion layer.	Geotextile has sufficient mass/unit area (≥1 100 g/m^2) to prevent physical disruption of sand cushion layer during placement of 9.5 mm clear stone LDS granular drainage layer.
Sand cushion (lower)	Woven geotextile separator. Secondary HDPE geomembrane.	Sand cushion layer is a filter that is compatible with the clear stone layer materials. Maximum particle sizes in sand cushion layer are small enough to prevent localized stress (dimpling/protrusions) on the secondary geomembrane.
Secondary HDPE geomembrane	Sand cushion layer (lower). GCL (lower).	Finished upper surface of HDPE geomembrane is to be free from standing water, snow, stones or other debris at the time of placement of the sand cushion. Finished upper and lower surfaces of the HDPE geomembrane are to meet the specified respective minimum interface friction requirements.
GCL (lower)	Secondary HDPE geomembrane. CCL.	Upper surface of the GCL is to be free of standing water, ice, snow, debris, and loose stones and free of wrinkles, folds, or "fish-mouths. The GCL shall not be in a saturated condition at the time of HDPE geomembrane installation. The HDPE geomembrane is to be installed as soon as possible after placement of the GCL. The GCL is to be placed under dry weather conditions and after removing temporary sacrificial liner. Pre-maturely hydrated GCL may need to be removed/replaced at direction of the Engineer.

Interfacing Layers / Components	Interfacing Components	Design Parameters / Specifications for Layer/Component Interfaces
Compacted Clay Layer (CCL)	GCL (lower). Sub Grade. Perimeter Berm (side slope see Figure 5-4).	The clay material is to be free of frozen lumps, visible organic matter (e.g. vegetation, roots, etc.) and any other deleterious material (e.g. waste, glass, metal, wood, plastic, etc. To minimize drying or excess wetting of the finished compacted clay layer surface, the GCL is to be placed over completed areas of the CCL as soon as practicable.
Additional Layers on top of the Base Liner System at the Intersection with the Side Slope (See Figure 5-4**)**		
Non-woven geotextile	Granular ‘A’ filter (Base Liner). Geogrid.	Geotextile is to provide a physical barrier over the Granular ‘A’ filter layer to prevent mixing with 19 mm clear stone layer.
Geogrid	Non-Woven Geotextile Cushion. 19 mm Clear Stone.	The surface of the geotextile is to be free of snow, stones, or other debris at the time of placement of the geogrid. The geogrid is to be placed to minimize any folds or wrinkles.
19 mm Clear Stone	Select Waste. Geogrid.	The clear stone is to be free of organic matter (i.e. roots, leaves, wood, etc.), concrete, metals, and construction debris.
Additional Layers – LCS Leachate Sump (See Figure 5-8**)**		
50 mm Clear Stone layer	Perforated HDPE pipe. Woven geotextile separator. 19 mm clear stone.	Clear stone is to be free of organic matter (i.e. roots, leaves, wood, etc.), concrete, metals and construction debris.
Woven geotextile separator	19 mm clear stone. Sand cushion layer.	Geotextile provides a physical barrier to prevent mixing of 50 mm clear stone layer and sand cushion.

Table 6-6
Design Parameters/Specifications for Individual ECM Final Cover System Component Interfaces

Interfacing Layers / Components	Interfacing Components	Design Parameters/Specifications for Component Interface
0.15 m thick topsoil layer	Atmosphere 0.6 - 1.2 m thick sandy loam soil layer	Finished upper surface of topsoil layer to be free from: debris and stones over 50 mm diameter, course vegetative material, 10 mm diameter and 100 mm length, occupying more than 2% of soil volume, and hollows and humps. Upper 25 mm thick portion cultivated immediately prior to seeding the upper 150 mm thick portion moistened prior to seeding.
0.6 - 1.2 m thick sandy loam soil layer	0.15 m thick topsoil layer 0.2 m thick granular ‘A’ stone layer (upper	Finished upper surface of sandy loam soil layer to be free from: debris such as wood, concrete, metal, glass, etc., and particles exceeding 100 mm in diameter.
0.2 m thick granular ‘A’ stone filter layer	0.6 - 1.2 m thick sandy loam soil layer 0.5 m thick intrusion barrier rock fill layer	Layer and layer surfaces to be free from: roots, leaves, wood, clay lumps, concrete, metals and construction debris, and reclaimed asphalt pavement, reclaimed hydraulic cement, concrete, glass, other reclaimed materials and slag materials.
0.5 m thick intrusion barrier rock fill layer	0.2 m thick granular ‘A’ stone layer 0.3 m thick granular ‘A’ stone layer	Finished upper surface of rock fill layer to be free from: roots, leaves, wood, clay lumps, concrete, metals and construction debris, and particles exceeding 200 mm in diameter.
0.3 m thick granular ‘A’ stone protection layer	0.5 m thick intrusion barrier rock fill layer Non-woven geotextile cushion	Layer and layer surfaces to be free from: roots, leaves, wood, clay lumps, concrete, metals and construction debris, and reclaimed asphalt pavement, reclaimed hydraulic cement, concrete, glass, other reclaimed materials and slag materials.
Non-woven geotextile protection layer	0.3 m thick granular ‘A’ stone layer HDPE geomembrane	Interface with granular ‘A’ stone layer and HDPE geomembrane: geotextile is to have a sufficient mass/unit area as determined through cushion puncture protection calculation to preclude damage to HDPE geomembrane from granular ‘A’ layer particles.
80-mil HDPE geomembrane liner	Non-woven geotextile cushion GCL	Finished upper surface of HDPE geomembrane line to be free from standing water, snow, stones or other debris at the time of deployment of the geotextile cushion. Finished upper and lower surfaces of HDPE geomembrane: meet specified respective minimum interface friction requirements.

Interfacing Layers / Components	Interfacing Components	Design Parameters/Specifications for Component Interface
GCL	80-mil HDPE geomembrane liner	Upper surface of GCL to be free of standing water, ice, snow, debris, and loose stones and free of wrinkles, folds, or "fish-mouths. GCL shall not be in saturated condition at the time of HDPE geomembrane installation. HDPE geomembrane is to be installed as soon as possible after placement of GCL. The GCL is to be placed on the first layer of the Final Cover System under dry weather conditions, and after removing temporary sacrificial liner. Pre-maturely hydrated GCL may need to be removed/replaced at direction of the Engineer.
	First layer of the Final Cover System (0.3 m thick sand layer) (initially interfaces with the temporary sacrificial liner below GCL)	
Temporary Sacrificial Liner	Atmosphere	Geosynthetic liner is to be durable, have a suitable coefficient of expansion, and be resistant to ultraviolet radiation damage. Sacrificial liner is to be adequately anchored to prevent uplift by wind during period of use and to minimize infiltration/recharge through the liner into the rough-prepared subgrade throughout its period of use.
	First layer of the Final Cover System (0.3 m thick sand layer)	
0.3 m thick first layer of Final Cover System	GCL	Finished upper surface of layer to be free from: standing water, snow, stones or other debris at the time of installation.
	1 m thick Select Waste layer	Debris and stones over 9.5 mm diameter. Concrete, slag, metals, and construction debris.

6.9 Low-Level Waste Characteristics

The projected waste volumes and inventory of significant radionuclides in the bulk and packaged waste were developed by CNL, and are documented in the NSDF Reference Inventory Report [6-36]. The NSDF Reference Inventory [6-36] has been used to inform the design and safety analyses. The Licensed Inventory is a modified reference inventory, and represents a maximum radiological inventory limit for the NSDF.

6.9.1 Waste Types and Volumes

The potential LLW from all CNL sources, have been categorized into six waste types based on physical characteristics [6-23] and [6-36], and include:

- Type 1 – Soil and soil-like waste.
- Type 2 – Comingled radioactive waste, debris, refuse, soil, and soil-like waste.
- Type 3 – Non-soil-like waste.
- Type 4 – Decommissioning and Demolition waste.
- Type 5 – Packaged waste.

- Type 6 – Oversized Debris.

The six waste types are independent of their radiological and chemical characteristics [6-23]. The NSDF Reference Inventory [6-36] was developed using:

- Data describing the radioactivity of stored packages.
- Data from scoping surveys and sampling for some of the CRL site structures.
- Data from investigations of affected land areas at CRL.

Table 6-7 provides the projected waste volumes by waste type, and Figure 6-2 provides a graphic representation of the projected waste volume distribution by waste type [6-36]. Type 1, 2, 3, 4, and 6 wastes constitute bulk waste, and Type 5 waste is packaged waste.

Table 6-7
Waste Types and Projected Volumes [6-36]

Waste Type	Projected Volume (m^3)	Projected Volume (m^3)	Projected Volume (%)
Bulk Waste		866 000	87
Type 1 – Soil and soil-like waste	472 432		
Type 2 - Comingled radioactive refuse, debris, soil and soil-like waste	67 939		
Type 3 – Non-soil-like waste	189		
Type 4 – Decommissioning and demolition waste	315 130		
Type 6 – Oversized debris	10 573		
Packaged Waste			
Type 5 – Packaged waste	133 737	134 000	13
TOTAL	**1 000 000**	**1 000 000**	**100**

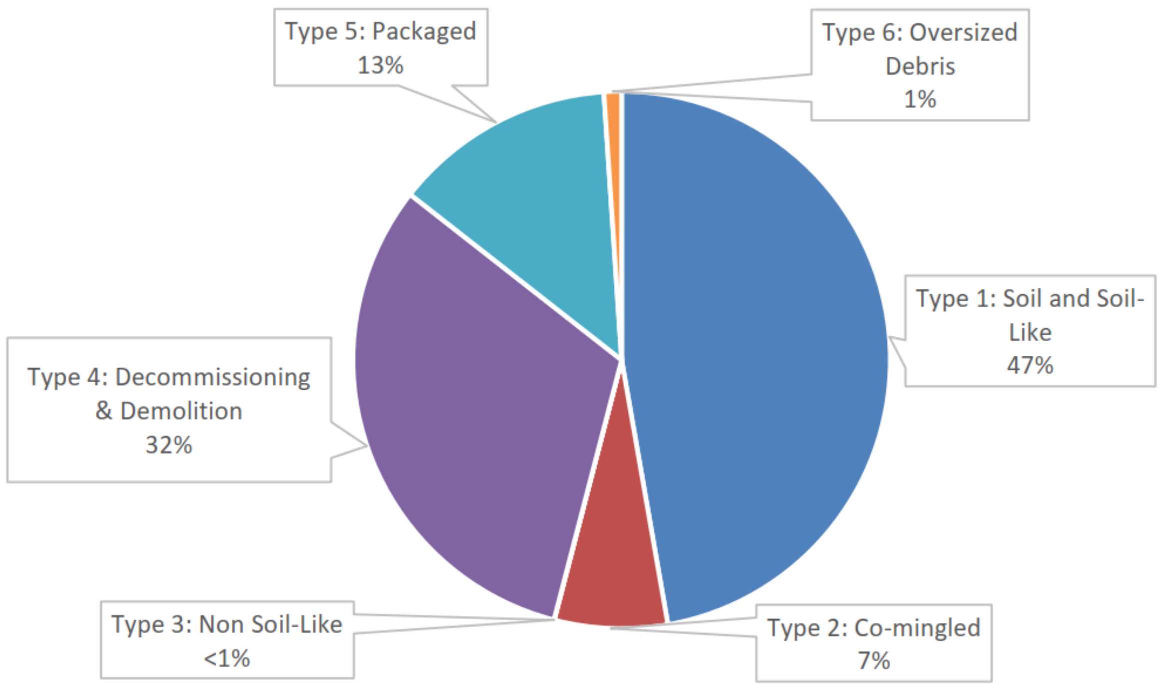

Figure 6-2 Projected Waste Volume Distribution by Waste Type [6-36]

6.9.2 Type 1 Waste – Soil and Soil-Like

Type 1 Waste is soil and soil-like wastes that includes contaminated soil and other waste materials with characteristics similar to soil, that can be placed in the mound with what would be required for disposal of soil [6-23].

Type 1 Waste is generally generated by environmental remediation of contaminated lands [6-36]. Where practical, higher activity Type 1 Waste will be placed at depth in the ECM, below lower activity waste to provide radiation shielding at the surface. This may only be practical in circumstances when soil waste streams with different radiation levels are delivered to the Facility for disposal at the same time.

The emplaced density of Type 1 Waste is assumed to be 1.5 g/cm^3 after compaction [6-37].

6.9.3 Type 2 Waste – Comingled Refuse and Soil or Soil-Like

Type 2 waste is comingled radioactive waste, debris, refuse, soil, and soil-like waste., and includes wastes that are anticipated to be at least 50% soil or soil-like in nature [6-23].

Type 2 waste is considered distinct from Type 1 waste, based on the heterogeneous nature of the waste [6-37]. The comingled waste is anticipated to be at least 50% soil or soil-like material, but also includes varying amounts of refuse containing organic and compressible materials that are considered impractical to separate from the soil or soil-like material [6-37].

Type 2 waste consists of waste generated by CRL Environmental Remediation projects, and includes material from the LDA pipeline remediation and the WMA A overburden remediation. The emplaced density of Type 2 waste is assumed to be 1.5 g/cm^3 after compaction [6-37].

6.9.4 Type 3 Waste – Non-Soil-Like

Type 3 Waste is non-soil like waste that includes materials that can be excavated and handled as bulk material, but do not have the physical characteristics of soil and soil-like materials [6-23]. Type 3 waste includes process wastes, highly organic wastes, highly compressible wastes, flowing wastes (i.e. wastes that do not pass the slump test), and similar waste type [6-23].

The volume of Type 3 waste is anticipated to be negligible, less than 1%, compared to the total waste volume of the ECM [6-36]. Type 3 wastes may require pre-treatment or special handling procedures for placement into the NSDF. Pre-treatment, including drying or solidification, would be determined on a waste-specific basis. The final in-place density of Type 3 waste is assumed to 1.5 g/cm^3 [6-37].

6.9.5 Type 4 Waste – Decommissioning and Demolition

Type 4 waste is Decommissioning and Demolition waste that includes typical materials used in construction, such as: concrete, asphalt, brick, lumber, structural steel, process equipment, piping, wood and other building materials produced by Decommissioning and Demolition activities [6-23]. Type 4 waste may include up to 28% wood, due to the number of wood frame buildings to be demolished [6-37]. Type 4 includes bulk waste materials (e.g. crushed concrete, masonry, asphalt), as well as waste requiring handling and placement as individual pieces (e.g. slab concrete or steel beam sections) or bundles (e.g. pipe or rebar) [6-37].

Type 4 waste will be placed in the disposal cell by one of two methods, provided that the final waste form has essentially no void space [6-37]:

- Comingle the Type 4 waste with soil sufficient to fill the voids between irregularly shaped pieces.
- Segregate the Type 4 waste in an area of the disposal cell and fill the voids with flowable grout.

Type 4 waste is assumed to have a density of 1.5 g/cm^3 after placement and compaction or grouting in the disposal cell [6-37]. Compaction or grouting minimizes voids for the purpose of limiting the potential for differential settlement across the disposal cell. In practice, the void ratio is expected to be zero [6-37].

6.9.6 Type 5 Waste – Packaged Waste

Type 5 waste is packaged waste contained in rigid packages. There are two types of rigid waste packages; Non-Leachate Controlled Waste Packages and Leachate Controlled Waste

Packages [6-23]. Table 6-8 shows the estimated volumes of Type 5 waste. Liners and soft-sided packages are not considered Type 5 waste [6-23].

Non-Leachate Controlled Waste Packages include shipping containers (e.g. 6.1 m (20 foot) ISO container), steel waste boxes (e.g. B-25 boxes) and drums (e.g. 205 L drum).

Leachate Controlled Waste Packages are packages that provide inventory management control and containment of the waste with more mobile and higher radionuclide activity concentrations during the time the disposal cell is not covered with the final cover. Containment can also be provided using approved overpacks or waste processing methods.

Based on the radionuclide concentrations in the individual waste streams that comprise the packaged waste category, shielding and special handling may be required. In addition to CNL waste, the NSDF packaged waste may also include waste from Whiteshell Laboratories, the National Programs, the Nuclear Power Demonstration Closure Project, and waste from off-site commercial sources.

Physical stabilization of waste may be required to provide a structurally stable waste form that will maintain its physical dimensions under the expected disposal conditions. Physical waste stabilization is a process whereby, the waste form is enhanced to provide a waste form that is capable of bearing the imposed loads in the ECM and maintaining its physical and structural characteristics over time. Examples include solidification of liquids or sludge into a concrete matrix or the use of a High Integrity Container to provide structural stability by its construction and materials. A High Integrity Container also isolates radioactivity and may reduce leaching to the environment and may provide time for radioactive decay. Structurally stabilized waste packages do not have significant interaction with the environment or other co-disposed waste. Structural stability can be provided by the waste form itself, processing the waste to a stable form, or placing the waste in a structure that provides stability after disposal. The need for waste stabilization will be based on the physical characteristics of the waste and not its radiological characteristics.

After voids within the waste packages have been reduced to meet the 10% maximum void space (either by grouting, compaction, or other means), the Type 5 waste is assumed to have a density of 1.5 g/cm^3 when disposed [6-37].

Table 6-8
Estimated Type 5 Volumes [6-36]

Type 5 Waste	Estimated Volume (m^3)	Ratio (%)
Non-leachate controlled packaged waste	122 957	92.1
Leachate controlled packaged waste	10 490	7.9

6.9.6.1 Non-Leachate Controlled Waste Packages

Non-Leachate Controlled Waste Packages are waste packages that must be able to contain the waste until placement in the NSDF. Pre-approved non-leachate controlled waste packages include [6-23]:

- Drums, which may be galvanized, stainless, carbon steel, or plastic; up to 386 L and a mass up to 450 kg.
- Waste Boxes, which may be galvanized steel, SS or carbon steel up to 2.7 m^3 and a mass of up to 5 000 kg.
- Intermodal waste containers, 6.1 m (20 foot). Various duty rated options are available including Type A, IP-1 and IP-2 Industrial Containers. Gross weight up to 36 000 kg.

6.9.6.2 Leachate Controlled Waste Packages

Leachate Controlled Waste Packages are waste packages that are able to provide containment of the waste during the time the disposal cell is not covered with the final cover (approximately 5-10 years) [6-23]. Containment of the waste can be provided by the final waste form itself, or having the waste in a package or overpacked package such that the waste package complies with the following guidance [6-23]:

- The package shall maintain structural integrity when subjected to the maximum NSDF overburden pressure (vertical pressure) of 350 kPa. This vertical pressure bounds the maximum anticipated live loads (e.g. compaction and vehicle loads).
- The package shall maintain structural integrity when subjected to the maximum NSDF soil pressure (lateral pressure) of 200 kPa. This lateral horizontal pressure bounds the maximum anticipated live loads (e.g. compaction and vehicle loads).
- The design of the packaging shall prevent the infiltration and/or exfiltration of water when the package is subjected to the above disposal pressures.
- The exterior of the packaging shall be chemically compatible with the expected NSDF disposal environment.
- The package shall include gas venting, if deemed an off-gas hazard exists.

Examples of acceptable leachate controlled waste packages include, but are not limited to, high integrity containers or macro encapsulation.

6.9.7 Type 6 Waste – Oversized Debris

Type 6 waste is oversized debris that includes waste that does not fall within the definition of waste Types 1 through 5, primarily by its size or shape [6-23]. The volume of Type 6 waste is anticipated to be negligible (approximately 1%) in comparison to the total waste volume [6-36]. All Type 6 wastes shall be accepted through the Infrequently Performed Operations [6-38] process. See Section 9.3.1.5 for additional details on the Infrequently Performed Operations process.

Type 6 waste is assumed to have the same in-place density (1.5 g/cm^3) as other waste types after disposal and compaction [6-37].

6.9.8 Radiological Characteristics

The various wastes to be disposed in the NSDF are described in terms of their characteristic radionuclide concentrations, or “fingerprint”. The fingerprint is a radionuclide concentration profile from a group of known waste streams that is used to represent the characteristics of a particular waste type. For example, bulk waste (Waste Types 1, 2, 3, 4, and 6), consists primarily of soil, debris, and demolition waste is represented by a combination of previously characterized environmental remediation waste streams and facility decommissioning debris. The packaged waste is represented by a combination of waste streams currently in storage in the CRL WMAs.

The NSDF Reference Inventory [6-36], establishes a representative radionuclide inventory by extrapolating existing waste packages, environmental remediation projects and decommissioning projects data to an assumed total volume of the NSDF at time of closure (i.e. end of operations phase in ~2070). The NSDF Reference Inventory [6-36] has been used to inform the design and safety analyses.

Based on the source term and radioactivity, non-leachate controlled waste packages are managed as bulk waste using the radionuclide activity concentration limits for bulk waste defined in the WAC and [6-23]. presents the radionuclide activity concentration limits in NSDF waste [6-23]. The reference inventory averaged radionuclide activity concentrations and total activities of significant radionuclides at placement in the bulk waste and package waste, including Leachate Controlled Packaged Waste and non-leachate controlled packaged waste, are shown in Table 6-10 [6-36].

The post-closure safety assessment modelling was used to refine the NSDF radiological inventory, Reference Inventory [6-36]. During this iterative process, a decision was made to adjust the activity concentrations of many long-lived radionuclides, to ensure that the total radioactivity in the NSDF decays to near-background levels within a reasonable timeframe. As a result, the quantity of Zr-93 was reduced to 40.8%, and Nb-94 was reduced to 10% of the original values in [6-36] and the values presented in Waste Characterization [6-37]. In the third iteration of the Post-Closure Safety Assessment [6-39], a recommendation was made to lower the maximum radioactivity of two radionuclides listed in the reference inventory, to support the claim that future public doses in the post-closure phase will be well below the long-term dose acceptance criteria. This modified reference inventory, known as the Licensed Inventory is part of the NSDF safety and licensing basis, and represents a maximum radiological inventory limit for the NSDF. In the Licensed Inventory, the radioactivity of both I-129 and Pu-239/Pu-240 were reduced to 58% of the reference inventory [6-36] values. Table 6-11 provides:

- The NSDF Reference Inventory [6-36], the proposed total activity of significant radionuclides at placement and at closure, including the radionuclide activity of bulk and packaged wastes, used as an input to the design and safety analyses; and

- The NSDF Licensed Inventory defines the maximum radioactivity of significant radionuclides at placement and at closure.

Table 6-9
Radionuclide Activity Concentration Limits in NSDF Waste [6-23]

Waste Type	**Radionuclides**	**Activity Concentration Limits (Bq/g)**
Bulk Waste, and Non-Leachate Controlled Packaged Waste	Alpha emitting radionuclides	100
	Long-lived beta gamma emitting radionuclides ($t_{1/2}$ > Cs-137)	1 000
	Short-lived beta gamma emitting radionuclides ($t_{1/2}$ ≤ Cs-137)	10 000
	Tritium (H-3)	100 000
Leachate Controlled Packaged Waste	Alpha emitting radionuclides	400
	Long-lived beta gamma emitting radionuclides ($t_{1/2}$ > Cs-137)	10 000
	Tritium (H-3)	10 000 000
	Cs-137	10 000
	Sr-90	10 000

Table 6-10
Reference Inventory Significant Radionuclide Activity and Average Activity Concentration at Placement – Bulk Waste and Packaged Waste [6-36]

Radionuclide	Bulk Waste		Packaged Waste	
	Total Activity (Bq)	Averaged Activity Concentration (Bq/g)[(a)]	Total Activity (Bq)	Averaged Activity Concentration (Bq/g)[(b)]
Ag-108m	1.87E+04	2.11E-08	2.73E+10	3.98E-01
Am-241	1.25E+10	1.41E-02	4.80E+10	6.99E-01
Am-243	6.38E+06	7.18E-06	4.62E+07	6.73E-04
C-14	2.07E+11	2.33E-01	1.50E+12	2.19E+01
Cl-36	5.74E+08	6.46E-04	3.40E+09	4.96E-02
Co-60	1.18E+13	1.33E+01	9.06E+16	1.32E+06
Cs-135	9.59E+06	1.08E-05	5.10E+08	7.43E-03
Cs-137	6.75E+11	7.60E-01	4.91E+12	7.16E+01
H-3	9.75E+13	1.10E+02	7.94E+14	1.16E+04
I-129	1.62E+08	1.82E-04	3.01E+10	4.39E-01
Mo-93	1.67E+04	1.88E-08	1.31E+05	1.91E-06
Nb-94	2.50E+09	2.82E-03	2.09E+10	3.05E-01
Ni-59	1.39E+08	1.57E-04	1.07E+09	1.56E-02
Ni-63	3.54E+10	3.98E-02	2.75E+11	4.01E+00
Np-237	2.12E+06	2.39E-06	1.53E+07	2.22E-04
Pu-239/240	1.03E+10	1.16E-02	7.74E+10	1.13E+00
Pu-241	2.02E+11	2.27E-01	1.46E+12	2.13E+01
Pu-242	7.68E+06	8.64E-06	5.55E+07	8.09E-04
Ra-226	1.92E+08	2.16E-04	3.63E+10	5.29E-01
Se-79	1.13E+07	1.28E-05	8.13E+07	1.18E-03
Sn-126	1.52E+07	1.71E-05	1.09E+08	1.59E-03
Sr-90	7.36E+11	8.29E-01	5.31E+12	7.74E+01
Tc-99	6.42E+07	7.23E-05	3.16E+11	4.61E+00
Th-230	8.01E+08	9.02E-04	4.50E+09	6.56E-02
Th-232	3.15E+09	3.54E-03	2.39E+10	3.48E-01
U-233	3.29E+07	3.71E-05	2.41E+08	3.51E-03
U-234	9.34E+09	1.05E-02	5.94E+10	8.66E-01
U-235	3.91E+08	4.40E-04	2.57E+09	3.75E-02
U-238	8.54E+09	9.62E-03	6.72E+10	9.79E-01
Zr-93	5.72E+10	6.45E-02	4.35E+11	6.34E+00

Notes:
[a] Concentration calculated using the total bulk waste mass of 9.52E+08 kg.
[b] Concentration calculated using the total packaged waste mass of 6.86E+07 kg.

Table 6-11
NSDF Reference Inventory and Licensed Inventory

Radionuclide	Reference Inventory [6-36]		Licensed Inventory	
	Total Activity (Bq) at Emplacement	Total Activity (Bq) at Closure	Maximum Activity (Bq) at Placement	Maximum Activity (Bq) at Closure
Ag-108m	2.73E+10	2.62E+10	2.73E+10	2.62E+10
Am-241	6.04E+10	9.74E+10	6.04E+10	9.74E+10
Am-243	5.26E+07	5.24E+07	5.26E+07	5.24E+07
C-14	1.71E+12	1.70E+12	1.71E+12	1.70E+12
Cl-36	3.97E+09	3.97E+09	3.97E+09	3.97E+09
Co-60	9.06E+16	1.47E+16	9.06E+16	1.47E+16
Cs-135	5.19E+08	5.19E+08	5.19E+08	5.19E+08
Cs-137	5.59E+12	3.17E+12	5.59E+12	3.17E+12
H-3	8.91E+14	2.79E+14	8.91E+14	2.79E+14
I-129	3.03E+10	3.03E+10	1.75E+10	1.75E+10
Mo-93	1.47E+05	1.47E+05	1.47E+05	1.47E+05
Nb-94	2.34E+10	2.34E+10	2.34E+10	2.34E+10
Ni-59	1.21E+09	1.21E+09	1.21E+09	1.21E+09
Ni-63	3.11E+11	2.59E+11	3.11E+11	2.59E+11
Np-237	1.74E+07	1.74E+07	1.74E+07	1.74E+07
Pu-239/240	8.77E+10	8.76E+10	5.07E+10	5.06E+10
Pu-241	1.67E+12	5.84E+11	1.67E+12	5.84E+11
Pu-242	6.32E+07	6.32E+07	6.32E+07	6.32E+07
Ra-226	3.65E+10	3.61E+10	3.65E+10	3.61E+10
Se-79	9.26E+07	9.26E+07	9.26E+07	9.26E+07
Sn-126	1.24E+08	1.24E+08	1.24E+08	1.24E+08
Sr-90	6.05E+12	3.35E+12	6.05E+12	3.35E+12
Tc-99	3.16E+11	3.16E+11	3.16E+11	3.16E+11
Th-230	5.30E+09	5.30E+09	5.30E+09	5.30E+09
Th-232	2.70E+10	2.70E+10	2.70E+10	2.70E+10
U-233	2.74E+08	2.74E+08	2.74E+08	2.74E+08
U-234	6.88E+10	6.88E+10	6.88E+10	6.88E+10
U-235	2.96E+09	2.96E+09	2.96E+09	2.96E+09
U-238	7.57E+10	7.57E+10	7.57E+10	7.57E+10
Zr-93	4.92E+11	4.92E+11	4.92E+11	4.92E+11

6.9.9 Non-Radiological

Table 6-12 shows the non-radiological constituents or COPC and the maximum estimated leachable quantity (kg) [6-40].

Table 6-12
Non-Radiological Inventory [6-40]

Constituent or Chemical Name	Maximum Estimated COPC Leachable Quantity (kg)
1,1,2,2-Tetrachloroethane	120
1,1,2-Trichloroethane	120
1,4-Dichlorobenzene	120
Acetone	3 200
Anthracene	68
Antimony	23
Arsenic	100
Barium	2 000
Benzene	200
Benzo(a)pyrene	68
Beryllium	24
Bis(2-ethylhexyl) phthalate	560
Boron	10 000
Cadmium	10
Carbon tetrachloride	120
Chromium (total)	100
Chromium VI (same as total)	100
Chlorobenzene	160
Chloroform	200
Chrysene	68
Cobalt	6 000
Copper	6 000
Dioxin	3.0E-05
Ethylene dibromide	300
Fluoranthene	68
Fluorene	68
Fluoride (aqueous)	360
Furan	3.0E-05
Lead	100
Mercury (aqueous)	2
Methylene chloride	600
Molybdenum	800
Nitrate	20 000
Nitrite	800
Nickel	220
Phenol	120
Phenolic compounds, non-chlorinated	200
Polychlorinated Biphenyl (PCB)	6

Constituent or Chemical Name	Maximum Estimated COPC Leachable Quantity (kg)
Selenium	110
Silver	100
Tetrachloroethylene	120
Thallium	4
Tin	6 000
Vanadium	2 600
Zinc	7 200

6.10 Wastewater Characteristics

Leachate, contact water, and water from decontamination facilities, are collectively referred to as wastewater that is treated in the WWTP. The sources generating wastewater at NSDF are [6-16]:

- Leachate that has percolated through the ECM waste and is collected in the LCS at the bottom of the ECM waste cells. The source of the leachate is precipitation that infiltrates into the waste.
- Contact water collected from the surface of the open waste cells and the TSWRPA during operations. This water is from precipitation that has not infiltrated into the waste.
- Active drain wastewater from the VDF, OSC (personnel decontamination), and WWTP.

Leachate quantities were estimated based on a water balance calculation conducted with the Hydrologic Evaluation of Landfill Performance model [6-16] and [6-19]. The Hydrologic Evaluation of Landfill Performance model, estimates the amount of infiltrating water from precipitation in the open active disposal cell with an area of 15 000 m^2 and with no cover over the waste [6-16] and [6-19]. The model uses the leachable inventory in the disposal cell that includes all of the placed bulk waste and 5% of the placed packaged waste [6-16]. Ten percent (10%) of total radionuclide activity at emplacement, in Table 6-11 for bulk and packaged waste is assumed placed in each disposal cell [6-16]. Waste compaction is assumed to result in the immediate failure of 5% of the waste packages [6-16]. As time progresses, waste containers are assumed to fail at a rate of 1% per year due to corrosion [6-16].

Table 6-13 shows the radionuclide partitioning coefficients, K_d values, and the radionuclide activity concentrations in wastewater [6-16] and [6-19]. The K_d values used in Table 6-13 and Table 6-14 [6-16] and [6-19] are from [6-18]. Table 6-14 shows the radionuclide partitioning coefficients, K_d values, and the non-radiological constituent concentrations in wastewater, respectively [6-16]. Table 6-15 show the non-target constituent concentrations in wastewater, [6-16] and [6-19]. Non-target constituents are not considered as COPCs, however are commonly found in leachate, industrial wastewater and in CRL groundwater [6-16]. Table 6-16 shows average total volume of wastewater generated during the NSDF operations [6-16] and [6-19].

Table 6-13
Radionuclide Activity Concentrations in Wastewater [6-16] [6-19]

Radionuclide	K_d (ml/g)*	Activity Concentration (Bq/L)
Ag-108m	1600	1.8E-04
Am-241	953	2.8E-03
Am-243	953	1.7E-06
C-14	16.7	3.1E+00
Cl-36	2.13	5.9E-02
Co-60	113	1.3E+03
Cs-135	175	4.1E-05
Cs-137	175	9.3E-01
H-3	0	1.4E+05
I-129	3.69	9.1E-02
Mo-93	10.5	4.1E-07
Nb-94	429	1.5E-02
Ni-59	205	1.7E-04
Ni-63	205	4.4E-02
Np-237	851	6.3E-07
Pu-239	596	4.4E-03
Pu-241	596	7.9E-02
Pu-242	596	3.3E-06
Ra-226	673	6.4E-04
Se-79	119	2.4E-05
Sn-126	534	7.2E-06
Sr-90	18.2	9.6E+00
Tc-99	0.403	5.7E+00
Th-230	841	2.2E-04
Th-232	841	9.6E-04
U-233	290	2.9E-05
U-234	290	7.8E-03
U-235	290	3.3E-04
U-238	290	7.6E-03
Zr-93	822	4.4E-02
Note: * k_d values are from [6-18].		

Table 6-14
Non-Radiological Constituents Concentrations in Wastewater [6-16]

Constituent	K_d (ml/g)*	Concentration (mg/L)
1,1,2,2-Tetrachloroethane	4.27	1.4E-03
1,1,2-Trichloroethane	2.71	2.2E-03
1,4-Dichlorobenzene	17.4	3.5E-04
Acetone	0.0792	6.9E-01
Anthracene	816	4.3E-06
Antimony	3600	3.3E-07
Arsenic	16.3	3.1E-04
Barium	146	7.1E-04
Benzene	6.62	1.5E-03
Benzo(a)pyrene	31500	1.1E-07
Beryllium	643	1.9E-06
Bis(2-ethylhexyl) phthalate	6600	4.4E-06
Boron	4.20	1.2E-01
Cadmium	179	2.9E-06
Carbon tetrachloride	1.95	2.9E-03
Chromium (total)	20.5	2.5E-04
Chlorobenzene	10.7	7.6E-04
Chloroform	1.40	6.6E-03
Chrysene	9440	3.7E-07
Cobalt	113	2.7E-03
Copper	386	8.0E-04
Dioxin	5840	2.7E-13
Ethylene dibromide	1.75	8.1E-03
Fluoranthene	2840	1.2E-06
Fluorene	452	7.8E-06
Fluoride (aq)	0	1.2E-01
Furan	5840	2.7E-13
Lead	218	2.4E-05
Mercury (aq)	44.1	2.3E-06
Methylene chloride	0.95	2.8E-02
Molybdenum	10.5	3.9E-03
Nitrate	0	6.6E+00
Nitrite	0	2.65E-01
Nickel	205	5.5E-05
Phenol	10.70	5.7E-04
Phenolic compounds - no chlorine	14.6	7.0E-04
PCB	12400	2.5E-08
Selenium	119	4.8E-05

Constituent	K_d (ml/g)*	Concentration (mg/L)
Silver	1600	3.2E-06
Tetrachloroethylene	4.27	1.4E-03
Thallium	54.3	3.8E-06
Tin	534	5.8E-04
Vanadium	314	4.3E-04
Zinc	239	1.6E-03
Note: * k_d values are from [6-18].		

Table 6-15
Non-Target Constituent Concentrations in Wastewater [6-16] [6-19]

Constituent	Concentration (mg/L)
Cations	
Aluminum	0.15
Calcium	100
Iron	125
Magnesium	68
Manganese	5.8
Potassium	26
Sodium	100
Anions	
Bicarbonate	660
Chloride	17
Phosphate	4
Sulfate	270
Organics/Other	
BOD5	62
EDTA	1
pH	6.5 - 9
Silica	5
Tannic acid	50

Table 6-16
Average Wastewater Volumes Generated during the NSDF Operation [6-16] [6-19]

	Time (yr)										
	0-5	5-10	10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50+
Cell 1	Active 10995	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 4.5
Cell 2	---	Active 10995	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 4.5
Cell 3	---	---	Active 10995	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 4.5
Cell 4	---	---	---	Active 10995	Final 15	Final 15	Final 15	Final 15	Final 15	Final 15	Final 4.5
Cell 5	---	---	---	---	Active 10995	Final 15	Final 15	Final 15	Final 15	Final 15	Final 4.5
Cell 6	---	---	---	---	---	Active 10995	Final 15	Final 15	Final 15	Final 15	Final 4.5
Cell 7	---	---	---	---	---	---	Active 10995	Final 15	Final 15	Final 15	Final 4.5
Cell 8	---	---	---	---	---	---	---	Active 10995	Final 15	Final 15	Final 4.5
Cell 9	---	---	---	---	---	---	---	---	Active 10995	Final 15	Final 4.5
Cell 10	---	---	---	---	---	---	---	---	---	Active 10995	Final 4.5
Decon water	100	100	100	100	100	100	100	100	100	100	0
Total (m^3/yr)	11095	11110	11125	11140	11155	11170	11185	11200	11215	11230	45

6.11 Effluent Discharge Targets

Table 6-17 and Table 6-18, provide the effluent discharge for radionuclides and non-radiological constituent's, respectively [6-24]. The effluent discharge targets are the maximum concentrations of each COPC in the WWTP effluent that can be discharged to the environment without adverse effects to human health or the environment [6-24]. Contaminant of Potential Concern include both radionuclides and non-radiological constituents.

Table 6-17
Effluent Discharge Targets for Radionuclides [6-24]

Radionuclide	Discharge Target (Bq/L)
Ag-108m	60
Am-241	0.7
Am-243	0.7
C-14	200
Cl-36	100
Co-60	40
Cs-135	70
Cs-137	10
H-3	360 000
I-129	1
Mo-93	40
Nb-94	80
Ni-59	2 000
Ni-63	900
Np-237	1
Pu-239	0.6
Pu-241	30
Pu-242	0.6
Ra-226	0.5
Se-79	50
Sn-126	30
Sr-90	5
Tc-99	200
Th-230	0.7
Th-232	0.6
U-233	3
U-234	3
U-235	3
U-238	3 [a]
Zr-93	100
Gross alpha	0.2
Gross beta (based on Sr-90)	5
Gross gamma (based on Co-60)	40 [b]

[a] The limit shown is for drinking water protection from radiological effects; a more restrictive limit of 0.06 Bq/L (5 µg/L) is required for protection of aquatic life from chemical toxicity of uranium.

[b] The gross gamma limit applies to any gamma-emitting radionuclide not listed in Table 6-17.

Table 6-18
Effluent Discharge Targets for Non-Radiological Constituents [6-24]

Non-Radiological Constituent	Effluent Discharge Target (mg/L)[a]
1,1,2,2-Tetrachloroethane	0.07
1,1,2-Trichloroethane	0.8
1,4-Dichlorobenzene	0.004
Acetone	1.5
Aluminum	**0.05**
Ammonia	0.02
Anthracene	8.0E-07
Antimony	0.02
Arsenic	0.005
Barium	**0.004**
Benzene	0.1
Benzo(a)pyrene	1.5E-05
Beryllium	0.011
Bis(2-ethylhexyl) phthalate	6.0E-04
Boron	0.2
Cadmium	**9.0E-05**
Calcium	116
Carbon tetrachloride	0.0133
Chloride	120
Chlorobenzene	0.0013
Chloroform	0.0018
Chromium (III)	0.0089
Chromium (VI)	0.001
Chrysene	1.0E-07
Cobalt	9.0E-04
Copper	**0.002**
Dioxin	1.0E-08
Ethylene dibromide	0.005
Fluoranthene	8.0E-07
Fluorene	2.0E-04
Fluoride (aqueous)	0.12
Furan	1.0E-08 [b]
Iron	**0.3**
Lead	**0.001**
Magnesium	82
Manganese	0.12
Mercury (aqueous)	**2.6E-05**
Methylene chloride	0.0981
Molybdenum	0.04

Non-Radiological Constituent	Effluent Discharge Target (mg/L)[a]
Nickel	0.025
Nitrate	13
Nitrite	0.06 (as Nitrogen)
Petroleum hydrocarbons, C6-C10	0.15
Phenol	0.004
Phenolic compounds, non-chlorinated	0.004 [c]
Phosphorus	**0.01** [d]
PCB	1.0E-06
Potassium	53
Selenium	**0.001**
Silver	**1.0E-04**
Sodium	680
Sulphate	128
Tetrachloroethylene	0.05
Thallium	3.0E-04
Tin	0.073
Trichloroethylene	0.02
Uranium	0.005 [e]
Vanadium	0.006
Zinc	**0.007**
pH, standard units	**6.5 - 9**
CBOD5	25
COD	125
Dissolved oxygen, >15°C - 20°C	≥6
Dissolved oxygen, <15°C - 20°C	≥9.5

[a] The **bolded** values indicate constituents where historic background concentrations from the Perch Lake watershed exceed the discharge targets listed in this table.

[b] The dioxin limit is used for furans because furans have similar, or slightly lower, toxicity than dioxins and the mechanism of toxicity is the same as dioxins, namely disruption of protein synthesis by binding to the aryl hydrocarbon receptor.

[c] Since no specific non-chlorinated phenols were identified in CNL's non-radioactive inventory, the limit for phenol is considered adequate to represent this class of compounds.

[d] The phosphorus discharge target is an investigation level triggering analysis on impacts if exceeded. An analysis has been completed indicating minimal impacts on Perch Lake and East Swamp for the projected phosphorus loading. The results of the analysis will be verified by monitoring Perch Lake water quality under winter conditions.

[e] Uranium discharge target based on chemical toxicity to aquatic life.

6.12 References

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7. SAFETY FEATURES

This section describes the safety features and safety systems, systems important to safety, in place within the NSDF design. Unmitigated consequences determine the safety features that are required to be put in place to mitigate the consequences of an accident [7-1].

7.1 Designed Safety Features

Designed safety features are those that achieve safety by eliminating or excluding inherent hazards through fundamental design choices. Safety features and controls are provided in designs to prevent and eliminate hazardous conditions that would otherwise fail to protect facility personnel, on-site workers, members of the public, and the environment.

Safety SSCs are relied upon to prevent accidents at the Facility or to mitigate their potential consequences, thereby, achieving one or more safety feature. This is achieved through active engineered features, passive engineered features and administrative controls.

Containment is used to prevent radioactive material from reaching the environment and can also provide a barrier for radiation shielding.

Designed safety features also provide additional protection to the primary fission product barriers, or to mitigate the release of radionuclides to the environment in case of barrier deterioration. The design purpose is to control or limit the release of radionuclides from the Facility, such that the total effective dose equivalents are within design guides for defined boundaries and ALARA.

7.1.1 Passive Engineered Safety Features

This section describes the passive engineered safety features associated with the NSDF, including engineered barriers for containing LLW.

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

7.1.1.1 Engineered Containment Mound Engineered Barriers

The ECM includes several engineered barriers to contain the LLW and limit releases of ECM contaminants to the environment and to minimize radiation doses to workers. Passive engineered safety features associated with the ECM include the base liner system, cover systems, gas venting system, and perimeter berm.

The base liner system includes the primary liner, and the secondary liner. This system controls the migration of contaminants into the soil and groundwater surrounding the ECM to a negligible level, and facilitate the collection and removal of leachate to the WWTP. The ECM is designed to maintain a minimum of 1.5 m between the top of the primary liner and the seasonal high groundwater, to minimize release of leachate to the subsurface soils and groundwater below the base liner system. Note that this minimum separation distance is not intended for contaminant attenuation purposes. Control of contaminant migration from the ECM is provided by the proposed liner and LCS without any reliance on the underlying native soils and soil fill materials.

Operational cover systems used during the operations phase include daily cover, interim cover and the final cover system, installed after cells are filled with waste. The interim covers are used to promote non-contact surface water run-off rather than leachate generation. The daily cover is placed over the active waste disposal area at the end of each work day. The interim cover is applied to waste disposal areas that will remain inactive for more than 30 days and to waste disposal areas that have reached the design waste fill grade. The final cover system is a multi-component system that includes a general fill layer to provide gamma shielding, a coarse stone layer for mitigating intrusion of biota, and HPDE and GCLs to control the ingress of water into the ECM to a very small amount. The GCL has a hydraulic conductivity of approximately $5x10^{-11}$ m/s [7-2]. The final cover system mitigates leachate generation and exposure to waste contaminants in the post-closure phase of the NSDF. The leakage rate through the base and final cover systems is evaluated in the Base Liner and Final Cover Evaluation and Optimization [7-2].

The gas venting system consists of intermittently placed geovent pipes, spanning from a sand layer below the GCL to pipes protruding 3 m above the final cover surface. Based on the expected waste inventory, the Radon and Other LFG Modelling and Evaluation Report [7-3], has indicated that the ECM will not generate sufficient LFG pressure or amounts to warrant the use of active operational controls during disposal to limit methane build-up in waste disposal areas or surrounding facilities, or require active gas collection and treatment. The gas venting system mitigates gas pressure build-up which could potentially impact cover integrity. The maximum vent pipe spacing is calculated to be 186 m. A LFG Monitoring Program [7-4], will be performed throughout operations and following final closure of the ECM; this will serve to protect workers from exposure to methane, and ensure that the methane concentrations in air do not exceed the LFG assessment limits.

The ECM is surrounded by a perimeter berm. This supports the structural integrity of the ECM, and provides containment for ECM leachate. Additionally, the perimeter berm mitigates run-on of water to the ECM from adjacent areas. The ECM features, including the size and shape of the berms and each of the elements and layers, are designed for a 1 in 10 000 year seismic event.

7.1.1.2 Waste Water Treatment Plant Passive Safety Features

The design of the WWTP incorporates passive safety features to mitigate hazards to workers and the environment that may occur as a result of abnormal events. These features include Equalization Tanks secondary containment and tank overflow lines connected to active drain.

The Equalization Tanks are located within a concrete secondary containment area, which prevents wastewater from affecting the surrounding environment in the event of tank failure or overflow. The secondary containment area has the capacity to contain 110% of the volume of a single Equalization Tank.

The WWTP process tanks have overflow lines connected to the active drain, which conveys wastewater to CWPS #2 for pumping to the Equalization Tanks. The tank overflow lines mitigate the possibility of overflow scenarios leading to worker exposure to contaminated wastewater.

7.1.2 Active Engineered Safety Features

The main active engineered safety features include radiation monitoring, active ventilation systems, LCS, LDS, and effluent monitoring at the WWTP.

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

Radiation monitoring at the NSDF includes air monitoring of dust, and radioactivity on the NSDF site, as well as at fixed points along the NSDF perimeter.

Near Surface Disposal Facilities buildings include active ventilation systems to remove and filter air from potentially contaminated spaces. Active ventilation is provided for Radiological Safety Zone 3 areas within the WWTP.

The ECM includes a LCS installed above the primary base liner. This system is designed to remove any contaminated leachate that may build-up in the ECM, facilitating treatment at the WWTP prior to release to the environment. This system mitigates against the possibility of leachate build-up within the ECM during the operational phase, when water infiltration may be higher (e.g. prior to cover installation).

A LDS is included within the base liner system. The LDS allows the integrity of ECM liner engineered barriers to be monitored.

The LCS and LDS include an automatic pumping system to convey leachate to storage tanks located outside the perimeter berm of the ECM, from which it is conveyed to the WWTP for treatment. Within the WWTP, tanks throughout the treatment process are equipped with level elements and level switches to maintain levels within set points by controlling process pumping rates (e.g. pH adjustment tanks, membrane filter feed and process tanks), or to indicate levels and alarm on high levels (e.g. contact water tanks, Equalization Tanks, chemical precipitation storage tanks, final effluent storage tanks).

The NSDF includes several monitoring features to verify that radiological and non-radiological releases are within the NSDF Effluent Discharge Targets [7-5]. These ensure the safety and protection of NSDF workers, off-site members of the public, and the environment.

Reliability of engineered safety features is increased by the use of redundant components and systems. In addition to Class IV Power, critical systems and equipment, including essential WWTP process loads, essential lighting, Fire Alarm Control Panels (FACPs), security systems, communication system, SCADA system, and BAS system, are backed up by Class III emergency power from a power generator set. Class II Power is also supplied to critical loads including the communication system, security system, and Public Announcement system in the HUB room in the WWTP.

Waste Water Treatment Plant process tanks are additionally fitted with level switches to warn workers of high wastewater levels, prior to a potential overflow scenario and level alarms to warn workers or directly initiate pumping operations prior to overflow conditions.

7.2 Administrative Controls

Administrative controls, serve as a complement to the design and engineered safety features, while not as direct-acting, ensure that appropriate hazard controls are developed, maintained and properly functioning. Administrative controls ensure that policies and decisions for safety are implemented, safety is continuously improved and a strong safety culture is developed and promoted.

A waste generator certification program, combined with a waste receiving inspection process, is employed to ensure received waste meets the NSDF WAC [7-6] in accordance with the procedures and protocols. Administrative controls for waste acceptance include:

- Waste generator certification.
- Waste characterization.
- Qualification for shipment.

Examples of administrative controls include documented procedures, policies, HSSE&Q Programs, personnel training, routine inspections and maintenance, and radiation monitoring. All of these administrative controls are described in this report.

7.3 Safety Classification - Structures, Systems and Components

The safety classification of NSDF SSCs involved the following activities:

- Development of a graded approach to the safety classification of the NSDF SSCs.
- Assessing and assigning a safety classification to the NSDF SSCs.
- Classify the NSDF safety SSCs.
- Determining the engineering design rules for the NSDF safety SSCs.

- Establishing the list of components that contribute to the performance of the NSDF safety functions.

Safety classification drives the design requirements and selection of CNL's quality program level. Robustness and reliability are set by the design requirements, embedded in applicable codes and standards for which the SSCs need to meet. Appropriate selection of the quality level ensures applicable design requirements are sustained for the life of the SSCs including procurement, manufacturing, installation, commissioning, testing, operating, maintaining and modifying or replacing the SSC. Multiple layers of engineered barriers are included in the design (e.g.: primary liner, secondary liner, CCL). The robustness and reliability of the engineered barriers were also considered to ensure that the safety SSCs were adequately protected against challenges and failures including:

- Challenges to the integrity of the engineered barriers.
- Failure of a barrier when challenged.
- Failure of a barrier as a consequence of failure of another barrier.

7.3.1 Safety Classification Process

The classification of NSDF type facilities requires a customized graded approach that captures the intent and principles of Design of Reactor Facilities: Nuclear Power Plants, REGDOC 2.5.2 [7-7] and IAEA SSG-30 [7-8], while ensuring that the approach is graded to and commensurate with the nature of hazards, design and operations of a NSDF [7-9]. Safety classification is a process used to identify nuclear Facility SSCs important to safety, and where appropriate, assign them to various safety classes. The process and requirements for the identification and safety classification used is documented in NSDF Systems Safety Classification [7-9].

Structures, systems and components in the NSDF design, that are considered important to safety, have been classified using NSDF Systems Safety Classification [7-9]. A SSC is deemed important to safety when the malfunction or failure of the SSC could lead to undue radiation exposure of the Facility/site personnel, or members of the public and/or the environment.

The fundamental safety functions for the NSDF SSCs are [7-9]:

- Containment of radioactive and hazardous constituents in the radioactive waste.
- Isolation of the waste from people and from accessible biosphere.
- Retardation of the migration/dispersion of radionuclides and COPCs in the geosphere and biosphere.
- Monitoring, surveillance and control of critical safety parameters and passive safety features credited in the post-closure period.

The process for classification of SSCs is established for distinct phases of NSDF: operating and post-closure. The safety classification is then used to select appropriate design rules to achieve the desired system reliability.

The Safety Classification and Design Rules for NSDF SSCs [7-10], presents the methodology developed to classify and determine the design rules for SSCs within the NSDF.

For the NSDF operations phase, accident scenarios that can potentially release hazardous radiological and non-radiological materials during operational phase, are determined primarily from the Facility hazard analysis. Thus, safety classification of safety functions is based on Postulated Initiating Events (PIEs) with potential for high or moderately high unmitigated consequences [7-10]. Classification of safety SSCs, are determined after an unmitigated accident analysis is completed. Accordingly, safety classification pertains only to those SSCs, and more specifically to assigned system safety functions, that prevent or mitigate accidents with high or moderately high unmitigated consequences.

At the component level [7-11], the NSDF safety classified systems identified in [7-10], are assessed to determine, for each system, all components, which contribute to mitigation of the postulated events (assigned safety functions).

For the post-closure phase, long term radiological acceptability of the disposal facility is assessed, based on a manner that protect human health and the environment from being exposed in the future to two broad categories that can potentially affect the Facility: natural physical hazards and human intrusion. Structures, Systems and Components that contribute to long-term safety requirements for the NSDF are identified [7-10]. These SSCs support the four fundamental safety functions of the disposal facility in the long-term in terms of containment of the waste, isolation of the waste, retardation of migration of radionuclides from the waste, and monitoring of passive safety features in the post-closure period.

7.3.2 Safety Classification Results

The safety classification in Safety Classification of NSDF Systems [7-12], is mainly based on rules-based (safety function) requirements of various systems [7-10]. A rules-based approach tends to over specify safety systems due to the importance of their safety function [7-10].

Through the report, Safety Classification and Design Rules for NSDF SSCs [7-10], a range of PIEs were considered and the potential consequences of these events were assessed and ranked according to their estimated frequency, severity, and relative risk rating. Hypothetical risk ratings ranged from negligible risk ranking of R0 to unreasonable high risk ranking of R3, wherein the proposed process or equipment would be considered inherently unsafe without further design modifications. Examples of PIEs identified and assessed included, but were not limited to the following [7-10]:

- Overflow of an Equalization Tank leading to overflow of leachate/contact water with resulting release to the environment.
- Influent Equalization Tanks maintenance or inspection deficiencies leading to instrumentation out of calibration, with resulting potential overflow and release to the environment.

- Loss of power causing loss of function of heat tracing system leading to potential for freezing of leachate/contact water in influent equalization piping and resulting potential failure with release to the environment.
- Lightning leading to failure of parts of a control system, resulting in malfunction with resulting potential overflow of tanks leading to release of contaminants to the environment.

Near Surface Disposal Facility safety classified SSCs determined to have a moderately high unmitigated consequence risk rating (R2, i.e. an unreasonable risk ranking, wherein engineered solutions need to be put in place to protect against the potential hazard), were identified as the following [7-10]:

- Influent Flow Equalization including, the following subsystems:
  - Influent Equalization Tanks (WWTP).
  - Concrete-curb secondary containment.
  - Equalization Tank heating and trace heating.
  - Electrical immersion heater fault alarms.
  - Local Control Panels (WWTP-I&C).
  - Alarms and Communications.
- Leachate and Contact Water Transfer System.
- Power Supply and Grounding Protection System including, the following sub-systems:
  - Class III electrical power.
  - Class II electrical power.
  - Lightning protection.
- Active Drain System (WWTP, VDF, OSC).

Three systems identified to contribute to long-term safety requirements in the post-closure phase [7-10]:

- Perimeter Berm.
- Base Liner System (primary and secondary liners).
- Final Cover System.

The process for selecting the quality level requirements for safety SSCs is defined in CNL's procedure, Quality Program Selection [7-13]. Canadian Nuclear Laboratories' Quality Selection Program [7-13], is implemented in a graded manner commensurate with risk associated with the considered Facility/yctivity. Three levels of quality are considered for safety SSCs, each level is associated with a defined level of perceived risk [7-10]:

- Level I (high risk) is associated with Items and services that are important to safety and whose failure lead to radiation exposure.
- Level II (medium risk) is associated with Items and services that may:

  - Impact industrial/conventional safety (cause serious injury to persons).
  - Lead to a breach of the Site Licence/Environmental/Program requirements.
  - Impact key operating functions.
  - Lead to a significant business cost.
- Level III (low risk) is for items and services that may have minimum impact on industrial or conventional safety.

The results of the safety classification [7-10] are:

- There is no system within NSDF that meets the criterion for Quality Level I.
- NSDF identified safety SSCs are consistent with Quality Level II (failure of a SSC leads to a breach of the Site Licence/Environmental/Program requirements).
- Events that result in unmitigated low risk ranking, R0 and R1, can rely on SSCs that are consistent with Quality Level III.

7.3.3 Components for Safety Classified Systems

Following the process established in [7-11], the NSDF safety classified SSCs were analyzed and sub-divided into a series of Components for Safety Classified Systems (CSCS). Components incorporated into the design of the NSDF, provide defense-in-depth by adding a supplementary means of ensuring that safety classified SSCs continue to satisfy their respective safety functions.

Specifically, CSCS are incorporated into various safety classified SSCs, to mitigate against potential vulnerabilities associated with each safety classified SSC that could affect its reliability and/or prevent it from meeting one or more of its required safety functions at some point in the future. The reliability of a safety classified SSC might be impacted due to a future failure in an instrument loop associated with that SSC, for example, in an instrument loop associated with a monitoring system, or a (e.g. temporary) malfunction in part of a SCADA system.

A potential failure in a control system associated with a safety classified SSC, such as a malfunction in the SCADA system, or an individual Programmable Electronic System component, if accompanied by an out-of-normal condition occurring in a safety classified SSC (such as failure of a high-high level alarm device in an Equalization Tank or CWPS resulting in a failure to detect an exceedance of a liquid level), could result in an unreasonable risk to public health and/or the environment. As an example, if a pump in a safety-important SSC were left in an on position, and the associated SCADA system were to fail and not shut it down, flows between subcomponents in the Leachate/Contact Water Conveyance System (such as flows to CWPS #1 from the leachate extraction box at the ECM), could continue unabated. This abnormal condition if not flagged to workers through other methods, could lead to an overflow of the CWPS and an uncontrolled release of leachate to the environment.

Ageing/degradation of CSCS, e.g. due to corrosion, could also lead to failure of the SSC to properly operate as designed. Ageing is the process by which the physical characteristics of an

SSC change with time (ageing) or use (wear-out). Ageing management is understood as the engineering, O&M actions undertaken to prevent or to control within allowable operating limits, ageing degradation of a component of a SSC following its installation.

To address the above reliability and ageing management considerations, a series of CSCS have been incorporated in to the NSDF design for safety classified SSCs to add an additional level of protection against the occurrence of an event of the type discussed above. Types of CSCS incorporated into the NSDF design fall into the following broad categories:

- Passive safety items/components.
- Active safety items/components.

Sub-categories of CSCS, include components that are designed to fulfill a containment function; and those that are designed to provide a prevention function/provide a preventative measure with respect to ensuring that the NSDF safety classified SSCs continue to perform effectively, i.e. are continuing to fulfill their required safety function(s).

Some examples of CSCS, include items whose function is to provide monitoring to help demonstrate that leachate and contact water are contained (prevented from release to the environment) and other CSCS include items whose function is to prevent occurrence of a condition that could cause a safety-impactful event from happening, such as a condition that would lead to an overflow of leachate from a Facility, a condition that could cause freezing of liquids conveyed in some section or segment of the Leachate/Contact Water Conveyance System.

Many of these CSCS items include built-in “hard-wired” (fail-safe) circuits/interlocks to alert NSDF operations personnel - via a signal consisting of a flashing light and/or an audible horn alarm device - to allow these personnel to intervene in a prompt manner to correct a malfunctioning component or out-of-normal condition in order to preclude an adverse event from occurring, such as an overflow of leachate from a SSC Facility or component (e.g. pumping station). By using such hard-wired circuits and alarms, the SCADA system is not relied upon to provide such a warning. This improves reliability of the operation of safety classified SSCs by not having to rely on continuous operation of digital I&C systems (e.g. SCADA systems/Programmable Electronic System) that can be vulnerable to common-cause failures caused by software errors. The inclusion of such hard-wired circuits also addresses limitations of the SCADA/PES systems resulting from potential degradation, leading to failure of components that are designed to support NSDF operations over the 50+ year operational period of the NSDF facilities and, where applicable, following closure of the NSDF.

The incorporation of additional CSCS into the NSDF design is consistent with CNL’s Equipment Reliability Program [7-14], Ageing Management Program [7-15], and Maintenance Program [7-16]. The Equipment Reliability Program [7-14], is developed to assist facilities in improving levels of availability and reliability in Facility operation in an efficient and effective manner.

A total of 61 CSCS are included in the NSDF design, a complete listing of the components incorporated into the NSDF safety classified SSCs can be found in Components for Safety Classified Systems [7-11].

7.3.4 Testing, Monitoring, Inspection/Surveillance and Maintenance/Repair of Components for Safety Classified Systems

A program of testing, monitoring, inspection (surveillance) and maintenance/repair will be implemented during the operation and closure period of the ECM and NSDF Facilities. This program is designed to verify that installed CSCS are operating as designed and without impairment, and to ensure that necessary maintenance/repairs are completed to the CSCS or the components are replaced as required. Test push buttons/switches are incorporated into the CSCS circuits to verify that the components are in proper working order and in the acceptable calibration range, so as to ensure the associated SSCs are meeting their required safety functions. The O&M Plan [7-17], presents details regarding this testing, monitoring, inspection/surveillance and maintenance and repair program.

7.4 Defence-in-Depth

Table 7-1 shows the safety classified SSCs incorporated into the NSDF design that provide defence-in-depth. In addition, Table 7-1 provides the corresponding defence-in-depth level determined in using the guidance in Design of Reactor Facilities: Nuclear Power Plants, REGDOC-2.5.2 [7-7], and the safety function of the SSCs. The NSDF design has used three levels of defence-in-depth: Levels 1 - 3 based on the guidance in [7-7].

The NSDF safety classified SSCs, coupled with implementation of planned operational requirements during NSDF operations, are designed to protect potential receptors (workers, members of the public, and the environment), by limiting release of radioactive material and/or hazardous material, or limiting radiation exposure during and following normal, anticipated transient and accident conditions.

Table 7-1
Near Surface Disposal Facility Defence-in-Depth

Structure, System, Component	**Safety Function(s)**	**Defence-in-Depth Level of Structure, System, Component**		
		Level 1	**Level 2**	**Level 3**
ECM final cover system	Containment, retardation, isolation	Final cover system (multi-layered engineered cover system)	NA	NA
ECM base liner system	Containment retardation, Structural stability	Primary composite liner, LCS	Secondary composite liner, LDS	Compacted clay liner, Perimeter berm
Below grade HDPE double-walled piping for leachate and contact water conveyance system structures: (i) Leachate extraction boxes; (ii) Sediment box; (iii) Wet wells (CWPS #1 and CWPS#2); (iv) Contact water chambers	Containment	Primary containment wall	Secondary containment wall	NA.
	Monitor and control	NA	LCS Leachate Sump High-High Level, LDS Leachate Sump High-High Level, CWPS #1 Overflow Prevention Pumps Trip, CWPS #2 High-High Level Alarm, low-point leak detection ports of piping.	NA
Above Grade Leachate/CW Pump/Piping Transfer System	Containment	Primary containment wall	Secondary containment wall	NA
	Monitor and control	Heat tracing	Low-point leak detection, Low Wastewater Temperature Alarm	NA
WWTP Process tanks and piping	Containment	Tank wall, primary containment piping wall, Floor in WWTP is inclined to direct water/spills toward floor drain.	Active drain system	NA
	Monitor and Control	NA	Interlocks, Hydrogen sulphide monitors	NA
Influent storage	Containment	Equalization Tanks' wall	Concrete secondary containment, Equalization Tank Level Control and Overflow.	NA
	Monitor and control	Equalization tanks heaters	Secondary containment sump is equipped with a	NA

			leak detection sensor, Low Wastewater Temperature Alarm.	
WWTP Filter Press	Containment	Ventilated enclosure, Active ventilation	HEPA filter	NA
	Monitor and control	NA	Radiation Monitoring System in enclosure	NA
WWTP Fume Hood	Containment	Ventilated enclosure, Active ventilation	HEPA filter	NA
Active drain system	Containment	Primary containment wall	Secondary containment wall	NA
Electrical power	Monitor and control	Class IV Power	Class III Power, Class II Power	NA
Chemical feed system	Containment	Primary containment wall	Secondary containment wall, Chemical Storage Room Secondary Containment	NA
Vehicle Decontamination Facility	Monitor and Control	Separate areas for vehicle decontamination, including ventilation.	Carbon monoxide monitor	NA
	Containment	Tank wall. Primary containment wall in double-walled piping used in active drain system.	Secondary containment wall in double-walled piping used in active drain system.	NA
Operations Support Centre	Monitor and Control	Separate areas for personnel decontamination, including ventilation.	NA	NA
	Containment	Primary containment wall in double-walled piping used in active drain system.	Secondary containment wall in double-walled piping used in active drain system.	NA

7.5 Systems Important to Safety

Table 7-2 is the list of systems important to nuclear safety and lists the SSCs within the NSDF that are essential for maintaining nuclear safety for Facility, personnel and the public. A nuclear system important to safety performs a nuclear safety function and failure of the system has a potential radiological consequence to on-site and/or off-site receptors. Table 7-2, the systems important to nuclear safety list, provides information on the SSC, the safety function, the basis for the selection related to radiological hazards, and the selected quality level.

Table 7-3 is the list of systems important to non-nuclear or conventional safety and lists the

SSCs within the NSDF that are essential for maintaining non-nuclear safety for Facility, personnel and the public. A non-nuclear system, important to safety, performs a non-nuclear or conventional safety function and is generally associated with limiting the release of hazardous material and exposure of on-site receptors. Table 7-3, the systems important to non-nuclear or conventional safety list, provides information on the SSC, the safety function, the basis for the selection related to non-radiological hazards, and the selected quality level.

Table 7-2
Systems Important to Nuclear Safety

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
ECM Base Liner System				
Primary Liner (HDPE Geomembrane) and GCL	Containment	The liner provides first layer of containment for water that comes into contact with the radioactive waste.	II	Passive
	Retardation	The GCL's low hydraulic conductivity retards the flow of water that leaked passes the primary liner into the sub-layers of the base liner system.		
Secondary Liner (HDPE Geomembrane) and GCL	Containment	The liner provides a second layer of containment for water that came into contact with the radioactive waste and leaked passed the first liner.	II	Passive
	Retardation	The GCL's low hydraulic conductivity retards the flow of water that leaked passed the secondary liner into the next sub-layer of the base liner system.		
Compacted Clay Liner (CCL)	Retardation	The CCL's low hydraulic conductivity retards the flow of water into the geosphere.	II	Passive
Perimeter Berm	Structural Stability	Primary function is to provide structural stability to the ECM to withstand a 1:10 000 year seismic event after closure (DBE). It will withstand a 1:2 500 year seismic event during operations (OBE), prior to installation of the cover.	II	Passive
	Containment	The perimeter berm is lined with a single layer HDPE membrane/GCL combination on the side slopes to contain the waste and water that comes into contact with the waste. The GCL's low hydraulic conductivity will retard the flow of water in the sub-layers of the base liner system.		
	Isolation	The perimeter berm forms the sidewalls of the ECM, deterring intrusion and thereby isolating the waste from the biosphere.		
ECM Cover System				

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
ECM Cover Liner (HDPE Geomembrane) and GCL	Containment	The liner provides containment by preventing infiltration of precipitation into the waste cell. The cover adds structural stability to the ECM to withstand a 1:10 000 year seismic event after closure (DBE). It should be noted that the following items by themselves are not safety SCCs but together with the last layers of cover material, contribute to the structural stability that form the base of the cover system: Waste packages; and Waste placement and compaction.	II	Passive
	Retardation	In the event of leaks through the liner, the GCL's low hydraulic conductivity retards the flow of water into the waste cells.		
	Isolation	The cover components together form an intrusion deterrence barrier, isolating the waste from the biosphere.		
Leachate Collection System (LCS and LDS) and Contact Water (CW) Management System				
LCS Leachate Sump High-High Level	Monitor and Control	Monitoring of a passive engineered barrier (the ECM primary liner). Failure of the basic process control system could lead to undetected High-High level in a LCS leachate sump, eventually leading to excessive liquid head on the ECM primary liner.	II	Active
LDS Leachate Sump High-High Level	Monitor and Control	Monitoring of a passive engineered barrier (the ECM primary liner). Failure of the basic process control system could lead to undetected High-High level in a LDS leachate sump, eventually leading to excessive liquid head on the ECM primary liner.	II	Active
Contact Water Pumping Station #1 Overflow	Monitor and Control	Failure of the basic process control system could shut down all output pumps of CWPS #1 without the corresponding shutdown of all input pumps, leading to	II	Active

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
Prevention Pumps Trip		overflow of untreated wastewater to the environment.		
Contact Water Pumping Station #2 High-High Level Alarm	Monitor and control	Monitor availability of CWPS #2 to receive drainage from NSDF active drain systems. Failure of the basic process control system could shut down all output pumps of CWPS #2, along with loss of level monitoring of the CWPS #2 wet well. Without worker notification, this could subsequently lead to overflow of active drainage to the environment.	II	Active
Secondary containment and LDS of double-walled structures and piping.	Containment	Secondary containment provides containment in the event of a failure of the primary containment. The secondary containment provides containment to prevent a release to the environment in the event of primary containment failure (spill or leak). Alarms provide indication that liquid is collecting in the secondary containment.	II	Passive
Single walled Leachate Piping Transfer System	Containment	Single wall, SS piping, will only be installed where line leaks will be collected by the Equalization Tanks secondary containment or inside the WWTP.	II	Passive
Buried Leachate/CW Pump/Piping Transfer System	Containment	All buried HDPE piping used to convey leachate/CW are double-walled. Provides primary and secondary containment of Leachate/CW. Below grade pipes will be located below the frost line.	II	Passive
	Monitor and Control	Low point leak detection ports will allow operators to conduct routine inspections of the annulus space between the two pipes. The presence of water in this space indicates a fault in the piping system.		Active
Above Grade Leachate/CW Pump/Piping	Containment	Provides primary and secondary containment of Leachate/CW. Above Grade piping used to convey	II	Passive

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
Transfer System		leachate/CW are HDPE double-walled.		
	Monitor and Control	Instrumented with low-point leak detection to inform operators of the presence of water in the annulus space (leak alarm).		Active
Heat Tracing on Leachate/CW Pump/Piping Transfer System	Monitor and Control	Heaters and insulation protect the structural integrity of the transfer lines/equipment by preventing water from freezing in the lines, potentially causing them to rupture (lines and equipment not installed below the frost line). Heat trace system monitors and control line temperatures above freezing (4°C). System alarms to notify operators of faults.	II	Active
Equalization Tanks Secondary Containment	Containment	Provides secondary containment from a leak or failure of Equalization Tanks or single-walled transfer piping installed within the containment boundary. Containment structure is designed to contain the maximum operational capacity of a single tank plus the accumulation of precipitation inside the secondary containment area from a 100-year storm event. Containment structure is designed to withstand a 1:2 500 year seismic event (OBE).	II	Passive
	Monitor and Control	Equalization Tank concrete curb secondary containment sump is equipped with a leak detection sensor, which activates an alarm in the WWTP Control		Active and Passive[2]

[2] The secondary containment is an active and passive system for the following reasons. The containment area requires operations personnel to respond to a flood detection alarm; the alarm and manual intervention are both active features. Following procedures, operators will determine if the accumulated water in the secondary containment sump is waste-water or rainwater. Rainwater collected in the secondary containment sump from previous precipitation events, will be routinely pumped-out in order for the containment system to have the available capacity to passively collect and contain the estimated volume of contact-water from a leaking or failed Equalization Tank/line caused by this PIE.

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
		Room to inform workers of the fault condition. The leak detection will alarm on liquid contacting the sensor. The activation of the leak detection alarm could be the result of precipitation or a spill / leak in the piping or Equalization Tank(s). The worker actions for an activated leak detection alarm in the secondary containment sump are to be determined and documented in the "to be prepared operating procedures". Worker action general response is: investigate alarm, monitor Equalization Tanks level for volume change, if tank leaking, transfer to available tank, transfer water from secondary containment to available tank. Spills or leaks from the Equalization Tanks are directed to the secondary containment sump and pumped back to the Equalization Tanks for treatment. Uncontaminated water (i.e. precipitation) in the Equalization Tanks' secondary containment may be managed as non-contact water and pumped to a surface water management pond. Monitoring of a passive engineered barrier, the Equalization Tanks secondary containment.		
Equalization Tanks Heaters	Monitor and Control	Heaters and insulation protect the structural integrity of the tanks by preventing water from freezing, potentially causing them to rupture. Heat trace system monitors and control tank temperatures above freezing (4^{o}C). System alarms notify operators of faults.	II	Active

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
Equalization Tank Heating - Low Wastewater Temperature Alarm	Monitor and Control	Warn of Low-Low wastewater temperature in any Equalization Tank. Failure of the basic process control system could lead to undetected low temperature of stored wastewater, eventually leading to freezing of wastewater.	II	Active
Equalization Tank Level Control and Overflow	Monitor and Control	Each tank is equipped with multiple level transmitters to indicate the level inside each tank and to provide early warning (alarms). Each tank is equipped with multiple level switches that warn of high and low levels. Upon activation of the High-High Level Alarm, power is automatically removed to stop all influent LCS, LDS and contact water pumps to avoid reaching a tank overflow situation.	II	Active
NSDF General				
Class III Power	Provide emergency back-up power to safety SSCs during Class IV Power outages	Class III Generator operates on an unlimited supply of natural gas. Generator will provide power to the individual components of the “active” SSCs (listed in this table), which require electricity to perform their safety functions during normal Class IV Power Outages.	II	Active
Class II Power	Battery Back-Up Power	Uninterruptable Battery Power Supplies will provide power to the SCADA system and critical input instruments to continue to log critical parameters for 30 minutes after loss of Class III Power and unavailability of Class IV. Class II Power is commonly used in buildings at CRL for emergency lighting, exit lighting, security and fire monitoring systems.	II	Active
Fire Water System	Fire Protection	A network of fire hydrants will be provided to service the NSDF support facilities.	II	Active

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
		A ventilated and heated fire pump house is located on top of the fire water storage tanks. It houses the fire pump control panels, an Automatic Transfer Switch (ATS) to redirect power from Class IV to III if needed, the fire pumps and supply lines. Failure of the fire water system could diminish response capability and result in greater fire-related injuries and/or exposures in the event of a fire.		
WWTP Facility				
Active Drain System	Containment	Floor drains in the WWTP process areas are connected to the active drainage system. The process tanks have overflow piping connected to the active drain system. The active drain provides containment of leaks and overflow of the WWTP process tanks.	II	Passive
Active Ventilation Exhaust	Provides ventilation exhaust for the removal of airborne contamination	Failure of the ventilation system exhaust, has the potential to have an impact on radiological safety of the Facility personnel and could result in unacceptable levels of airborne contamination. The room air in the filter press area is continuously HEPA filtered and exhausted.	II	Active
Fire Protection System	Monitor and Control	Building Fire Detection system provides early warning for building occupants to evacuate the building and simultaneously transmits the alarm to the CRL Fire Department to activate their emergency response protocols. Building fire separations are rated to provide the required level of protection for compartments within the building. Building is equipped with emergency and exit lighting. The communication HUB room is protected by a dry agent fire suppression	II	Active

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
		system. Duct-mounted smoke detectors are installed on all air handling equipment with flow rates above 944 L/s, and on two Zone 3 HEPA filter exhaust units. Failure of the fire detection system could result in fire related exposures, injuries or damage to the building.		
Lightning Protection System	Instrument/ Equipment Protection	Protects the Equalization Tanks, the monitoring and control systems, process equipment and instruments from potential high voltage/current surges as a result of a lightning strike.	II	Passive
Radiation Monitoring System in Filter Press Enclosure	Monitor and Control	Portable, real-time alpha/beta particulate monitors (iCams). Fixed area dose-rate monitors.	II	Active
Other Support Facilities				
VDF Fire and RP Systems	Fire Protection	Failure of the fire detection system could result in fire related exposures, injuries or damage to the building.	II	Active
	Radiation Protection Monitor and Control	Portable, real-time alpha/beta particulate monitors (iCams) and fixed area dose-rate monitors. Failure of the Continuous Air Monitor (CAM) systems could result in a loss of indication of elevated airborne contamination levels in the buildings and has the potential to have an impact on radiological safety of the Facility personnel. Provides audible and visual alarms for excessive alpha/beta/gamma-in-air particulate activity levels in accordance with RP requirements. Provides personnel with early indication of a potential release of airborne contaminants, due to waste management activities. If the airborne concentration exceeds the set point (as determined by RP), an audible alarm annunciates and a		

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
		red visual alarm illuminates.		
Operations Support Center - Fire protection Systems	Fire Protection	Failure of the fire detection system could result in fire related exposures, injuries or damage to the building.	II	Active
Administration Office Fire Protection System	Fire Protection	Failure of the fire detection system could result in fire related exposures, injuries or damage to the building.	II	Active
Kiosks (North and South) Fire Protection System	Fire Protection	Failure of the fire detection system could result in fire related exposures, injuries or damage to the building.	II	Active

Table 7-3
Systems Important to Non-Nuclear or Conventional Safety

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
Chemical Feed Tanks	Containment	Tanks are dual-walled. The secondary containment provides containment to prevent a release in the event of primary containment failure.	II	Passive
	Monitor and Control	The interstitial space is equipped with leak detection and alarms provide notification that liquid is collecting in the secondary containment.		Active
Chemical precipitation system interlocks	Control	The interlocks prevent the mixing of incompatible chemicals within the WWTP process tanks. Chemical precipitation system interlocks: • Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running. • pH Low or pH High Alarm, plant held state is triggered. • pH Instrument fails for the tank that has pH control enabled. • Sodium sulphide and sulphuric acid or ferric chloride dosing pumps running together is not allowed.	II	Active
Polishing system interlocks	Control	The interlocks prevent the mixing of incompatible chemicals within the WWTP process tanks. Polishing system interlocks: • Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running. • pH Low or pH High Alarm, plant held state is triggered. • pH instrument fails for the tank that has pH control enabled.	II	Active

System, Structure, Component (SSC)	Safety Function	Basis for Selection/Justification	Safety Classification Quality Level	System Type
Final pH adjustment interlocks	Control	The interlocks prevent the mixing of incompatible chemicals within the WWTP process tanks. Final pH adjustment interlocks: • Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running. • pH Low or pH High Alarm, plant held state is triggered. • Final pH adjustment tank pH Instrument failure.	II	Active
Hydrogen sulphide monitors in WWTP	Monitor and Control	Hydrogen sulphide gas monitor for gas formation resulting from mixing incompatible chemicals. Alarms provide notification that hydrogen sulphide gas levels are unsafe.	II	Active
Carbon monoxide monitor in VDF	Monitor and Control	Carbon monoxide gas monitoring. Alarms provide notification that carbon monoxide gas levels are unsafe.	II	Active
Chemical Storage Room Secondary Containment	Containment	The secondary containment provides containment to prevent a release in the event of primary containment failure. Two storage rooms are available to store incompatible chemicals separately, and the secondary containments are not interconnected.	II	Passive

7.6 References

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[7-10] *Safety Classification and Design Rules for NSDF Structures, Systems, and Components,* 232-03620-REPT-002, Revision 0, 2018 December.

[7-11] *Components for Safety Classified Systems,* 232-03620-REPT-003, Revision 0, 2019 January.

[7-12] *Safety Classification of NSDF Systems*, 232-03620-REPT-001, Revision 0, 2018 November.

[7-13] *Quality Program Selection*, 900-514200-MCP-007, Revision 2, 2019 April.

[7-14] *Equipment Reliability Program Requirements Document*, 900-508230-PRD-002, Revision 0, 2017 February.

[7-15] *Ageing Management Program*, 900-508222-STD-001, Revision 0, 2018 February.

[7-16] *Maintenance Program Requirements Document,* 900-508230-PRD-001, Revision 1, 2019 March.

[7-17] *Operations and Maintenance Plan*, 232-508220-PLA-006, Revision 0, 2019 September.

8. BUILDING SERVICES AND INSTRUMENTATION AND CONTROL

This section describes the NSDF building services and I&C.

8.1 Building Services

The building services include Class IV Power, Class III Power, natural gas, domestic water, fire water, sanity sewage, communications (voice and data), public address system, security system, and fire alarm system.

8.1.1 Off-Site Power

The CRL site power is supplied from the Hydro One 115 kV network of overhead lines [8-1]. The CRL site is fed from two circuits, one circuit originating at Des Joachims and the other from Petawawa [8-1]. The site is configured with both switches closed and the Hydro One tie switches are closed at all times. In the event of a power outage, faulted circuits must be isolated and then power restored to CRL. Switching orders are completed as detailed during discussions with Hydro One Operating Control Centre [8-1]. Presently, Hydro One comes to site and performs switching [8-1]. However, Hydro One and CNL have a third party switching agreement under which Powerhouse Shift Engineers will (after training is complete), be authorized to operate Hydro One switching equipment in the switch yard under Hydro One instructions, pursuant to written “Orders to Operate” received from Hydro One [8-1]. The 115 kV switching equipment including towers, power lines and poles to the CNL property lines is maintained by Hydro One [8-1].

8.1.2 On-Site Class IV Power System

The 115 kV power is transformed down to a 2.4 kV on the CRL site transformer sub-station, located at Building 422, and then is distributed around the site [8-1].

8.1.3 Class IV Power

The Class IV Power supply for the NSDF is provided from existing CNL Feeder #41 (3 phase, 60Hz) 12.47/13.8kV distribution line at pole P13 located on Plant Road [8-1]. New pole P13-1 is added to accommodate a 15kV class load break switch to minimize power interruption at existing 12.47/13.8kV [8-2]. Power supply from pole P13-1 runs underground duct bank to the two substations within the NSDF site. The substations are WWTP substation and support facilities substation. One outdoor substation contains a pad mounted switchgear (CRL-00510-SWGR-6) and 1 250 kVA transformer (CRL-00510-T-O-195) located adjacent the WWTP [8-2]. Another outdoor substation contains a pad mounted 500 kVA transformer (CRL-00510-T-O-196) is for the support buildings within the NSDF site [8-2]. High resistance grounding system is applied at the two transformers. Class IV Power provides normal power to the WWTP and support facilities.

A 600V distribution board for the support buildings is located in the power distribution center, Building 1561, adjacent OSC, Building 1553 [8-2]. The 600V distribution switchboard, B1561-53340-SWBD-1, provides Class IV Power to the Administration Office Building 1552, OSC Building 1553 and VDF, Building 1554.

8.1.4 Class III Power

The Class III Power supply to selected NSDF equipment, is provided from a 750 kW natural gas emergency back-up generator adjacent to the WWTP. The generator provides Class III Power in the event of loss of the Class IV Power, and is powered by a natural gas engine that provides 600V, 3-phase, and 60Hz back-up supply. The generator supplies back-up power to the Class III switchboards via the Automated Transfer Switch (ATS). The generator automatically starts upon loss of the Class IV Power system detected from any ATS and connects via an ATS to the Class III distribution system.

Class III Power for WWTP essential loads are fed via ATS (B1551-53330-ATS-2) and ATS (B1551-53330-ATS-1).

Class III Power for essential loads at the support buildings is fed via ATS (B1561-53330-ATS-1) [8-2]. Facility wide, North Kiosk Building 1556, South Kiosk Building 1557, CWPS #1 Building 1558, CWPS #2 Building 1559, site fuel station, leachate detection/collection systems Building 1550 and PWPS, Building 1563, are fed from the Class III Power distribution switchboard B1561-53330-SWBD-1 [8-2].

Class III loads for the WWTP include:

- Class III Process loads in the WWTP.
- Class III Mechanical loads in the WWTP.
- 20% of lighting loads will be on Class III in case of Class IV Power failure in the WWTP.
- 50% load of Equalization Tank heater.
- Security system and communication system.
- Fire Alarm Control Panel.
- Uninterrupted Power Supply units.
- Control room lighting.
- Contamination monitoring (e.g. hand and foot monitors).
- Continuous Air Monitors and Area Radiation Monitors.

Class III loads for the support buildings/facilities include:

- Contamination monitoring (e.g. hand and foot monitors) in OSC.
- Continuous Air Monitors and Area Radiation Monitors.
- Class III mechanical loads and 20% lighting loads in VDF.
- Class III mechanical loads and 20% lighting loads in OSC.

- Class III mechanical loads and 20% lighting loads in Administration Office.
- Security system and communication system.
- Contact water pump station #1.
- Contact water pump station #2.
- Site vehicle refueling station.
- Fire Alarm Control Panel.
- North Kiosk.
- South Kiosk.
- Fire Water Pump Station.
- Potable Water Pump Station.

8.1.5 Class II Power

The Class II Power system in the WWTP HUB room consists of an UPS, and derives its normal Class II Power from the 600V Class III system and its back-up power from an integral batter/inverter system. The output of the UPS is monitored by SCADA system. The UPS has a matching external maintenance bypass to enable the UPS to be completely isolated from the electrical system while the load is powered from the external maintenance bypass switch. The battery system is designed to support Class II Power supply for one hour at rated load.

Individual UPS, supply uninterrupted power to the following systems:

- Main telecommunication rack in the HUB room.
- Telephone rack in the HUB room.
- Security rack in the HUB room.
- Public Address system rack in the HUB room.
- Administration Office HUB room.
- Operations Support Centre HUB room.
- Programmable Logic Controller control panels in the WWTP.
- Components for Safety Classified Systems control panels, including leachate and contact water transfer system, and influent flow Equalization Tanks system.

8.1.6 Communication and Systems Network

The network fibre optic service, and 25 pair copper cable for the NSDF site, are derived from an existing system network that runs along Plant Road (via an existing Bell termination box, adjacent pole P13) [8-2].

The communication service supports voice, data, security, fire alarm, SCADA, and BAS communication [8-2]. A minimum 24 strand single mode fibre optic cable is extended from the Bell box at Pole 13 to the support buildings [8-2].

8.1.7 Natural Gas

The natural gas service to the NSDF site, is routed to the NSDF site via EMR from Plant Road, where the service connects to the existing 150 mm gas main on the north side of Plant Road. A pressure reducing station and site gas metre is located at the fence line [8-2]. Additional pressure reducing valves are located at each building and at major pieces of equipment to reduce overall pipe sizing [8-2].

Natural gas is used for domestic hot water heaters, building ventilation and air handling systems, including make-up air units and gas-fired unit heaters [8-2]. The natural gas services is connected to the WWTP, VDF, OSC, Administration Building, and the natural gas generator [8-2].

8.1.8 Active Drain System

The active drain system is connected to the WWTP, VDF and OSC. Contact Water Pumping Station #2, receives the water from the active drain system generated by these facilities/buildings and conveys the wastewater to the Equalization Tanks.

The WWTP active drain peak flow rate is 45.75 L/s [8-2]. The active drain peak flow rate is 0.81 L/s for the VDF and the OSC [8-2].

8.1.9 Water

The water distribution system for the NSDF, interfaces with the CRL site water distribution system in the southeast quadrant of the Plant Road and EMR intersection [8-2]. Water is delivered to the NSDF site via a 50 mm diameter water main to the PWPS [8-2].

8.1.9.1 Potable Water

The PWPS includes 15 m^3 day-use storage tank, water meter, chlorination boosting station and pressure boosting pumps for distributing water to the NSDF site. Potable water from the PWPS, is provided to the NSDF site via a 100 mm diameter water main with a minimum supply pressure of 690 kPa [8-2].

Potable water is provided to the WWTP, VDF, North Kiosk, OSC, and Administration Office for various uses including showers, toilets, eyewash stations, faucets floor/equipment wash down, and VDF wash water reclaim system make-up [8-2]. The South Kiosk is serviced by a potable water storage tank.

8.1.9.2 Fire Water

Fire water is provided through a network of fire hydrants connected via a 150 mm diameter fire water main to the two 403 m^3 fire water storage tanks in the FWPS. The minimum storage volume of 403 m^3 for the fire water tanks, is based on supplying 56 L/s to the NSDF fire water systems for a two hour duration, as per CSA N393 [8-3] requirements [8-4]. The fire water capacity at the NSDF is 806 m^3 based on two fire water storage tanks being 403 m^3 each, and thus, the total fire water capacity exceeds the minimum storage volume of 403 m^3, identified in the FHA [8-4]. The two hour duration for the fire water supply is based on the largest expected flow for a fire response, 56 L/s, which is derived from the four hose stream attack scenario [8-4].

Each fire water tank provides 100% stand-by capacity. Water levels in the fire water storage tanks are monitored by the fire alarm system. Minor losses of water from the fire water tanks, are replenished via a 50 mm diameter piped supply from the site potable/service water distribution network. The potable service water supply to the fire water tanks, is protected with a backflow preventer [8-2]. Bulk filling of the fire water tanks is required to be completed with water tanker trucks, as the volume of water within the tanks exceeds the maximum water volume that can be delivered to the NSDF by existing CNL systems on the CRL campus.

The fire water storage tanks are equipped with pressure boosting pumps (P-701, P-702), capable of providing the design flow rate of 63.1 L/s, and jockey pumps to maintain the system in a pressurized condition. The fire water tanks supply fire water to site fire hydrants via a 150 mm diameter PVC fire water main. The network of fire hydrants includes two adjacent to the Administration Office, one at the OSC parking area, two at the refueling station, and four around the WWTP.

8.1.10 Sanitary Sewage System

Two sanitary sewage systems services the NSDF site. A larger sanitary sewage system adjacent to the EMR, services the WWTP, VDF, OSC, Administration Office and North Kiosk, and one smaller sanitary sewage system services the South Kiosk [8-2]. The sewage generation average daily flow is 5 625 L/day and the minimum daily flow is 52.297 L/day.

8.2 Instrumentation and Control

The I&C includes fire detection, WWTP process control, ventilation leak detection, and tank level monitoring.

8.2.1 Fire Detection

The fire detection system provides a means to warn building personnel of the existence of a fire within the building, and to alert fire department personnel that a fire is occurring within the building. The NSDF Fire Detection and Alarm Systems are designed to automatically detect a fire, alarm a detected fire, and annunciate detected fire on the FACP and transmit fire alarm signals to the respective conventional FACPs located in the WWTP and South Kiosk, and to the CRL Fire Alarm System. The CRL Fire Alarm System is monitored 24 hours a day for alarm conditions by the Security Monitoring room in Building 700. Personnel in the Security Monitoring Room will notify the CRL Fire Station in the event that an alarm is received.

The fire protection system has fire detection and suppression capabilities, and includes the following components:

- Two on-site independent buried concrete fire water tanks (403 m^3 each).
- Network of fire hydrants that are pressurized from electric duty/stand-by turbine fire pumps.
- A packaged fire pump house, located above the fire water storage tanks.
- Fire Alarm Control Panel with annunciators at the WWTP main entrance, which transmits alarms to the Central Monitoring Room in Building 700.
- Fire alarm bells, set above ambient noise levels, and an outdoor flashing strobe.
- Heat and smoke detectors, including duct mounted smoke detectors in the WWTP active ventilation.
- Manual pull fire alarm stations.

The FACP and fire alarm annunciators are networked through the BAS. Back-up battery supplies power to the FACP during a loss of Class IV Power.

8.2.1.1 Building Fire Detection System

Fire detection devices and audible devices are included in the WWTP, VDF, OSC, Administration Building, FWPS, and the PWPS. The installed fire detection systems shall be operational. These consist of fire detection devices (smoke, heat), manual pull stations, alarm sounders, strobes, equipment monitoring modules, flow switches, pressure switches, supervisory valve switches and FACPs.

Fire resistance rated fire separations, will provide passive fire compartmentation in the WWTP, VDF, OSC, and Administration Building.

The WWTP has an active fire protection system, which includes dry fire suppression systems in the HUB room. Duct-mounted smoke detectors have been provided for all air handling equipment with flow rates above 944 L/s. In addition, the two WWTP active ventilation HEPA filters have duct smoke detection capabilities. The smoke detectors are hardwired into the fan start circuits, and automatically stop the respective fans upon detection of smoke within the ductwork. In the WWTP high ceiling area, wall mounted beam detectors are installed in chemical rooms and electrical/mechanical rooms.

Photoelectric smoke detectors are located in corridors and stairwells.

Dual combination fixed temperature/rate of rise temperature type 135 C heat detectors and reflector beam smoke detectors are used in storage area(s).

Bells are used to emit a sound that is heard above moderate ambient noise levels in the NSDF. A flashing strobe is provided outside the Facility for easy identification of the building by the Fire Department.

Fire alarm annunciators are located in the Administration Office, OSC, VDF, and North Kiosk.

Fire dampers are provided in all ductwork penetrating fire related partitions or slabs.

The following drawings specify the type and location of fire detectors:

- B1551-67140-101-01-GA-D
- B1551-67140-111-01-GA-D
- B1551-67140-601-01-ED-D
- B1552-67140-101-01-GA-D
- B1553-67140-101-01-GA-D
- B1554-67140-101-01-GA-D
- B1556-67140-101-01-GA-D
- B1557-67140-101-01-GA-D
- 232-67140-601-01-ED-D
- 232-67140-602-01-ED-D
- 232-50000-001-01-GA-D

If any of the installed fire detection systems are unavailable, compensatory measures as proposed by the Fire Protection Program and approved by the Facility Manager shall be put in place. Compensatory measures could include routine patrols of the area, use of a fire watch or provision of an alternate water supply, depending on the nature of the unavailability.

Actuation of smoke/heat detectors shall be investigated promptly. Normal operations shall be allowed to proceed only when the cause(s) are known and corrective actions have been taken. If causes cannot be determined, or corrective actions cannot be completed immediately, normal operations shall not resume without a formal risk review and authorization by the FA and Fire Protection Program Authority or Designate. The authorization of the FA and Fire Protection Program Authority or Designate shall be documented.

8.2.2 Waste Water Treatment Plant Process Control

The WWTP is designed for continuous operation, 24-hours per day, seven days per week, throughout the year. A process flow diagram for the WWTP is shown in Appendix A. Individual processes include instruments and controls, to allow for automated operation with minimal worker intervention. The intermittent and variable production of wastewater may require the WWTP to remain idle for a period of time, however, when insufficient wastewater is available to warrant treatment. The WWTP controls and instrumentation design considers WWTP start-up and shutdown operational activities and sequencing.

Much of the process equipment in the WWTP consists of vendor packages, which are supplied with their own stand-alone control system, and which may include local PLC and Operator Interface Terminals. Other equipment (non-vendor packages), in the Facility is controlled and monitored by a Plant Control System, which consists of a WWTP PLC Control Panel (001). The plant PLC and vendor package PLC controllers, are connected to a plant wide SCADA system that includes a SCADA server, two SCADA workstations, as well as an engineering station located in the Control Room within the WWTP building. The SCADA monitors the status of packaged equipment, and provides control for other operating functions, including pumping tank level control and chemical feed. Chemical feed systems are automatically controlled to achieve selected set-points for pH or chemical dosage. The SCADA workstations are fully redundant, such that if one fails, the worker can operate the plant from the other workstations.

The SCADA system logs critical operating and monitoring data generated by the WWTP instruments and equipment operation. The SCADA system will alert the WWTP staff via alarms when critical parameters are outside of acceptable operating limits, and when worker attention is required to investigate and address these alarm conditions.

An alarm dialer system, installed within the WWTP electrical room, is connected to the WWTP PLC Control Panel (CP-001). In case of critical alarms, the alarm dialer system will automatically notify authorized personnel via a dedicated phone line.

8.2.2.1 Control Logic

Under normal WWTP operation, it is expected that the equipment will be operational in SCADA-Auto mode, allowing fully automatic functionality of the WWTP. The HAND/LOCAL and SCADA-Manual modes of process equipment operation are mainly used during equipment testing, troubleshooting, maintenance or emergency operational conditions only under close supervision of WWTP workers.

8.2.2.2 Start-Up Sequence and Power Outage

During a power outage, the WWTP will stop treating wastewater. Flow from remote pump stations will continue to discharge to the Equalization Tanks. The emergency back-up generator provides electrical power to the following critical process equipment in the WWTP:

- Contact Water Pumping Station #1.
- Contact Water Pumping Station #2.
- Equalization Tank influent valves.
- All mixers.
- Filter Press.
- Compressed air system (service air).

8.2.2.3 Waste Water Treatment Plant Monitor and Alarms

The WWTP alarms are documented in Table 8-1. In addition to the listed alarms in Table 8-1, the following systems/components are equipped with leak detection monitoring (see Section 8.2.4), resulting in alarms, should a leak be detected:

- Chemical storage tanks.
- Chemical feed dual-walled piping.

- Equalization Tanks/containment.
- Contaminated water dual-walled force mains.

The hydrogen sulfide monitors and alarms have an alarm set-point of 10 ppm and a warning alarm set-point of 5 ppm.

Table 8-1
Waste Water Treatment Plant Alarms

WWTP Alarms	Automatic Action by Plant PLC
PLANT	
Hydrogen sulphide gas detection in any of the tanks Operations personnel manually Initiates Hold State from HMI by pressing "Hold" pushbutton.	Following equipment stops operation: WWTP Feed pumps. Polishing system feed pumps. Membrane filter transfer pumps. Membrane filtration system. All liquid process chemical dosing pumps. Membrane System and Membrane Filter Feed Pumps (to allow for recirculation); Held state control by Membrane System PLC. Residuals De-watering System (to allow for completion of a filter press cycle).
Chemical feed system fault	Chemical dosing pumps stops. Plant equipment continues to operate, provided the pH levels are maintained. Upon pH Hi or pH Lo alarm generation, the corresponding equipment stops based on pH Hi/Lo held condition provided above.
CHEMICAL PRECIPITATION SYSTEM	
Insufficient water (Low level in the Equalization Tank feeding the treatment system). High-High level switch activated in the chemical precipitation tanks. High-High level switch activated in membrane filter feed tank. pH Low or pH High alarm in chemical precipitation tanks	Following equipment stops operation: WWTP feed pumps.
MEMBRANE SYSTEM	
High-High level switch activated in membrane filter process tank. High-High level switch activated in polishing system pH adjustment tank. High-High level switch activated in polishing system feed tank. pH Low or pH High alarm in polishing system pH adjustment tank.	Following equipment stops operation: Membrane filter transfer pumps
POLISHING SYSTEM	

WWTP Alarms	Automatic Action by Plant PLC
High-High level switch activated in final pH adjustment tank or final effluent tank. pH Low or pH High alarm in final pH adjustment tank.	Following equipment stops operation: Polishing system feed pumps
RESIDUALS SYSTEM	
High-High level switch activated in residuals storage/conditioning tank.	Following equipment stops operation: Membrane residuals transfer pumps

8.2.2.4 Hardwired Trips, Interlocks and Alarms

The various WWTP processes are controlled by Programmable Electronic Systems and none are credited for the performance of safety functions. The safety instrumented functions (i.e. trips, interlocks or alarms important to safety), reduce the risk due to a specific hazard, and are fully independent of the basic process control systems (e.g. the various PLC systems, interconnecting industrial networks, the BAS and the SCADA server).

Hardwired alarms are annunciated visually and audibly in various field locations, as well as by a window-type alarm annunciation panel located in the WWTP control room (which is independent of the alarm functionality provided by the SCADA system or by the BAS).

8.2.2.5 Waste Water Treatment Plant Interlocks

Interlocks are incorporated in the WWTP systems; chemical precipitation system, polishing system, and final pH adjustment.

Chemical precipitation system interlocks are:

- Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running.
- Concurrent dosing of sulphuric acid and sodium hydroxide, to avoid exothermic neutralization reaction during control to a pH set-point.
- pH Low or pH High Alarm, plant held state is triggered.
- pH Instrument fails for the tank that has pH control enabled.
- Sodium sulphide and sulphuric acid or ferric chloride dosing pumps running together.

Polishing system interlocks are:

- Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running.
- pH Low or pH High Alarm, plant held state is triggered.
- pH Instrument fails for the tank that has pH control enabled.

Final pH adjustment system interlocks:

- Sodium hydroxide/sulphuric acid pumps are allowed to run only when mixer is running.
- Con-current dosing of sulphuric acid and sodium hydroxide, to avoid exothermic neutralization reaction during control to a pH set-point.
- pH Low or pH High Alarm, plant held state is triggered.

- Final pH adjustment tank pH Instrument failure.

8.2.3 Ventilation

All HVAC systems, except for those units located in the North and South Kiosks, are networked controlled and monitored by the BAS.

The WWTP active ventilation system, provides confinement and cleaning of airborne contaminant by performing the following functions:

- Differential pressure between the different radiological zones, so that air moves from areas of lower to higher potential for radiological contamination.
- HEPA filtration of exhaust from active ventilation (Radiological Safety Zone 3 areas).
- Provision for stack monitoring in active ventilation (Radiological Safety Zone 3 areas).

The active ventilation (Radiological Safety Zone 3 areas), has a separate HVAC system. Alarms indicate abnormal conditions and failure of a major component, initiates orderly shutdown to avoid potential backflow. On loss of power, isolation dampers in the exhaust ducts close to minimize exfiltration of indoor air. If a supply air handling until fails in the WWTP or VDF process areas, interlocked emergency dampers open to allow outdoor air into the Radiological Safety Zone 2 or Radiological Safety Zone 3 areas, to replace the lost supply air and an alarm is activated on the OWS. The exhaust air system will continue to run. In Radiological Safety Zone 2 and Radiological Safety Zone 3 areas, hard wired control of the ventilation system is provided in case of BAS failure. In the Supporting Facilities and buildings, fire dampers are provided in all ventilation ductwork penetrating fire rated partitions or slabs.

When the *"Stay In"* button is pushed, the BAS either shuts down the ventilation systems where appropriate or places the systems into recirculation mode, dependent on the functional requirements of the building.

8.2.3.1 Waste Water Treatment Plant Active Ventilation

The WWTP active ventilation design includes the capability of exhaust monitoring, and box-up does not occur to contain radioactivity.

The WWTP exhaust system draws air from potentially contaminated areas through filter units prior to release from the monitored WWTP main exhaust stack.

The Radiological Safety Zone 3 active exhaust air systems, provides 100% exhaust air discharging directly outside of the building after being filtered, and are dedicated to serve the filter press modular enclosure, laboratory fume hood and other equipment in the laboratory (ventilated storage cabinets and the hood above the oven). Each system consists of a pre-filter, cartridge filter and a HEPA filter bank. In each system, an exhaust fan draws air from potentially contaminated spaces and through the filters, prior to discharging the air through a monitored roof top exhaust stack.

High Efficiency Particulate Air filters are of Bag In-Bag Out filter replacement design, using bubble tight isolation dampers on upstream and downstream end of the filter box. The Bag In-Bag Out system, is designed to protect Facility personnel from dangerous materials captured in this filter. The Filter box is provided with a pressure monitoring system to indicate filter replacement via the BAS. High Efficiency Particulate Air filter sampling ports are integral to the filter housing boxes, and the filters are located as close to the source of contamination as possible, to minimize contamination of ductwork.

Provisions for exhaust stack monitoring are provided for the active ventilation (Radiological Safety Zone 3) laboratory Fume Hood and Filter Press Modular Enclosure. Stack sample and stack sample return probes, are to be provided in accordance with CNL Standard Drawing, Standard for Stack Testing Sampling Probe Elevation & Detail.

Where the active exhaust ductwork penetrates the fire-rated second floor slab, the ductwork is insulated with fire wrap in accordance with NFPA 91, to maintain the floor fire separation integrity.

The need for continuous airborne effluent monitoring in the WWTP has been assessed. Based on the analysis of the residuals management system, (see Appendix C), the release of Co-60, which is the dominant radionuclide in the filter press residuals, is a small fraction of the CRL weekly DRL (i.e. <0.0037%). Therefore, continuous monitoring and box-up are not expected to be required at the WWTP.

At the WWTP, active exhaust systems are provided for the laboratory fume hood and the filter press modular enclosure. The ventilation system of the filter press ventilated enclosure, operates at 8 air changes per hour when the space is unoccupied, and when the space is occupied, the ventilation system operates at 20 air changes per hour [8-5].

Inactive exhaust systems are provided for washrooms, change rooms, HVAC and equipment rooms, and janitor rooms.

The exhaust systems are designed to exhaust air in excess of the supply rate, to ensure that the open areas are at a slight negative pressure relative to the surrounding spaces.

8.2.4 Liquid Leak Detection

Double-walled piping, equipped with leak detection, is used for transfer of wastewater to and from the Equalization Tanks for all below-grade transfer piping installed outside of the Equalization Tank area and WWTP. Manual leak detection ports are located along the alignments of the leachate force main piping to the Equalization Tanks, with spacing at 100 m, intervals linking the pump station to the Equalization Tanks. In the event that wastewater is observed from the leak detection ports, a possible breach of the force main system is possible, and the system is isolated in order to confirm the nature and location of any leak. Similar leak detection ports are provided at each of the CWPSs, as well as at each of the contact water gravity sewer pipe chamber locations, as these structures are all dual containment structures.

The Equalization Tank concrete secondary containment sump is equipped with a leak detection sensor, which activates an alarm in the WWTP Control Room to inform workers of the fault condition. Since the leak detection sensor is in the secondary containment sump, the leak detection will alarm on any liquid contacting the sensor, and the activation of the leak detection alarm could be the result of precipitation or a leak in the piping or Equalization Tank(s). The general actions in response to the alarm being activated are to:

- Investigate the alarm.
- Monitor the Equalization Tanks level for volume change.
- If a tank is leaking transfer the wastewater in the leaking tank to an available Equalization Tank.
- Transfer water from the secondary containment to an available Equalization Tank.

Leak detection is achieved in leachate and contact water systems piping by way of visual leak detection as well as through electronic cabling and probes. Manual leak detection ports are provided along both piping systems at 100 m intervals, to allow for visual leak detection by Operations staff by way of ports and pressure gauges. If a leak is present in the carrier or containment pipe of either system, it would be captured within the interstitial space of the dual pipe and would travel by gravity to the next manual leak detection port down gradient.

For the CWPSs #1 and #2, a leak detection sensor is installed in the interstitial space between the carrier wall and containment wall. The valve chamber is also alarmed with a leak detection sensor. The valve chamber leak detection sensor consists of a leak detection sensor, installed within the void space between the out-going force main casing pipe and the carrier pipe. The leak detection sensor is connected to the adjacent pump station leak detection sensor alarm. If the leak detection sensor detects moisture, an alarm is generated. For the contact water gravity piping to CWPS 2, leak detection for the gravity system is passive through visual inspection of the secondary containment annular space, manual leak detection ports, at each of the maintenance access chambers.

For the effluent piping to Perch Lake, the dual containment piping system includes manual leak detection ports. These manual leak detection ports are spaced at approximately 100 m intervals and include valves and ports to allow for bypassing sections of pipeline in the event of an emergency. These leak detection/by-pass stations are equipped with valves to isolate flow when necessary. Bypass valves are located at the downstream or low side of the leak detection stations to allow for drainage.

The chemical storage tanks are dual-walled and have interstitial leak detection. If leaks are detected, the chemical storage tank is removed from service. The chemical feed systems piping is dual-walled with interstitial leak detection.

The spent CIP solution storage tank is double-walled HDPE, with interstitial leak detection.

8.2.5 Vehicle Decontamination Facility

The carbon monoxide monitor and alarm in the VDF has an alarm set-point of 35 ppm.

8.2.6 Tank Level Monitoring

The following tanks have liquid level monitoring and high level alarms:

- Equalization Tanks.
- Process and chemical tanks in the WWTP.
- Fire water tanks in the FWPS.
- Wastewater tank in the VDF.

8.3 References

[8-1] *CRL Site Characteristics*, CRL-03510-SAB-001, Revision 5, 2018 June.

[8-2] AECOM, *Building Services Summary Report*, 232-503212-REPT-014, Revision 1, 2018 November.

[8-3] CSA Group, *Fire Protection for Facilities that Process, Handle or Store Nuclear Substances*, CSA N393-13, Revised 2016 May.

[8-4] *Fire Hazard Analysis,* 232-503230-FHA-001, Revision 2, 2019 March.

[8-5] AECOM, *HVAC Design*, B1551-508243-REPT-001, Revision 1, 2019 September.

9. PROCESS DESCRIPTIONS

This section provides an overview of the operation and process activities at the NSDF Facility. The main operational activities include placement and compaction of LLW in the ECM, and processing of wastewater in the WWTP. Other operational activities include: waste receipt, general maintenance, surveillance, record keeping, and new construction of roads, ponds and berms, opening cells, and closing cells.

Facility operations, equipment tests, inspections, and emergency response are performed according to written and authorized procedures. Activities performed on Facility systems are covered under the Integrated Work Control [9-1] or Work Permit system (WP) [9-2], unless covered by operating procedures and exempted from the process in the WP system [9-2]. Any activity affecting the setting or serviceability of an alarm, control system, pressure relief, safety related, or fixed radiological or other safety warning instrument, or any check or calibration of the setting of these devices, shall be performed under a Trip, Alarm or Controller WP.

9.1 Ingress and Egress

The NSDF perimeter fence and posted warning signs, shall be maintained with gates locked when unattended, to resist intrusion by unauthorized people. Access to the buildings is controlled by use of a card access system.

Workers who work with radioactive material, or who have entered zones where hand or other skin contamination is possible, shall wash their hands and/or shower as necessary, or as directed by the clearance/permit, WP, work procedures or a RP Group 1 qualified employee [9-3].

Canadian Occupation Health and Safety Regulations, require that a person who performs strenuous physical work in a high temperature or high humidity situation or whose bodies may be contaminated by a hazardous substance, shall have shower facilities available [9-4].

All persons shall monitor themselves for radioactive contamination after working or handling unsealed radioactive material, when suspecting personal contamination, when leaving an area that may be contaminated, when exiting from a higher Contamination Zone to a lower Contamination Zone, when exiting a CA where the potential for contamination exists, and when asked to do so by a Supervisor or Group 1 qualified employee [9-5] and [9-6].

In the event of an emergency, personnel will follow building emergency procedures, which will direct personnel to place work in a safe state, if safe to do so, leave the work area and congregate at a designated safe location. Contamination monitoring and follow-up will then be performed.

9.2 Plan of the Day

The Plan of the Day meeting occurs each work day. The Plan of the Day meeting is an administrative control to ensure safe and efficient Facility operation. This meeting provides the following:

- Identify roles and responsibilities including leadership and oversight.
- Review of previous day(s) operations.
- Review of the planned work schedule for the day.
- Review of relevant ImpActs and OPEX.
- Ensuring that safety issues are identified and effectively addressed.
- Ensuring that identified emergent work is planned, approved and scheduled.

9.3 Near Surface Disposal Facility Activities

This section describes the activities associated with the operation of the NSDF, including those pertaining to waste disposal, inspections, maintenance, and monitoring.

9.3.1 Waste Receipt and Inspection

Wastes arrive at the NSDF kiosk after Qualified for Shipment has been completed by a Waste Technician. All shipments of waste received, shall be accompanied by a completed Waste Package Data Form and supporting documentation as required. The Waste Package Data Form lists, or references a document that lists, the origin of the waste and a description of the waste form, volume, radionuclide content, and content of any other hazardous materials, as identified by the waste generator. The supporting documentation may include a Waste Profile Form, Waste Management Plan, Waste Assessment Form, Characterization Documentation, Waste Container Inventory Form, and pictures. All waste packages received shall have a Waste or Package Identification label/sticker attached to the package.

The general process, used by the Waste Technician, for receiving bulk and packaged waste involves:

- Completion of pre-shipment documentation, including a waste package data form for the associated Waste Profile.
- Qualify for Shipment and shipment schedule.
- Documentation verification accompanying the waste shipment.
- The waste identification labels are recorded and cross-referenced to the Waste Package Data Form and supporting documentation.
- Off-site waste – The waste identification labels are recorded and cross-referenced to the waste manifest completed by the off-site generator.
- Physical inspection of waste packages for damage or non-compliance with the WAC [9-7] packaging requirements.

- Visual inspection of the waste packages or transportation containers against the supporting documentation [9-7].
- Visual inspection of the bulk waste against the bulk waste physical requirements in the WAC [9-7].
- Radiological monitoring of the waste packages or transportation containers for external radiation and contamination, and assessment against radiation limits in the WAC [9-7].
- Waste packages are assigned a unique identification number that is recorded in the waste database along with the information in the waste manifest.
- Waste placement into the ECM.
- Waste inventory record keeping and tracking against performance criteria.

Waste packages may be randomly selected for compliance monitoring, prior to shipment. The mass of waste shipments is tracked using the measurements taken at the North or South Kiosk scale.

Near Surface Disposal Facility personnel are on duty during operational hours to ensure WAC [9-7] compliance, and that only approved wastes are disposed at the ECM. Unauthorized waste will be rejected and not accepted for disposal. In the event, that unauthorized wastes are received, NSDF operations will follow CNL's reporting and notification procedure in accordance with Continuous Improvement Ideas Process [9-8] and Improvement Action (ImpAct) Corrective Action Program [9-9].

9.3.1.1 Fissionable Materials

Waste packages containing Fissionable Materials and SFMs, are assessed by the NM&SM Program. The NM&SM Program contacts CNSC and the IAEA to analyze the potential for recovering the Fissionable Material and/or SFM in the radioactive waste. During this process, the radioactive waste could be deemed to have recoverable quantities of SFM, depending on the amount, form and type of fissile or Fissionable Material. If the waste contains recoverable quantities of SFM, the waste will not be accepted for disposal. If Fissionable Material and/or SFM are not deemed to have recoverable quantities of SFM, the NM&SM Program will create an exception memo to approve the waste movement into the NSDF. Only after these details and the waste receipt process described in Section 9.3.1 have been completed, can the shipment date and time be coordinated with the waste generator, the NM&SM Program and the NSDF Nuclear Criticality Control Officer.

Receipt of Fissionable Material into the Facility, and movement of Fissionable Material within the Facility, shall be recorded and shall be in conformance with limits and restrictions specified in the NSDF CSD [9-10].

9.3.1.2 Waste External Radiation Fields

Radiation protection requirements must be considered and radiation exposures must be kept ALARA to personnel who handle the waste. The dose rate limits and the means of handling and transferring that shall be applied to the bulk and packaged waste at the NSDF are presented in Table 9-1.

The beta dose rate limit of <10 mSv/h in Table 9-1 is applied directly from CNL's RP Program Documentation, ALARA Review and Assessment – Planning and Control of Radiation Work [9-11]. This RP document sets the Hazard Level for beta dose rates at Low if less than 10 mGy/h, which means that the hazard lies well inside the level of work approval for CNLs' Group 1 RP Staff. Beta dose rates will be reduced via packaging, but the limit is specified to ensure that excessive shallow/skin doses are not encountered on packages that may simply comprise a bagged/double bagged contaminated item.

The dose rate limits in Table 9-1, are applied to the exterior of the transportation container or bulk waste packaging containing bulk waste by the following process:

- Radiation Protection staff using dose rate meters assess the radiation levels, quantitatively, on the transportation container or bulk waste packaging in different locations.
- Contamination levels on the transportation container or bulk waste packaging exterior are measured on swipe in different locations.
- The highest measured radiation and contamination readings on the transportation container or bulk waste packaging are compared to the dose rate and contamination limits.

Table 9-1
Dose Rate Limits and Means of Handling and Transferring

Radiation Type	Dose Rates	Means of Handling and Transferring
Total gamma and neutron	≤0.5 mSv/h near contact **and** ≤0.01 mSv/h at a distance of 1 metre.	Manual or mechanical means.
Total gamma and neutron	>0.5 mSv/h to ≤2 mSv/h near contact **and** >0.01 mSv/h to ≤0.1 mSv/h at a distance of 1 metre.	Mechanical means.
Total gamma and neutron	>2 mSv/h near contact **or** >0.1 mSv/h at a distance of 1 metre.	Handling and transferring is subject to RP Program controls, Infrequently Performed Operations [9-12], and assessment approval by the NSDF FA.
Beta	<10 mSv/h near contact	Based on total gamma and neutron dose rates.

9.3.1.3 External Surface Contamination on Waste Packages

The maximum non-fixed surface contamination on the outer surfaces of each waste package and transportation container, averaged over 300 cm^2, must be less than 3.7 Bq/cm^2 beta gamma, and less than 0.37 Bq/cm^2 alpha [9-7].

9.3.1.4 Quality Assurance

The Waste Certification Program is the basis for ensuring wastes are managed in a manner that meets all applicable rules, regulations, license conditions, and requirements CNL must follow. The Waste Management Plan (WMP) has been developed to house all the relevant information of how a waste generator will best manage their waste. The WMP will then be used as the reference point for comparing the agreed to process, and the actual processes that take place for the generation, packaging, verification, and shipping of waste. This will also include the periodic generator self-assessments, WMP updates, and audits completed by Waste Programs personnel.

The specific format and input requirements for a WMP can be found in the Waste Management Plan [9-13].

Canadian Nuclear Laboratories uses a series of Management Control Procedures (MCPs) to provide quality controls and govern the waste management process in general; waste characterization and waste certification are also administered by the following documents:

- Management of Waste, 900-508600-MCP-004 [9-14].
- Waste Characterization, 900-508600-MCP-001 [9-15].
- Waste Certification, 900-508600-MCP-003 [9-16].

9.3.1.5 Infrequently Performed Operations and Waste Acceptance Criteria Variance Process

Waste that does not meet all of the criteria listed in the WAC [9-7], may be considered for disposal on a case-by-case basis only after receiving the documented authorization from the NSDF FA following the Infrequently Performed Operations process [9-12]. This may be supported by the Operational Decision Making process [9-17] or Problem Validation & Technical Operability Evaluation [9-18] as applicable.

Waste that is acceptable for disposal after going through the Infrequently Performed Operations process [9-12], requires the documented decision to be attached with the waste's documentation (e.g. Waste Management Plan, Waste Package Data Form).

In order to obtain a variance for a specific Waste Profile, a documented assessment following the requirements of the Facility Authorization will be performed. Recordkeeping requirements for the waste management process are provided in Waste Data [9-19].

All Type 6 wastes shall be accepted through the Infrequently Performed Operations [9-12] process.

All disused sources being considered for disposal at NSDF, shall be evaluated through the Infrequently Performed Operations [9-12] process. The evaluation of disused sources shall follow the IAEA guidelines Disposal Options for Disused Radioactive Sources [9-20], and Safety Considerations in the Disposal of Disused Sealed Radioactive Sources in Borehole Facilities [9-21].

9.3.2 Waste Placement and Compaction

Objectives for the placement and compaction of wastes in the ECM, are described in the Waste Placement and Compaction Plan [9-22]. Waste placement activities will be performed in a manner that protects and maintains the integrity of the base/sidewall liner system, LCS, final cover system, and all ancillary NSDF features. The objectives for waste placement and compaction include [9-22]:

- Waste handling, from receipt at the NSDF to final placement, is minimized to mitigate the potential for dust generation [9-23] and exposure to workers and the environment.
- When possible, wastes with higher dose rates (waste having gamma dose rates approaching or equal to 2 mSv/h near contact or 0.1 mSv/h at 1 m) are placed in the lower portions of the disposal cells and covered with waste having lower dose rates or fill materials to provide shielding from radiation. The design allows for 0.8 m of granular material on top of the primary liner to protect against radiation doses to the liner.
- Regardless of placement location, all waste exhibiting higher dose rates (e.g. non-contactable handleable waste), is placed and immediately covered with waste having lower dose rates or fill material to maintain doses to ECM workers ALARA.
- Waste is placed to maximize its in-place density and reduce void space to minimize the potential for future settlement of the waste and to ensure seismic stability of the ECM.
- As waste is placed into the disposal cells, the surface of the waste is maintained at a minimum 2% slope to promote run-off and minimize infiltration of surface water into the waste.
- Waste placement is conducted to minimize the time that on-site workers are required to work directly on the LLW working (disposal) face in accordance with ALARA principles.
- The waste placement sequence is conducted in a manner that provides flexibility in final side slope construction and future cell construction.
- Waste placement is designed to accommodate expected variations in the waste mix (relative percentages of the various waste types), and delivery times for waste arriving for placement.
- A key to waste placement efficiency and meeting ALARA objectives is an effective planning and waste delivery schedule approach that is adopted by Waste Operations and the Facility Manager.

The following general criteria are applied to the waste placement activities to prevent differential settlement and maintain ALARA conditions during operations [9-22]:

- Waste placement will allow for specified areas where different waste types can be disposed of while limiting the vertical height of the column of each type of waste (e.g. operational lift); this is intended to ensure that adjacent columns of waste exhibit the same potential for long-term settlement.
- Waste placement will not allow any column of waste, cell floor to cover, to consist of only one waste type. The specified placement criteria is intended to prevent differential settlement.
- Waste placement will allow for placement of waste exhibiting high radiation levels only on a scheduled basis to maintain ALARA conditions associated with cell operations. Receipt of packaged wastes exhibiting high radiation levels must be scheduled in advance to allow planning of the waste placement. Such waste packages will be placed in a predesignated area of the disposal cell and covered with lower activity bulk or packaged waste for radiation shielding and worker protection.
- Bulk wastes (Type 4) and packaged wastes (Type 5), are not placed within 10 m of the sidewall slopes or within 1 m of the LCS and final cover system of the cell to minimize any potential risk of damage to the LCS and liner system.

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

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

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

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

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

Waste handling operations using the crane, shall be cancelled when wind conditions are greater than 40 km/h. Waste placement activities shall be cancelled when weather conditions are severe based on Environment Canada weather warnings.

The six waste types described in the WAC [9-7], and described in Section 6.9, have specific waste placement and compaction procedure requirements described in Table 9-2 [9-22].

Table 9-2
Waste Placement Procedures for each Waste Type

Waste Type	Description	Waste Placement and Compaction Procedures
Type 1	Soil and soil-like waste	Type 1 waste is placed and graded in approximately 0.3 m lifts. Compacted to a minimum 92% Standard Proctor Density to minimize settlement. Moisture content is controlled between 1% below and 3% above optimum moisture content (water content at which a maximum dry weight is achieved or all voids are filled). High moisture waste may be spread out to facilitate drying, or drying agents may be used. Grading is completed using dedicated bulldozers or similar heavy equipment, and compaction will be performed using a dedicated wheel tractor soil compactor or sheepsfoot roller. This material may also be used as berm material for berm containment areas used to contain Type 3 and 4 wastes.
Type 2	Comingled radioactive waste, debris, refuse, soil, and soil-like waste.	Type 2 waste is placed and graded in lifts of up to 0.3 m thickness using a bulldozer or similar equipment. Compaction of Type 2 waste is performed using a combination of landfill compactor or wheel tractor soil compactor, depending on the waste composition, the percentage of refuse within the waste.

Waste Type	Description	Waste Placement and Compaction Procedures
		To the extent possible, the variable components of Type 2 waste will be uniformly distributed within each disposal cell lift. Waste placement is conducted to reduce concentrated areas of refuse and to limit the potential for differential settlement.
Type 3	Non-soil-like waste	Type 3 waste consists of bulk material placed in specific dedicated and prepared containment areas within each disposal cell. The dedicated areas are typically constructed on top of Type 1 waste, with perimeter berms constructed of Type 1 waste. The waste is spread evenly within the bermed containment area to a maximum thickness of approximately 0.3 m, then typically covered with approximately 0.3 m of Type 1 or Type 4 waste. Waste placement and compaction procedures will be developed on a case by case basis.
Type 4	Decommissioning and demolition wastes	Type 4 waste is typically placed in 0.3 m lifts in designated and prepared areas that are co-located with placement of Type 1 waste, and is covered with approximately 0.3 m of Type 1 waste. Type 4 bulk waste may also be used to cover Type 3 wastes within the designated bermed containment areas before covering with Type 1 material. Non-bulk Type 4 waste (i.e. individual pieces of debris), is individually placed in designated and prepared areas on top of Type 1 waste with thicknesses of at least 0.3 m, and subsequently backfilled with Type 1 waste to minimize voids. Large Type 4 items (e.g. beams), are placed with sufficient spacing to allow proper compaction of Type 1 waste around the debris. Large concrete and building debris will be broken down into pieces with placed dimensions no greater than 0.3 m prior to acceptance for disposal in the ECM. Void space between monoliths must be less than 10%. If the void space is greater than 10%, then grout may be placed between the monoliths to reduce void space. Small building rubble is placed with a minimum horizontal spacing between rubble loads, with loads spread as necessary to ensure proper filling of voids with Type 1 waste. Type 1 waste is placed around the small rubble in approximate 0.3 m lifts and compacted using conventional compaction equipment. As necessary, some wood wastes may be grouted in place. This placement and compaction procedure is designed to prevent "nesting" of clusters/ bundles of wood debris within the mound, and not allow for any column of waste (i.e. cell floor to cover) to be made up of only one type of waste (e.g. soil or soil-type, debris/Type 1 backfill mixtures, grouted debris, etc.).
Type 5	Packaged Waste	Packaged waste is placed in specific dedicated and prepared containment areas within each disposal cell. The dedicated areas are constructed on top of previously placed Type 1 waste, with perimeter berms constructed of Type 1 material or alternatively, forms of plywood or steel. These prepared areas will typically be limited to a maximum area of 30 m by 60 m, a 0.3 m base of granular drainage material graded at 2% towards a contact water catchment area. The berms are typically a minimum height of 1.2 m with 1H:1V side slopes. The granular base layer may also be overlain by a geogrid to provide enhanced subgrade bearing capacity and to function as a working surface for the placement of the packaged waste. Packaged wastes are placed on an individual basis using loaders or excavators, or specialized equipment (e.g. cranes) if needed. Type 1 waste is placed around the

Waste Type	Description	Waste Placement and Compaction Procedures
		packaged waste in 0.3 m lifts. Steel or metal box containers may be stacked two high, while concrete containers will not be stacked. These containers stacked two high may be placed adjacent to one another in an arranged pattern, with grout or other flowable fill material placed to reduce void space to <10%. Box containers will not be placed within 1.8 m of the primary liner system. Drummed waste containers are placed in the dedicated area using a hydraulic excavator equipped with drum handling equipment. Two layers of drums are placed in each operational lift, with the layers separated vertically by a 0.15 m thick grout layer. Drums are placed in an upright position on the prepared base, evenly spaced with no separation between adjacent drums. Rows of adjacent drums are positioned in a staggered pattern to minimize the overall footprint of the dedicated area and to minimize the void space between drums. The void space between drums will be grouted or flowable fill may be used to meet compaction requirements. Drums placed in the ECM will have a maximum of 10% void space within the container to prevent drum collapse. Packaged waste in Non-Leachate Controlled Waste Packages, compressible containers, such as bagged waste (e.g. used personal protection equipment and clothing, insulation, etc.), is handled and placed similar to Type 2 waste. Asbestos-containing materials (ACM) are to be received in packaged form and handled and placed within the ECM using debris trenches in accordance with Ontario Environmental Protection Act, Regulation 347, General – Waste Management [9-24]. The Bearing Capacity, Settlement, and Lateral Earth Pressure Analysis document, confirms the minimum separation distance and placement criteria for Type 5 waste with a sensitivity analysis included.
Type-6	Oversized debris that do not fit into Types 1 - 5	Waste placement safety analysis, approvals and procedures will be developed on a case by case basis to ensure the design basis is satisfied.

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

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

The interim cover applied to the waste disposal areas that will remain inactive for more than 30 days is removed to the extent practicable prior to further waste placement. For waste disposal areas that have reached the design waste fill grade that have an interim cover, only the sacrificial liner of the interim cover is removed prior to the installation of the final cover system.

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

As recommended in IAEA SSG-31, Monitoring and Surveillance of Radioactive Waste Disposal Facilities [9-25] waste retrieval, may be performed to reverse the action of waste placement. For the NSDF, waste may only be retrieved from a cell before the final cover is installed. Waste retrieval is not intended, nor is required, thus is not assessed in this SAR. In the unlikely event that a waste retrieval becomes necessary, a safety assessment for waste retrieval will be required prior to the retrieval activities. The assessment will be unique to the type of waste being retrieved, the volume of waste excavated, and the types of wastes surrounding the retrieval target.

9.3.3 Landfill Development and Sequencing

The design of the ECM is described in Section 5. The sequence for developing the ECM is described in the Landfill Development/Sequencing Plan [9-26].

The placement of waste in the ECM is completed in a phased approach:

- Phase 1, with total waste capacity of 525 000 m^3, accommodate waste now in storage and to be generated for a 20 to 25 year period beginning with the operations period.
- Phase 2, with total waste capacity of 475 000 m^3, expands the ECM to total capacity of 1 000 000 m^3 and allow for wastes generated through 2070.

The cell layouts for Phase 1 and Phase 2 are shown in Figure 9-1 and Figure 9-2, respectively. The following subsections describe the sequencing and construction of each phase and respective final cover systems. Cell construction is limited to the late spring, summer and early fall months to prevent damage from soft/wet ground conditions and/or freezing temperatures. Waste are accepted 12 months per year, but waste placements are only performed when the ground and temperature conditions are suitable.

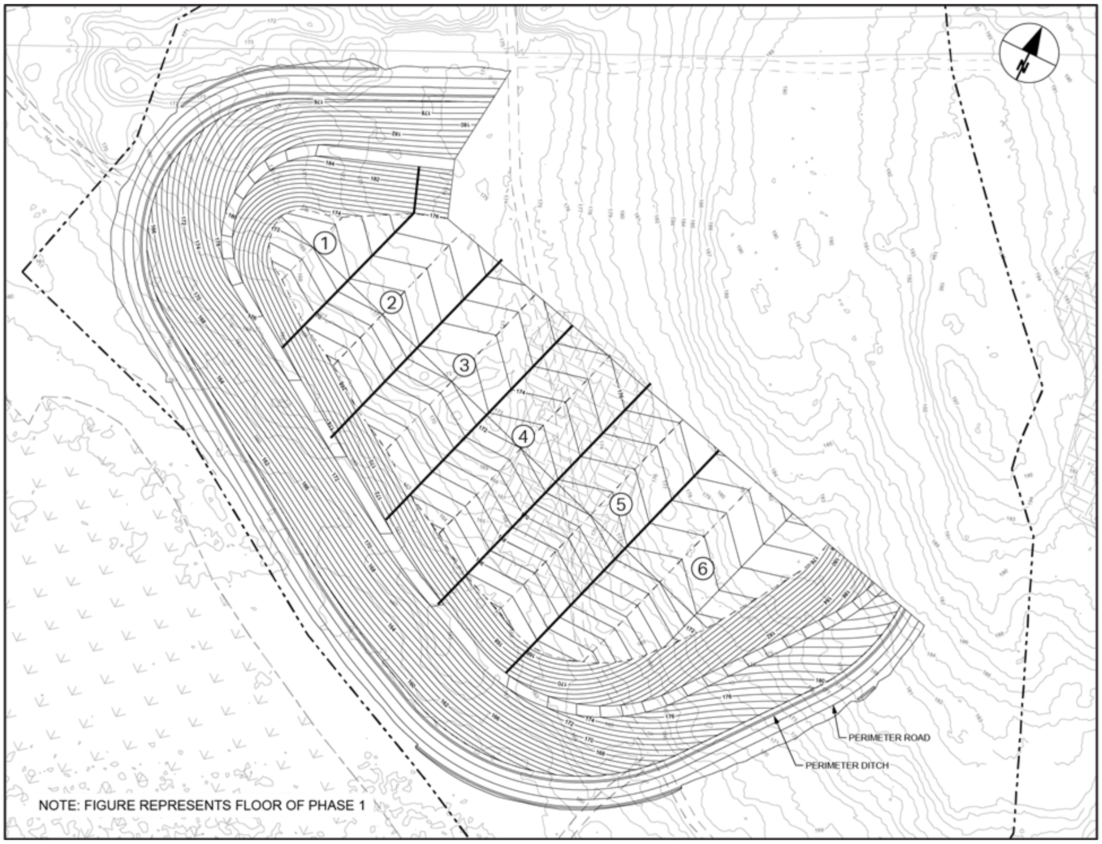

Figure 9-1 Phase 1 Cells and Sequencing Plan

Figure 9-2 Phase 2 Cells and Sequencing Plan

9.3.3.1 Phase 1 Construction

The waste placement in the ECM begins after construction of the perimeter berm and the ECM floor of Phase 1. Figure 9-1 shows, in numeric sequence, the current CNL Operations sequencing approach for the waste placement locations for Phase 1 disposal cells. The TSWRPA for open cells is within the open cell footprint. Waste are placed in each cell as described in the Waste Placement and Compaction Plan [9-22] and in Table 9-2. Toward the end of the Cell 5 waste placement, the notch in the south berm is closed to allow for the filling of Cell 6 as shown in Figure 9-3. This will allow the disposal of 525 000 m^3 of waste and will complete Phase 1 of the ECM.

The notch is left in the mound at the location of the existing EMR on the north, so that waste transport vehicles can enter and exit the mound at floor level, eliminating the need for ramps.

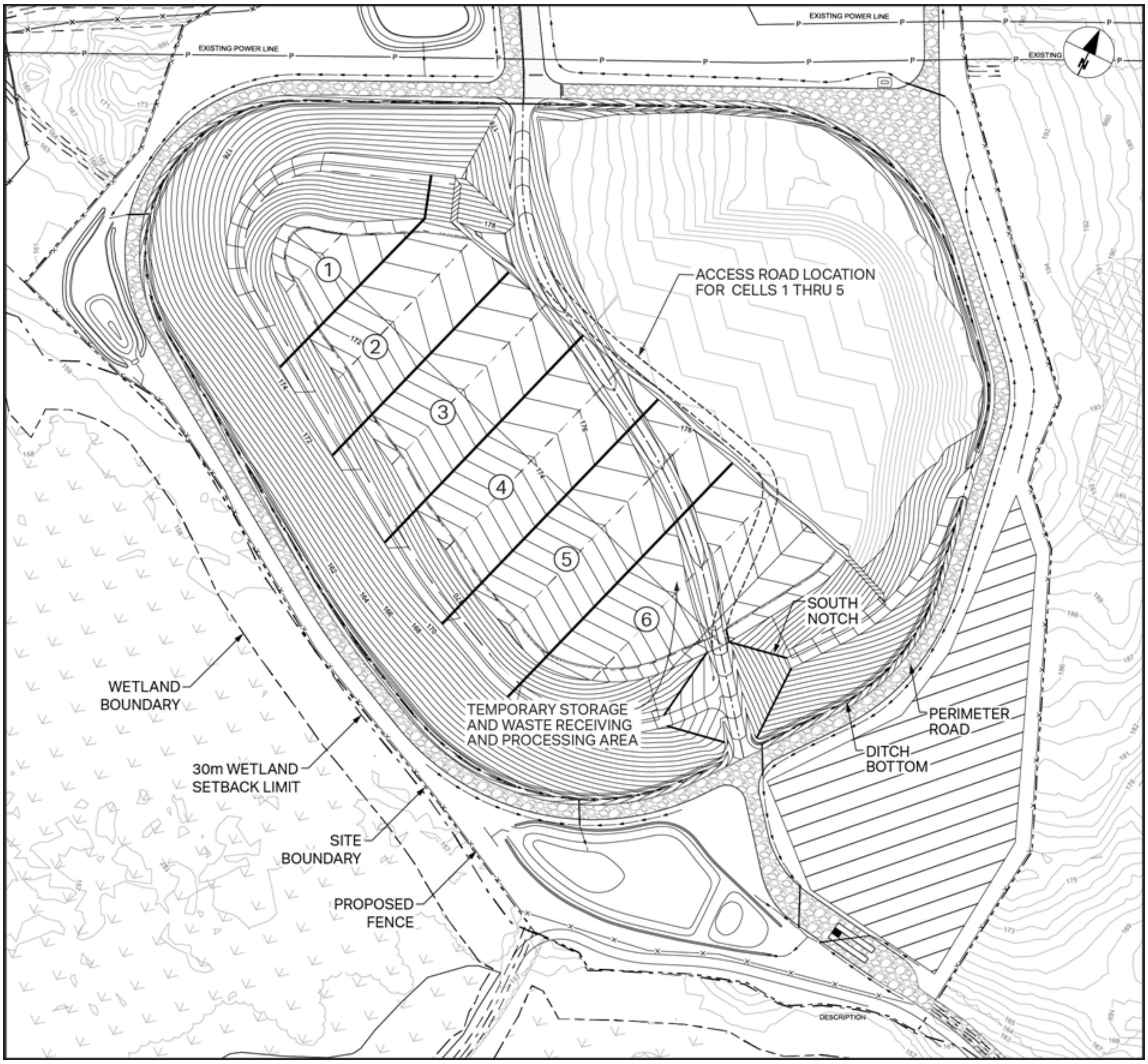

Figure 9-3 Phase 1 Plan with Notch on South

9.3.3.2 Phase 2 Construction

As waste disposal progresses in Cell 6 of Phase 1, construction should be started on the remainder of the containment berm and the floor system for Phase 2 to accommodate the full 1 000 000 m^3 of waste. The waste placement sequencing could be accomplished as shown in Figure 9-2, but likely the order will be reversed in order to move in the windward direction with waste emplacement. With this approach, delivery vehicles would enter from the South Kiosk to access Phase 2.

9.3.3.3 Phase 1 (Cells 1 through 6) Final Cover Construction

The final cover system will be placed on each cell as the waste is brought up to bottom of the final cover elevation with the placement of the 1 m select waste layer, to the cell boundary [9-26].

As waste is placed to the final upper elevation with the 1 m select waste layer, an interim cover is installed over the select waste layer. The interim cover consists of a 300 mm sand layer, first layer of the final cover system, overlain with a sacrificial liner in order to minimize infiltration of precipitation into the waste, and promote non-contact surface water run-off. When waste placement in Cell 2 reaches the southern boundary of Cell 1, the sacrificial liner of the interim cover is removed, and the remaining layers of the final cover system are placed on Cell 1. This final cover system sequencing scenario continues through all six disposal cells in Phase 1. Further detail is provided in the Waste Placement and Compaction Plan [9-22] and the Landfill Development/Sequencing Plan [9-26]. Temporary 3:1 slope disposal areas that will remain inactive for greater than 30 days, and are scheduled to receive additional waste in the future, will be covered with an interim cover.

9.3.3.4 Phase 2 (Cells 7 through 10) Final Cover Construction

Final cover system placement and sequencing for Phase 2 cells will continue with the same scenario as Phase 1, with the final cover system being placed on each cell as the waste is brought up to bottom of the final cover elevation with the placement of the 1 m select waste layer, to the cell boundary [9-26].

9.3.4 Operation and Maintenance

This section describes NSDF activities, including those associated with waste placement and compaction, landfill development and sequencing, WWTP operation, monitoring and reporting, closure, and post-closure care.

9.3.4.1 General Operations

The NSDF is expected to operate four days a week for 10 hours per day with extra shifts added to meet demands on the schedule. The WWTP is designed to operate for seven days per week with 24-hour continuous operations as needed throughout the year. The Facility Manager or designee, may halt or restrict operations during periods of inclement weather such as high winds, significant precipitation events, extreme cold periods, or inability to compact waste due to frozen conditions. In heavy snow, restrictions may include limiting the shipments of incoming waste to disposal cells or stopping non-essential activities. The application of road salt on the NSDF site is to be minimized as dissolved salt within contact water may compromise the treatment effectiveness of the WWTP systems.

Key O&M tasks are identified in Table 9-3 through Table 9-7. This provides estimates for resources, task frequency and duration.

Table 9-3
Engineered Containment Mound Operations

Key Task		Suggested Resources	Job Analysis	Duration	Reference
1	Unload bulk LLW from shipment vehicle. This includes application of daily cover.	2 Waste Technicians, 1 Mechanical Service Attendant (MSA), 1 Driver, and 1 RP staff.	Work in Radiological Safety Zone 1 on offloading ramp. Industrial hazards are covered by existing procedures. Standard personal protective equipment and clothing (PPE&C) is required. Tyvek and respirators are not required PPE&C.	Work 8 hours in a 10 h day, 4 days per week for 6-8 month season. Occasional overtime on day 5 and day 6. Work is shared by several crews.	Benchmarking – Hanford ERDF, NSDF Staffing Levels, [9-27]
2	Move and grade LLW.	2 Heavy Equipment (HE) Operators, and 1 RP staff.	Heavy Equipment Operator working within the Radiological Safety Zone 3 in the ECM inside a dozer or compactor. The worker is not using a respirator, and there is no vehicle cab air filtration system.	Work 8 hours in a 10 hour day, 4 days per week for 6-8 month season. Occasional overtime on day 5 and day 6. Work is shared by several crews.	Benchmarking – Hanford ERDF
3	Deliver material and grade clean roads within and around the ECM.	2 HE Operators, and 1 RP staff.	Heavy Equipment Operator working within the Radiological Safety Zone 3 in the ECM inside a dozer or compactor. The worker is not using a respirator, and there is no vehicle cab air filtration system.	On average work one 8 hour day once per week for 6-8 month season.	Benchmarking – Hanford ERDF

Key Task		Suggested Resources	Job Analysis	Duration	Reference
4	Packaged waste placement	1 MSA, 1 Technician, 1 Driver, 2 RP staff, 1 Millwright, and 1 Hoisting Engineer.	Half of the resources are on Radiological Safety Zone 1, clean road, and the other half of the resources are in the ECM Radiological Safety Zone 3. The PPE&C for the ECM Radiological Safety Zone 3 work includes respirator and Tyvek coveralls.	One 8 hour work day per week.	Benchmarking – Clive ES, [9-28]NSDF Staffing Levels [9-27]
5	Grouting of packaged waste	1 Civil Engineer, 1 Technician, 1 MSA, 2 Carpenters, 2 RP staff, 1 Contamination Monitor, 1 Millwright, and 1 Hoisting Engineer.	Half of the resources are on Radiological Safety Zone 1, clean road, and the other half of the resources are in the ECM Radiological Safety Zone 3. The PPE&C for the ECM Radiological Safety Zone 3 work includes respirator and Tyvek coveralls.	Work 8 hours in a 10 hour work day and 2 days per month for 6-8 month season.	Benchmarking – Hanford ERDF [9-27]

Table 9-4
Engineered Containment Mound Maintenance

Key Task		Suggested Resources	Job Analysis	Duration	Reference
1	Repair/ maintain cell and side slopes	1 Civil Engineer, 1 Technician, and 2 HE Operators.	2 HE Operators operating machinery on clean fill within ECM.	2 days per month during 6-8 month season.	Benchmarking – Pembroke OVWRC
2	Repair/ maintain cell cover	1 Civil Engineer, 1 Technician, 1 HE Operator, and 2 MSA for grass cutting.	Grass maintenance on final cover to monitor for burrowing animals. Repairs as required due to washout and burrowing animals.	1 day per week during 6 month season.	Benchmarking – Hanford ERDF
3	Repair/ maintain berm condition	1 Civil Engineer, 1 Technician, 2 HE Operators, and 2 MSA for grass cutting.	Work on the ECM perimeter berm	2 days per month during 6-8 month season or after severe weather.	[9-29]
4	Repair/ maintain ECM equipment	1 Mechanic, 1 HE Operator, 1 RP staff, and 1 Contamination Monitor.	Work under a temporary shelter on a designated pad within an open cell. Perform gross decontamination of machinery and repair.	1 day per week during 6-8 month season.	Benchmarking – Hanford ERDF
5	Leachate piping water jetting	1 Technician, 2 MSA, 2 RP staff, and 1 Driver.	Work from top of the perimeter berm to operate equipment within the LCS and LDS.	30 hours each worker for 2 weeks each year.	Benchmarking – Hanford ERDF
6	Leachate extraction box and leachate sump sediment clean out	1 Supervisor, 2 MSA, 2 RP staff, and 1 Driver.	5 leachate extraction boxes and leachate sumps are cleaned out and sediment is removed annually, using a vacuum truck.	Approximately 2-3 hours per leachate extraction box.	Benchmarking – Hanford ERDF
7	Maintain	1 Supervisor,	5 sumps, pumps	10 pumps serviced	Benchmarking

Key Task		Suggested Resources	Job Analysis	Duration	Reference
	submersible LCS and LDS plumps	2 MSA, 2 RP staff, 1 Millwright, 1 Electrician, and 1 Instrument Mechanic.	likely maintained in conjunction with task 6.	by Millwright, Electrician and Instrument Mechanic for 2 days per pump once per year	– Hanford ERDF

Table 9-5
Waste Water Treatment Plant Operations

Key Task		Suggested Resources	Job Analysis	Duration	Reference
1	Operator interface with WWTP SCADA System	1 Technician.	Occupy Radiological Safety Zone 2 control room to ensure that control room is continuously manned (i.e. staggered breaks, lunch coverage). SCADA interaction – Alarms can only be acknowledged in the control room.	Work 8 hours in a 10 hour work day, 4 days per week for 6 - 8 month season. Over time on day 5 and day 6. Work shared by several crews.	Human Factors Verification and Validation Report [9-30]
2	Test samples in lab	1 Lab Supervisor, and 1 Lab Technician	Work in Radiological Safety Zone 2 laboratory. Prepare and analyze samples of wastewater at various points in the treatment process. Radiological Safety Zone 3, fume hood with active exhaust is available.	Work 8 hours in a 10 hour work day, 4 days per week for 6 - 8 month season. Occasional over time on day 5 and day 6. Work shared by several crews.	Benchmarking – Knoxville Perma-Fix
3	Annual cleaning of Equalization Tanks and removal of sediment	1 Supervisor, 2 MSA, 2 RP staff, and 1 Driver.	3 tanks, 1 removed from service for one week per year. 2 MSA and 1 RP staff enter the tank to clean using a	Work internal to tank for 36 man hours for each tank (2 days, 3 hours per entry and 2 entries per day).	[9-27]

Key Task		Suggested Resources	Job Analysis	Duration	Reference
			vacuum truck.	Operating de-watering for 36 man hours each tank.	
4	Residuals Handling in the WWTP – GAC change out	1 Supervisor, 1 Technician, 2 MSAs, and 2 RP staff.	Estimated 17 m^3/year or 9 column changes per year. Vessel is dewatered and capped. Void space is grouted and the vessel can be disposed in ECM.	1 Technician, 2 MSAs and 2 RP staff working <1 m from vessel for 6 hours for each change out.	[9-31] and [9-27]
5	Residuals Handling in the WWTP – IX change out	1 Supervisor, 1 Technician, 2 MSAs, and 2 RP staff.	Estimated 30 m^3/year or 15 column changes per year. Vessel is dewatered, resin is transferred to a waste container. Void space is grouted or stabilized and the vessel can be disposed in ECM.	1 Technician, 2, MSAs and 2 RP staff working <1 m from the vessel for 6 hours for each change out.	[9-31] and [9-27]
6	Residuals Handling in the WWTP – De-watered Residuals Handling	1 Supervisor, 1 Technician, 2 MSAs, 2 RP staff, and 1 Driver.	Operate filter press in Radiological Safety Zone 3, store residuals in 1 m^3 tote, characterize and transport to ECM for disposal. Estimated waste volume 42 m^3/year.	Weekly, 1 RP staff and 1 Technician work in Radiological Safety Zone 3 for 6 hours, disposal in ECM is covered in off-loading ramp operations	[9-31] and [9-27]
7	Manage membrane filtration CIP process	2 Technicians, and 1 RP staff.	Operating closed system, clean membrane filter with 93% sulphuric acid.	Once per week per operating train and cleaning solution is used three times before it is changed.	[9-31] and [9-27]
8	WWTP Precipitation	1 Technician, 1 MSA,	Open process system, clean	Technician, MSA and Pipefitter in	[9-31]

Key Task		Suggested Resources	Job Analysis	Duration	Reference
	Membrane cleaning	1 Pipefitter, and 2 RP staff.	membrane twice per year for each train. Use sodium hypochlorite and sodium hydroxide and remove residual chlorine with sodium bisulphite. PPE&C for temporary Zone 3 work includes respirator and Tyvek coveralls.	close proximity to open system for 6 hours for each of four occasions.	

Table 9-6
Waste Water Treatment Plant Maintenance

Key Task		Suggested Resources	Job Analysis	Duration	Reference
1	Service/ Replace Heaters	1 Technician, 1 Electrician, and 1 RP staff.	Work in Radiological Safety Zone 2. Routine maintenance on open system.	Assume all workers perform Table 9-6 activities all year at 40 hours per week as a maintenance crew.	Human Factors Verification and Validation Report [9-30]
2	Replace Level Sensors	1 Instrument Mechanic, 1 Technician, and 1 RP staff.	Work in Radiological Safety Zone 2. Routine maintenance on open system.	see above	Human Factors Verification and Validation Report [9-30]
3	Service motor and instrumentation	1 Electrician, 1 Instrument Mechanic, and 1 RP staff.	Routine maintenance work in Radiological Safety Zone 2.	see above	Human Factors Verification and Validation Report [9-30]
4	Clean and Inspect Tanks	2 Technicians, 2 MSA, 1 Pipefitter, and 1 RP staff.	Routine maintenance work in Radiological Safety Zone 2. May incorporate temporary Radiological Safety	see above	Human Factors Verification and Validation Report [9-30]

Key Task		Suggested Resources	Job Analysis	Duration	Reference
			Zone 3.		
5	Service Mixer Assembly	1 Technician, 1 MSA, 1 Millwright, 1 Pipefitter, and 1 RP staff.	Routine maintenance work in Radiological Safety Zone 2. May incorporate temporary Radiological Safety Zone 3.	see above	Human Factors Verification and Validation Report [9-30]
6	Maintain building systems under Preventative Maintenance Program	1 Technician, 1 MSA, 1 RP staff. All trades listed above.	Routine maintenance work in Radiological Safety Zone 2.	see above	Human Factors Verification and Validation Report [9-30]

Table 9-7
Leachate Collection and Monitoring

Key Task		Suggested Resources	Job Analysis	Duration	Reference
1	Monitor level in contact water and non-contact water ponds	1 Technician, 1 MSA, and 1 RP staff.	Inspect all collection ponds and manually take level measurements.	Twice weekly or after severe weather.	-
2	Pump out contact water pond within an open cell to the Leachate Extraction Boxes	1 Technician, 2 MSA, 1 RP staff, and 1 HE Operator.	Install pumps in the contact water pond with an excavator. Three workers within an open cell and remainder of workers outside of the disposal cell on the berm.	2 days per month during 6-8 month season.	-
3	Construct internal berms and new collection ponds within the ECM.	1 Technician, 2 MSA, 1 RP staff, 2 Drivers, and 2 HE Operators.	Workers in an unopened cell working adjacent to a cell with waste.	5 days during 6-8 month season.	-
4	Pump out	1 Technician,	Workers in an open	5 days during 6-8	-

Key Task		Suggested Resources	Job Analysis	Duration	Reference
	contact water ponds, remove sediment for de-watering and dismantle old ponds as waste placement progresses.	2 MSA, 1 RP staff, 2 Drivers, and 2 HE Operators.	cell near floor level working to remove a contact water pond. For half of the work, the workers would be able to work from the clean side of internal berm.	month season.	

Cell construction is limited to the late spring, summer and early fall, to prevent damage from soft/wet ground conditions and /or freezing temperatures. Facility staff are present at the WWTP during operations.

Following a heavy rainfall event, ECM personnel will check culverts and storm water ponds for debris. If the on-site gauge records 3 cm of rainfall in a rainfall event, personnel will inspect ECM drainage structures and cover areas for erosion.

Dust control measures are defined for the construction and operations phases in the Dust Management Plan [9-23] and documented in more detail in Section 9.3.4.2. During the Operations Phase, exposed waste that has been placed in the ECM will be covered as soon as practical during operations and as a general rule will not be left uncovered, especially during high winds. Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face, to control the release of fugitive dust from the surface of the waste. Operations will be halted in dust prone areas when sustained wind speeds exceed 40 km/h for more than two hours, unless it can be demonstrated that the work site is sufficiently protected so that wind will not generate dust.

The Facility Manager has the discretion to suspend bulk waste disposal operations when the ground temperature prevents proper waste compaction. This low temperature suspension applies only to the disposal of soil and soil-like waste.

In the event of heavy snow, the ECM Supervisor will determine if it is necessary to modify or temporarily suspend operations, until snow removal on access roads and in the disposal areas permit continued operation. Restrictions to operations may include:

- Limiting the shipments of incoming waste to disposal cells.
- Stopping non-essential earthwork or other non-essential operational activities.

A comprehensive operating manual will be developed in accordance with CNL requirements [9-32], prior to the start of NSDF operations.

The operating manual will be developed based on the information in the O&M Plan [9-33]. The manual will include operating procedures for waste placement, daily cover and interim cover placement, leachate collection and LDS, contingency plans, and radiation monitoring. A complete listing of anticipated procedures is included in the O&M Plan [9-33].

9.3.4.2 Dust Controls

The approach to managing fugitive dust emissions follows the Dust Management Plan [9-23] and best management practice guidance is provided in Management Approaches for Industrial Fugitive Dust Sources [9-34].

Dust controls methods will be implemented during NSDF operations [9-23] as required to meet specified criterion. Use of water spraying or misting techniques (e.g. water trucks) will be the primary dust control method including:

- Water is applied to roads to minimize dust generation on NSDF haul roads and ECM access roads using a water truck or other method as needed.
- Dampening soil in dry areas prior to commencing truck/machinery activities in the area.
- Water is applied to the stored waste to mitigate dust emissions.

If water spraying or misting techniques are insufficient or not optimal to control dust to meet the specified criterion, the following guidelines will be used instead of or to supplement water spraying and misting techniques:

- Approved chemical agents are applied to the stored waste to mitigate dust emissions. A tarp or fabric cover may be used or the material may be stored within a sheltered area to prevent dust generation.
- Limit the material/waste fall distance.
- Limit the size of the disposal cell working face.
- Dust suppression of the inactive surfaces of the ECM and surrounding support areas.
- Restrict or postpone work activities that are likely to cause dust if sustained wind speeds are predicted to exceed 40 km/h, unless the work activity can be shown to be sufficiently protected, such that wind will not generate unacceptable amounts of dust. Operations will be restricted or shut down during sustained wind speeds of 40 km/h as registered by the on-site wind gauge, or if visible dust plumes are observed on-site.
- Restrict or limit vehicle access to the ECM and NSDF site.
- Use of fixatives (e.g. chemical suppressant) for dust control.
- Covering stockpiles and exposed areas with tarps or fabric covers prior to high wind or dry conditions where standard dust suppressants may be inadequate in preventing dust generation caused by wind erosion.
- Minimizing the size of the exposed working areas containing contaminated materials to the extent practicable using a phased excavation approach. Limit the size of the disposal cell working face.

- Revegetating affected areas or adding mulch to completed cells and excavated areas as soon as practicable.
- Reducing activities to avoid unnecessary dust generation.
- Restrict or limit vehicle access to the ECM and NSDF site.
- Use wind fencing around work areas.

9.3.4.2.1 Chemical Dust Suppressants

The selection of a suitable dust suppressant is based on Ontario Provincial Standard Specification (OPSS) 506, Construction Specification for Dust Suppressants [9-35]. Additionally, dust suppressants must be compatible with the ECM engineered barriers and the wastewater treatment processes.

Specific to water run-off, the following requirements are to be followed:

- Applications shall not proceed during periods of rain when the surface is in a saturated condition or on areas of ponded water.
- Applications shall not proceed when weather forecasts indicate a high probability of rainfall.
- If used, calcium chloride and magnesium solutions/concentrations shall follow the specifications in OPSS 2501 [9-36] and OPSS 2503 [9-37].
- All surface water run-off shall be monitored for discharge criteria.

9.3.4.3 Monitoring and Reporting

Leak detection, leachate collection, environmental monitoring and effluent monitoring will be performed as described in the Environmental Protection Plan [9-38]. Monitoring actions and contingency responses for leachate, wastewater, groundwater, surface water, and LFG are specified in the Contingency Plan for Leachate, Wastewater, Groundwater, Surface Water, and Landfill Gas [9-39] and in the CNL Environmental Protection Program [9-40].

Leachate from the LDS leachate sump is pumped via riser pipes up the ECM side slope to HDPE leachate extraction boxes located on the crest of the perimeter berm and then conveyed to the WWTP Equalization Tanks. Samples are collected from the riser pipes adjacent to the LCS and LDS leachate extraction boxes. These riser pipes run from the LDS and LCS leachate sumps in each cell to their respective leachate extraction boxes on the perimeter berm. The LCS and LDS are monitored with continuous depth measurements through pressure transducers located inside the LCS/LDS leachate sump. The volume of leachate removed from the leachate sumps is recorded continuously by a flow totalizer on the leachate sump discharge line.

As per the Monitoring and Reporting Plan [9-41], baseline values and response actions for LCS leachate flowrates and contaminant concentrations, will be established during the first two years of operations after initial waste placements in the ECM. For releases of treated wastewater from the WWTP, effluent will be tested along the processing train to build confidence that the effluent discharge targets, release criteria will be met.

Leachate conveyance system components are inspected on a weekly basis, or more frequently if needed. This includes monitoring and recording liquid levels in the Equalization Tanks; measuring and recording readings for flow totalizers; measuring leachate levels in the LCS and LDS leachate sumps; testing alarms; and evaluating evidence of possible trends in leachate production rates.

Each leachate sump and removal system provides a method for measuring and recording the volume of liquids present in the leachate sump and of liquids removed. The ECM LCS employs pressure transducers to measure the depth of the liquid in the leachate sumps as an indirect method of determining the volume, and to activate the leachate sump pumps to remove the accumulated leachate. A correlation will be derived between the leachate sump depth and volume for each sump. The actual volumes removed from each collection sump are measured and recorded by a flow totalizer meter on each pump's discharge line.

Surveillance will be performed including inspecting the condition of pumps/pumping components and periodically cycling the pumping systems to help minimize clogging potential.

Following a precipitation event greater than 3 cm, run-on/run-off controls and proper operation of leachate pumps will be verified. Results of the inspections and surveillance are documented.

Quantities of leachate removed from the LCS and LDS sumps and time series records of levels of leachate in the leachate equalization storage tanks, are documented and maintained.

Assessment and reporting procedures are listed in the O&M Plan [9-33]. These will be developed and approved by CNL prior to the start of operations at the NSDF.

A summary of major monitoring activities to be performed at each lifecycle phase is shown in Table 9-8 [9-41]. The monitoring activities during the ICP, have been included in Table 9-8 for completeness.

Table 9-8
Summary of Major Monitoring Activities at the Near Surface Disposal Facility

Description	Operations (50 y)	Closure (30 yrs)	Institutional Control (300 y)
Meteorological Data Collection - (precipitation, temperature, evaporation, transpiration, wind speed and direction, atmospheric stability)	Data acquired on a monthly basis to determine water balance.	Data acquired on an annual basis to track water balance and determine local changes to hydrogeologic and climatological processes.	Data acquired on an annual basis to track water balance and determine local changes to hydrogeologic and climatological processes.

Description	Operations (50 y)	Closure (30 yrs)	Institutional Control (300 y)
Stability and Structural Performance Monitoring			
Settlement / Subsidence Monitoring	Settlement plates will be installed on top of the final cover system as the cover is constructed. In addition, interim settlement plates will be installed on the backfill between the final lifts to observe settlement during operations.	Permanent settlement plates installed on top of the final cover system will continue to be monitored annually for subsidence to the final cover system.	Permanent settlement plates installed on top of the final cover system will continue to be monitored every two years.
Vertical alignment monitoring	Interim monument pins will be installed at the top of the lifts, and will be surveyed monthly to establish a baseline and monitor potential vertical displacement. Variations outside of acceptable results will invoke remediation.	The vertical alignment monitoring will not be required once the disposal cells are closed. The monitoring pins will be abandoned in place and vertical alignment monitoring will cease after closure.	Not required after closure.
Surface Surveillance/ Visual Monitoring			
Visual Inspections	Visual Inspections will be performed semi-annually and after severe weather events to ensure haul roads, ditches, fence lines and other areas are clean, sound, and functional.	Visual inspections will continue on an annual basis and following severe weather events to ensure fence lines are clean and functional and erosion is minimized.	Visual inspections will occur once every two years or following severe weather events and inspect surfaces for erosion.
Drainage/Diversion Channels	Particular attention will be focused on drainage channels and diversion ditches to ensure that stormwater flows away from the disposal cells, that outfalls are kept clean and free flowing, and that riprap and other corrective actions are added in evidence of scouring or erosion in channels.	Visual inspections will occur once every two years or following severe weather events.	Visual inspections will occur once every two years or following severe weather events.

Description	Operations (50 y)	Closure (30 yrs)	Institutional Control (300 y)
General Visual Inspections	Visual inspections of the facilities will ensure that required routine maintenance is scheduled and performed. Maintenance will be conducted to remove deep-rooted vegetation from undesired areas, clean up litter and other debris on-site, remove burrowing animals from the site, inspect fence lines, ensure proper operation of gates, and visually inspect monitoring points for proper operation. The LFG passive venting system will be inspected. Photographs of pertinent features will be documented. These will occur monthly.	Visual inspection of the disposal cells will be performed to ensure settlement/subsidence is not causing localized grade reversal or depressions in the final cover, litter is removed, burrowing animals are not present, and perimeter fence lines are intact and properly maintained. The LFG passive venting system will be inspected. A review of historic photographs of pertinent features or problems will be conducted to assist in the inspection. These will occur quarterly.	Visual inspection of the disposal cells will be performed to ensure settlement/subsidence is not causing grade reversal or depressions in the final cover, burrowing animals are not present, and perimeter fence lines are intact and properly maintained. The LFG passive venting system will be inspected. These will occur semi-annually.
Infiltration Monitoring	Infiltration measurements will be conducted on completed cells with final cover to ensure that the cover is operating correctly. Infiltration monitoring will consist of neutron moisture probes being placed in the cover system to measure water content and suction pressures in the cover. In addition, meteorological data will be acquired on the final cover surface to provide an estimate of the amount of water that could potentially infiltrate into the final cover system.	Moisture probes will be removed or abandoned in place during closure of the Facility and infiltration will no longer be monitored if there is adequate confidence in the long-term infiltration rate. It is anticipated that over the 50 year period of operations adjustments to the final cover will be made as required from the data collected during operations that will ensure the cover functions as required. Records of meteorological data will be reviewed on an annual basis to ensure that the final cover system is not overloaded in any post-operational year.	Records of meteorological parameters will be reviewed on an annual basis to ensure that the final cover system is not overloaded in any post-operational year.
Leachate Monitoring			

Description	Operations (50 y)	Closure (30 yrs)	Institutional Control (300 y)
Leachate Collection Piping	Leachate collection sumps are constructed at the lowest elevation to ensure any leachate is collected at this point. During operations leachate is collected from the cells and conveyed to the Equalization Tanks for treatment.	The leachate collection piping will be monitored on a monthly basis to verify the proper performance of the cover system. When and if leachate is detected in the disposal unit, it will be analyzed for radionuclides and disposed of appropriately. If necessary, further investigation will be conducted to pinpoint the location of potential problems.	Continued quarterly monitoring of the leachate collection piping and system will ensure the Facility is functioning properly. The monitoring frequency may be reduced in subsequent years based on previous results. Inspection and monitoring of the LCS and LDS will be performed as long as leachate is generated.

9.3.5 Closure

Closure of ECM cells will be performed as an ongoing process, with phased closing of cells as landfill development progresses. An interim cover will be installed when the disposal cell is filled with waste, and the waste disposal area has reached the design waste fill grade. The final cover system will be installed when a sufficient extent of interim cover is present and the cell has reached the design waste fill grade. After installation of the final cover over these closed portions of the ECM containment area, the cover will be maintained for the remainder of the Operations phase.

Final decommissioning and closure of the site will include demolition and removal of surface structures, modification of surface water and erosion controls, installation of the final cover system over remaining open portions, and installation of permanent markers.

Decommissioning of the WWTP and associated structures will be performed after it is determined that leachate quantity no longer requires a dedicated WWTP at the NSDF site and is able to be sent to an alternate Facility.

Following closure of the ECM, the final cover system will be vegetated to provide an aesthetically pleasing surface, enhance evapo-transpiration and reduce the potential for erosion.

The NSDF Closure Plan [9-42], additionally specifies actions to be undertaken in the event of temporary cessation of ECM operations (i.e. lay-up). This includes considerations to ensure that the base liner termination in unfilled cells is protected from damage due to equipment traffic, freeze-thaw processes, erosion from surface water flows, and infiltration or other environmental or mechanical processes.

9.4 Engineered Containment Mound

The ECM is a double-lined near-surface waste disposal Facility designed for the disposal of LLW that meet the NSDF WAC [9-7]. A multi-layer final cover system is installed over the placed waste upon completion of disposal operations in each waste cell. The ECM is located within a CA and is designed for 50 years of operations and 550 years design life.

9.4.1.1 Engineered Containment Mound Equipment

Equipment associated with the ECM includes operating equipment used for waste placement and ECM construction, as well as equipment used in the LDS, LCS and contact water and non-contact water conveyance systems. Anticipated operating equipment identified for ECM operations are found in the O&M Plan [9-33].

The LCS and LDS include pumps for transferring leachate to a containment box at the top of the containment berm. These pumps have level control instrumentation such that pumps operate when leachate is above a specified level.

9.5 Contact Water and Non-Contact Water Conveyance

Non-contact water is diverted away from waste such that the water does not come in contact with the waste. Contact water has come in contact with the waste and is collected in the contact water pond, pumped to the CWPS #1, then to Equalization Tanks and to the WWTP for treatment, as shown in Figure 9-4.

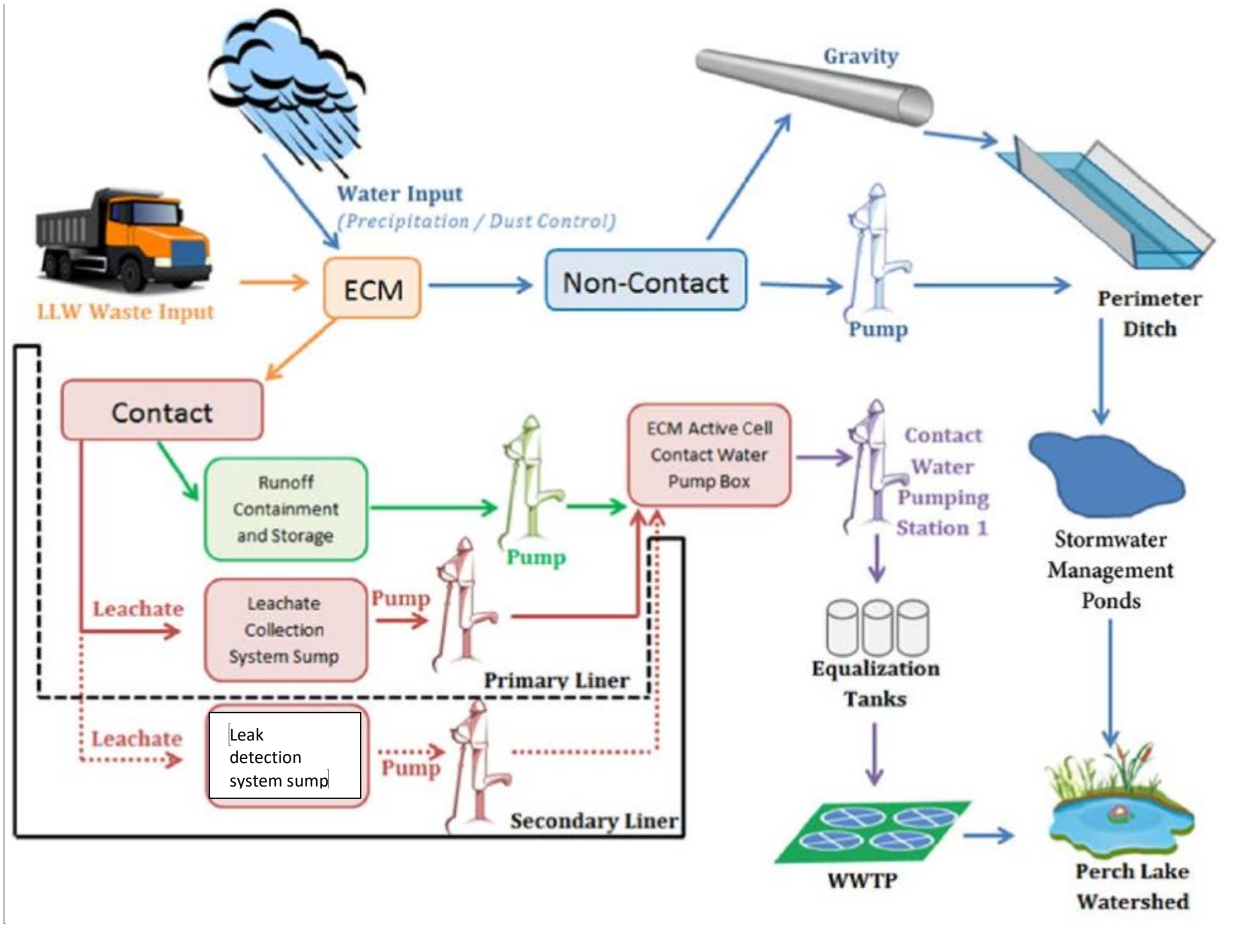

Figure 9-4 Contact Water and Non-Contact Water Conveyance

9.6 Waste Water Treatment Plant

The WWTP includes a dual-process train system (described in Section 5.2) for treating NSDF generated wastewater from the following sources:

- ECM leachate.
- ECM contact water.
- Decontamination water from VDF.
- Laboratory wastewater.
- Wastewater generated during WWTP operations including recycle flow.

The WWTP can be operated in two discharge modes: a batch discharge mode and a continuous discharge mode. In the batch mode, a sample is taken and analysed to confirm the final effluent quality before the effluent is released. In the continuous mode, effluent composite samples are taken during discharge for subsequent confirmatory analysis of the effluent quality. Additionally, samples taken after key process steps (e.g. precipitation), will be analysed to provide early indication of abnormal process conditions that could affect effluent quality to allow remedial action to be taken prior to discharge of the potentially affected effluent.

During active commissioning and initial operations, the WWTP will be operated in a batch mode to demonstrate that the treatment systems are producing water that meets the effluent discharge targets. Once confidence in the treatment systems has been established, the WWTP would normally be operated in continuous discharge mode.

Secondary radioactive waste generated from the WWTP (e.g. spent polishing media, residuals, sludge from Equalization Tanks, etc.), would be dewatered (if required), and disposed in the ECM.

9.6.1.1 Filter Press

After applying the pre-coat that enhances residuals de-waterability, the filter press is filled with residuals from the filter press feed tank, gradually building the pressure in the filter press to approximately 690 kPa. When the rate of filtrate drops below the desired level, the filter press operation is stopped, and any residuals that remain in the feed line are pneumatically discharged back into the residuals storage tank.

The filter press plates are opened to allow dewatered residuals that have formed between the filter press plates and cloths to drop into the dewatered residuals bin located below the filter press. Optional styles of dewatered residuals bins that are compatible with the filter press operation, including a B25 box, or a soft-sided container. The soft-sided container is positioned in a collapsible frame located beneath the filter press during de-watering and discharge of dewatered filter cake. De-watered residuals are transported in the dewatered residuals bin to the ECM for disposal.

Based on the results of the pilot scale test, it is expected that the dewatered residuals will have a solids content in excess of 30%, with a density of 1 390 kg/m^3. The filter press is specified to achieve minimum dewatered cake solids of 30%.

9.6.1.2 Spent Polishing Media

Spent media from GAC and IX vessels are sluiced from the vessel into a disposal container. The vessel is isolated from the process flow by closing valves on the inlet and discharge of the vessel. A connection is made between the vessel and disposal container, and the vessel's sluice valve is opened. Service water is applied to the vessel through the effluent internals to slightly fluidize the media bed. When the media has become fluidized, compressed air is applied to the vessel influent valve from the plant air system. The compressed air pressure is throttled to maintain an even flow of media from the vessel to the disposal container, and additional service water is applied as necessary to maintain a slurry. After all spent media has been removed from the vessel, application of service water and compressed air is alternated to completely clean the vessel of spent media. Compressed air is applied at the end of the spent media transfer operation to remove any remaining water.

Fresh media is transferred to the vessel after removal of spent media. The media change-out can be performed with the vessel in-place, or the vessel can be moved to another location in the polishing treatment area for the media change-out. Moving the vessel to a different area would allow the vessel to be immediately replaced with a standby vessel, such that treatment can continue with minimal interruption. De-watering liquid and water used to wet and prepare the fresh media is discharged to the trench drain located in the polishing treatment area.

After slurrying, the spent IX resin or GAC into the container, most of the free liquid is pumped from the container using an air operated diaphragm pump. The pump removes liquid through de-watering laterals equipped with fine strainers to keep the media within the container. After removal of the bulk fluid, a high velocity vacuum is applied to the container to remove remaining free liquid to less than 1%. The high velocity vacuum operation can be repeated if the container is stored for a longer period and additional removal of free liquid is required. After de-watering, any remaining void space in the container would be grouted prior to disposal in the ECM.

9.7 Inspection, Monitoring and Surveillance

The inspection, monitoring and surveillance of the NSDF was prepared following the guidance and requirements defined in Monitoring and Surveillance of Radioactive Waste Disposal Facilities [9-25]. The inspection, monitoring and surveillance of the NSDF is a requirement to confirm that the NSDF is performing as expected.

The proposed periodic inspection and testing requirements is provided in Table 9-9 [9-43] for the ECM, civil structures, WWTP, and Support Facilities. Table 9-9 is representative of the major systems and components that require inspection and testing in accordance with the system O&M manuals and CNL requirements. The system O&M manuals include a complete and detailed listing of the inspection, maintenance, and testing requirements.

Records from Inspection and Maintenance activities shall be maintained and findings/yctions from these activities shall be formally tracked. Records of these inspections are maintained and abnormal observations are promptly reported to the NSDF Facility Manager, and the EnvP Program. Repairs to facilities and fences are conducted as required.

Table 9-9
Inspection, Monitoring and Surveillance

Element	System/Component	Requirement	Proposed Frequency
ECM	LCS perforated pipe / cleanout risers	Video inspection and jet flushing	Annually
ECM	LCS risers	Visually inspect pump risers	During pump replacement
ECM	LDS risers	Visually inspect pump risers	During pump replacement
ECM	Cell and waste side slopes	Visually inspect for erosion and instability	Daily

ECM	Daily cover	Visually inspect following placement	Daily
ECM	Interim Cover(s)	Visually inspect for integrity and deterioration.	Daily
ECM	Cell final cover (once installed)	Visually inspect for differential settlement, erosion, animal burrows, vegetation distress and general stability	Annually
ECM	Cell final cover (once installed)	Inspect for differential settlement (topographic survey)	Annually
ECM	Perimeter Berm condition	Visually inspect for erosion and instability	Daily
ECM	Non-contact water ponds	Visually inspect condition of geomembrane liner	Daily
ECM	Haul vehicles and ECM equipment	Inspect daily (or prior to operation)	Daily
Civil	Contact Water Pump Stations 1 and 2	Inspect chambers for leakage, and pressure gauges for correct operation	Monthly
Civil	Contact water and final effluent pipelines - integrity of interstitial spaces	Pressure test the interstitial space per manufacturers recommendations	Five years
Civil	Contact water force main leak detection ports	Visual inspection for leakage.	Monthly
Civil	Surface Water Management Ponds	Visual inspection of ponds and sampling	Monthly (March November), and after significant precipitation events
WWTP	All tanks, equipment and instruments	Perform manufacturer required inspection and testing	As required by manufacturer
WWTP	All tanks, equipment and instruments	Comply with applicable codes and standards	As required by codes and standards
WWTP	Equalization Tanks	Drain and visual inspection every five years	Five years
WWTP	Chemical feed systems (tanks and containment systems)	Visual inspection for leaks around tanks. Check leak traps on containment pipes	Weekly
WWTP	Chemical precipitation, residuals, final effluent, membrane filter feed tanks	Cleanout and inspection	Yearly
WWTP	Instrumentation: pH probes	Remove from service and calibrate	Bi-weekly

WWTP	Chemical precipitation and pH adjustment tanks	Inspect mixer operation Lab verification of pH and solids concentrations	Weekly
WWTP	Membrane filters	Visual inspection for leakage around membrane modules	Daily
WWTP	Membrane filters	Module integrity test/flow rate/pressure drop	Weekly
WWTP	Filter press	Visual inspection for plate seal wear/leakage	Weekly
WWTP	Treated effluent composite sampler	Check operation	Daily (during discharge)
WWTP	GAC and IX vessels	Pressure drop reading	Weekly
WWTP	GAC and IX vessels and filter cake bin	Check radiation levels at tank and bin surface	Weekly
WWTP	HEPA Filters	Inspection and Testing	As per RP
WWTP	Effluent force main leak detection ports	Visual inspection for leakage.	Weekly
General	Instrumentation: Flow meters air and water, temperature, pressure)	Recalibration	Annually
General	Components Safety Classified Systems	Testing	Monthly
General	Pressure and temperature gauges	Inspect reading compare to SCADA value or alternative	Quarterly
General	Piped system valves	Exercise valves that are not cycled on a regular basis	Yearly
General	Pressure boundary systems	Visual and non-destructive testing	3 years
General	Pressure relief valves	Manual lift test	Annually
Support Facilities	Fire detection systems	Testing and verification	Monthly/Annually
Support Facilities	Emergency lighting	Testing and verification	Annually
Support Facilities	Fire protection systems	Testing and verification	Monthly/Annually
Support Facilities	HVAC filters	Inspection	Monthly
Support Facilities	HVAC equipment	Inspection	Monthly/Quarterly
Support Facilities	Emergency generator	Inspection Load Testing	Monthly/Annually
Support Facilities	Portable fire extinguishers	Inspection	Annually

Support Facilities	Gas-fired equipment	Inspection	Annually
Support Facilities	Electrical switchgear and switchboards	Thermal inspection	Annually (peak load period)
Support Facilities	Radiation monitors	Inspection and testing	Quarterly
Support Facilities	Lighting systems	Visual inspection (blown lamps) and operational checks	Quarterly
Support Facilities	Backflow preventers	Testing and verification	Annually

9.7.1 Daily

Daily inspections are performed during normal working hours and are not performed on weekends, statutory holidays and plant shutdowns. In addition to Table 9-9, the following daily inspections are performed.

Daily radiological monitoring are conducted for NSDF and include the inspection of the roadways, TSWRPA, and ECM disposal cells. The results of the survey are compared to the NSDF Radiation Level Map and the NSDF Radiation Level Map shall be updated if any differences are identified.

Inspection of the waste stored in TSWRPA with particular attention paid to any evidence of deterioration that could indicate potentially unsafe or deteriorating conditions.

Inspection of the interim covers for integrity and deterioration.

Inspection of the sacrificial liners for integrity and deterioration.

9.7.2 Monthly

In addition to Table 9-9, the following monthly inspections are performed.

Visual inspection of the NSDF site including the perimeter fence for erosion, subsidence, fence penetrations or any other abnormal conditions, with particular attention paid to any evidence of deterioration that could indicate potentially unsafe or deteriorating conditions.

The surface water management ponds shall be sampled and monitored for increased sedimentation, monthly during the timeframe of March to November, and after significant precipitation events. During excavation and blasting (when additional groundwater flow is expected) and during larger storm events (when TSS levels are expected to be higher than normal), the SWMPs should be monitored for increased sedimentation and cleanout undertaken, when required, to maximise SWMP efficiency [9-44].

9.7.3 Five years

To maintain SWMP capacity, cleanouts are typically required every five years, and if the TSS capacity is reached, the SWMPs will be cleaned out [9-44].

9.8 Fire Protection Equipment

Testing and inspection of the fire detection and protection equipment shall be in accordance with CAN/ULC S537-13 [9-45], and performed by qualified fire technicians and/or CRL Fire Department Staff.

Waste delivery vehicles and ECM heavy equipment used for waste placement and compaction shall be provided with on-board fire suppression systems [9-45]. To control the spread and severity of fire and minimize operator injury, the on board extinguishing systems shall be certified to FM Global FM 5970 standards [9-45].

9.9 Integrated Environmental Monitoring

The NSDF design supports the CRL environmental management system, including an integrated environmental monitoring system that includes site-wide groundwater monitoring and that conforms to the CNSC regulatory document REGDOC-2.9.1 Environmental Protection Policies, Programs and Procedures [9-46], and the requirements set by CSA standard N288.4-10, Environmental Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills [9-47], N288.5, Effluent Monitoring Programs at Class 1 Nuclear Facilities and Uranium Mines and Mills [9-48] and N288.7-15 Groundwater Protection Programs at Class 1 Nuclear Facilities [9-49].

The design has incorporated environmental sampling/monitoring features to support CRL's EnvP Program in meeting the CRL site compliance monitoring requirements.

The NSDF design supports an integrated environmental monitoring system that includes site-wide groundwater monitoring and that conforms to the CNSC and CSA regulatory requirements. In particular, the NSDF design and integrated environmental monitoring program supports:

- The radiological and non-radiological environmental monitoring program.
- Radiological and non-radiological effluent monitoring program.
- The groundwater monitoring for the CRL WMA and the CRL CAs.

9.9.1 Environmental Monitoring

Environmental monitoring is conducted on behalf of the CNL EnvP Program Authority and is generally performed by the environmental monitoring staff. The monitoring results are reported directly to the Environmental Protection Branch and the NSDF Facility Manager, and shall be evaluated annually by the Facility Manager as supplementary indications of the environmental impact of the operation of the Facility.

The CNL EnvP Program establishes sampling and monitoring of liquid discharges and gaseous effluents to the environment. Data is collected, monitored, and reported as required by the EnvP Program. The management and monitoring of emissions and the environment at the NSDF follows company-wide requirements [9-40] for management and monitoring of emissions as well as project specific requirements [9-41] for monitoring and reporting including:

- Effluent monitoring of airborne radiological emissions.
- Effluent monitoring of radiological liquid emissions.
- Estimation of airborne non-radiological emissions.
- Effluent monitoring of non-radiological liquid emissions.
- Environmental monitoring of radiation levels in environmental media at the CRL site and surrounding communities.

The monitoring results are summarized in the annual safety report and annual environmental monitoring report that are submitted to the CNSC in support of the CRL site licence. As part of the CRL Environmental Management System, additional monitoring of the groundwater in the vicinity of the NSDF is conducted. The results of the monitoring are reported to the CNSC.

The NSDF EPP [9-38] for construction and operations of the NSDF, includes monitoring and control plans for dust, air, and surface water. The EPP [9-38] establishes practices and performance criteria to prevent unacceptable dispersal of radioactive and non-radioactive materials through environmental pathways and provides mechanisms for early detection of radioactivity, as well as monitoring for both radioactive and non-radioactive releases.

9.9.2 Effluent Monitoring

The dust controls implemented for the NSDF Project include road watering and chemical dust suppressant, on-site vehicles and equipment meeting Tier 2 emission standards, on-site vehicles and equipment being maintained in good working order, limiting idling of vehicles on-site, stabilization of stockpiles with dust suppressant as necessary, use of daily disposal cell cover, and those other requirements detailed in the Dust Management Plan [9-23].

The construction contractor and CNL personnel will implement a dust monitoring program in accordance with the CNL Standard for Management and Monitoring of Emissions [9-50], which includes operational control monitoring, air verification monitoring and environmental monitoring.

The WWTP Radiological Safety Zone 3 active exhaust air systems provide 100% exhaust air discharging directly outside of the building after being filtered by HEPA and are dedicated to serve the filter press modular enclosure, laboratory fume hood and laboratory vented storage cabinets [9-43].

Active exhaust air system qualification inspection and testing is in accordance with ASME N510 [9-43]. Construction inspections and testing, frequencies and means and methods are included in the NSDF Construction Quality Assurance Plan [9-51].

An Operational Control Monitoring Program shall be established [9-50] to achieve the following objectives:

- To provide feedback to Facility Staff on system performance with respect to emissions to the environment within a time frame consistent with routine operational control decisions.
- To confirm the adequacy of controls on emissions from the source.
- To provide timely indication to Facility staff of abnormal emissions that may be in excess of release limits in order to initiate corrective action, incident reporting, quantitative monitoring, investigations or emergency actions as appropriate.
- To differentiate sources of abnormal emissions where there is more than one Facility, system or subsystem that discharges to the environment through a single or common effluent stream.

9.9.3 Groundwater Monitoring

Groundwater monitoring wells are used to verify performance of the secondary liner system in accordance with protocols described in the Contingency Plan for Leachate, Groundwater, Surface Water, and Landfill Gas [9-39] and the Post-Closure Care Plan [9-52].

9.10 Foreign Materials Exclusion

The CNL Foreign Materials Exclusion (FME) practices [9-53], are followed in the NSDF to address concerns of foreign material intrusion in any of the NSDF processes, systems and components.

The CNL FME Program defines FME practices, which enhance CNL organizations' equipment reliability and system integrity. Foreign Materials Exclusion is applicable to Facility systems or components that are normally open or opened for maintenance/operation activities, where the potential introduction of foreign material could result in degraded product or worker injuries.

Foreign material entering Facility processes, systems and or components can cause degradation or inoperability and have an impact on safety and economic consequences. The severity of these consequences can vary widely, depending on the nature of the foreign material and the process, system and component involved. Examples include:

- Component malfunction or damage.
- Damage to the process system.
- Worker injuries.
- Financial loss.

Control of foreign material, is assessed whenever operational activities are performed in or around open systems or when Facility system boundaries are breached to perform operational, maintenance or inspection activities. The level of control specified takes into consideration the severity of the consequences of foreign material intrusion in Facility process systems or equipment.

9.11 References

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[9-4] *Occupational Safety and Health*, 900-510400-PRD-001, Revision 1, 2017 April.

[9-5] *Personnel Contamination Monitoring*, 900-508740-MCP-031, Revision 0, 2018 November.

[9-6] Training Manual RP-G1-031, *Group 1: Comprehensive Survey*, RADP-510220-TM-026, Revision 2, 2016 January.

[9-7] *Near Surface Disposal Facility Waste Acceptance Criteria,* 232-508600-WAC-003, Revision 2, 2020 September.

[9-8] *Continuous Improvement Ideas Process*, 900-514000-MCP-011, Revision 0, 2017 March.

[9-9] *Improvement Action (IMPACT) Corrective Action Procedure*, 900-514000-MCP-004, Revision 1, 2018 August.

[9-10] *Criticality Safety Document*, 232-503230-CSD-001, Revision 7, 2020 September.

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[9-12] *Infrequently Performed Operations,* 900-508200-MCP-008, Revision 1, 2019 November.

[9-13] *Waste Management Plan*, 900-508600-FID-001, Revision 1, 2019 March.

[9-14] *Management of Waste*, 900-508600-MCP-004, Revision 2, 2020 February.

[9-15] *Waste Characterization*, 900-508600-STD-003, Revision 0, 2019 December.

[9-16] *Waste Certification*, 900-508600-MCP-003, Revision 1, 2020 February.

[9-17] *Operational Decision Making,* 900-508200-MCP-002, Revision 1, 2019 August.

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[9-21] IAEA, *Safety Considerations in the Disposal of Disused Sealed Radioactive Sources in Borehole Facilities*, IAEA-TECDOC-1368, 2003 August.

[9-22] AECOM, *Waste Placement and Compaction Plan*, B1550-508600-PLA-001, Revision 2, 2019 October.

[9-23] *Dust Management Plan*, 232-03700-PLA-001, Revision 1, 2018 September.

[9-24] Ontario Environmental Protection Act, Ontario Regulation 347, *General – Waste Management*, R.R.O. 1990.

[9-25] International Atomic Energy Agency, *Monitoring and Surveillance of Radioactive Waste Disposal Facilities*, SSG-31, STI/PUB/1640, 2014.

[9-26] AECOM, *Landfill Development/Sequencing Plan*, B1550-505240-PLA-001, Revision 1, 2018 August.

[9-27] *NSDF Staffing Levels and Estimated Dose Control Points for ALARA Assessments*, 232-50870-021-000-0001, Revision 0, 2018 September.

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[9-29] *Benchmarking and Peer Review of Port Hope Project Operations and Port Granby Project Operations*, 232-508120-041-000-0003, Revision 0, 2018 May.

[9-30] AECOM, *Human Factors Verification and Validation Report,* 232-03800-HFR-002, Revision 0, 2017 May.

[9-31] AECOM, *WWTP Material and Energy Balance Report*, B1551-503212-REPT-001, Revision 2, 2018 December.

[9-32] *Operating Procedures and Operating Manuals*, 900-508200-MCP-006, Revision 3, 2020 September.

[9-33] *Operations and Maintenance Plan*, 232-508220-PLA-006, Revision 0, 2019 September.

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[9-35] Ontario Provincial Standard Specification, *Construction Specification for Dust Suppressants*, OPSS 506, 2005 November.

[9-36] Ontario Provincial Standard Specification, *Material Specification for Calcium Chloride Solid and Calcium Chloride Solution*, OPSS 2501, 2011 November.

[9-37] Ontario Provincial Standard Specification, *Material Specification for Magnesium Chloride Solid and Magnesium Chloride Solution*, OPSS 2503, 2011 November.

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[9-40] *Environmental Protection*, 900-509200-PRD-001, Revision 2, 2018 May.

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[9-46] CNSC, Environmental Protection: *Environmental Principles Assessments and Protection Measures*, REGDOC-2.9.1, 2017.

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[9-51] AECOM, *Construction Quality Assurance Plan*, 232-508244-QAP-001, Revision 2, 2019 September.

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10. FACILITY OPERATIONS AND MAINTENANCE

This section outlines the organization, responsibilities, processes and controls for the NSDF O&M. The NSDF operation is governed by the following documentation.

- CNSC CRL Site Licence [10-1].
- CRL Licence Conditions Handbook (LCH) [10-2].
- Near Surface Disposal Facility Authorization [10-3].
- Quality Program [10-4].
- Management System [10-5].
- Management System Governing Documentation Index [10-6].

10.1 Conduct of Facility Operations

The Conduct of Operations Program [10-7], applies to Class I and Class II Nuclear Facilities as listed in Site Licences, Certificates, Permits, Building / Facility Contacts & Licence Representatives [10-8]. The Conduct of Operations Program [10-7] will apply to the NSDF after in-active commissioning and turn over to Operations.

The NSDF O&M Plan [10-11], provides a listing of the operation procedures that will be developed to support the O&M of the NSDF systems. The listing of anticipated operations procedures is included in Section 10.12.

Figure 10-1 provides an overview of the Conduct of Operations Document Hierarchy [10-9]. Facility specific procedures are written within a suite of Conduct of Operations Procedures that are yet to be developed for NSDF and they are organized with placeholders as:

- Facility Organization and Management, 232-508200-COP-001.
- Communications, 232-508200-COP-002.
- Operational Control, 232-508200-COP-003.
- Operations Surveillance / Chemistry Control, 232-508200-COP-004.
- Surveillance Testing, 232-508200-COP-005.
- Operating Procedures and Operating Manuals, 232-508200-COP-006.
- Emergency Operating Procedures, 232-508200-COP-007.
- Infrequently Performed Operations, 232-508200-COP-008.

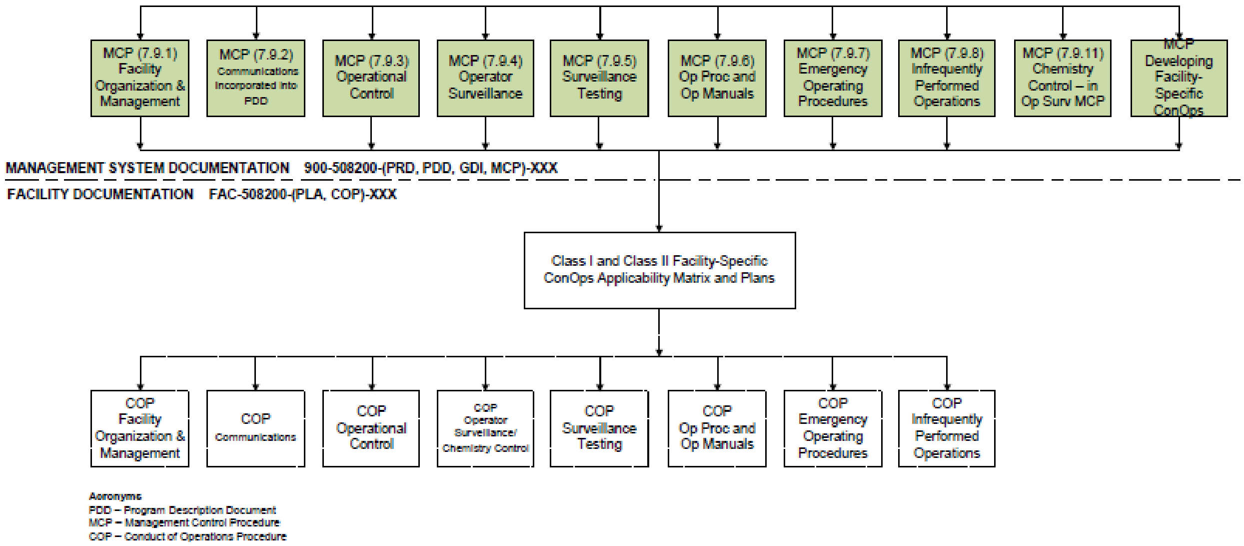

Figure 10-1 Conduct of Operations Hierarchy of Documents

10.2 Conduct of Maintenance

A comprehensive maintenance manual will be developed in accordance with CNL requirements [10-10] prior to the start of NSDF operations. The NSDF O&M Plan [10-11], provides a listing of the maintenance procedures that will be developed to support the O&M of the NSDF systems. The listing of anticipated maintenance procedures is included in Section 10.12.

The maintenance manual will be developed based on the information in the O&M Plan [10-11]. The manual will include requirements for inspection and maintenance of the LCS, pumping systems, instrumentation, monitoring systems, and other SSCs. Maintenance and equipment replacement facilities will be defined based on the needs of the NSDF Project and specific equipment requirements. Where applicable, considerations for maintenance in potential radiation fields will be defined in the maintenance manual and will also be addressed in the RP Plan [10-12]. Provisions for maintenance during system operation will be defined, including instrument calibration and maintenance activities for various systems and components.

Redundancy will be provided for process-critical equipment that requires significant time for replacement; shelf spares and replacement parts will be provided for equipment that can be readily replaced and/or repaired.

Canadian Nuclear Laboratories uses the Enterprise Asset Management System to provide an asset and maintenance management system for CRL buildings, systems and equipment that ensures physical assets perform as intended, combining safety and environmental requirements. The NSDF comprehensive equipment list is available in Enterprise Asset Management System.

Records from Inspection and Maintenance activities shall be maintained and findings/yctions from these activities shall be formally tracked.

10.3 Ageing Management

The Ageing Management Program [10-13] provides direction for the procedures, arrangements, and activities for managing within acceptable design limits the effects of physical aging and obsolescence of SSCs occurring over time or with use. The CNL Aging Management Program [10-13], will be applied in a risk-graded approach via the graded approach for Fitness for Service: Aging Management, REGDOC 2.6.3 [10-14], to the safety systems of Class 1 Nuclear and support facilities at the CRL site, to ensure that it is appropriately and proactively applied from design through decommissioning.

The Ageing Management Program [10-13] will be applied to the NSDF SSCs. The purpose of the Ageing Management Program [10-13], is to identify ageing mechanisms relevant to SSCs important to safety; to evaluate their possible consequences; and to provide direction for the activities required to maintain the operability and reliability of these SSCs throughout the entire life of the Facility. The Ageing Management Program [10-13] is designed to improve system performance by decreasing ageing related malfunctions and critical failures.

Condition assessments, inspections, maintenance and repairs of the NSDF engineered SSCs are performed as aging management activities. Effective aging management is in practice accomplished by coordinating existing programs, including maintenance, equipment reliability, as well as operations, and OPEX. In-service inspection programs (structural deterioration, performance decline), will be developed prior to NSDF going into the operations period.

The main ECM SSCs are the base liner systems, cover systems, perimeter berm, and leachate transfer systems. The durability of engineered barriers is addressed in the design through the selection of natural, stable materials, high performance HDPE geomembranes, and the ongoing long term performance tests to validate the 550 year design life of the geomembranes. The SSCs with a careful design and material selection ensures the design service life requirement is met. The rigorous construction QA Program during construction, in-service inspection and surveillance activities (leak detection, vibration monitoring, strain measurement, etc.) during the period of active institutional control to monitor the performance are part of the aging management.

The WWTP SSCs have been designed for a 55 year design life and have both preventive maintenance and periodic maintenance programs based on equipment vendor recommendations and CNL practices. The maintenance and inspections of SSCs are part of the ageing management. The WWTP systems and system components are either specified with materials that will endure more than 50 years operational life (e.g. SS), or are designed for periodic refurbishment or complete replacement. The key systems have redundancy design features (e.g. three Equalization Tanks, two WWTP process trains, triple pumps in the pumping stations (i.e. lead, lag, and standby)). The WWTP Systems and components are designed with adequate access to allow inspection or replacement of components. Chemistry control, corrosion monitoring, leak detection, vibration monitoring, cathodic protection, and thermal imaging are some of the key technologies used in WWTP SSCs for ageing management.

10.4 Responsibilities and Organization

The organization and the lines of authority for the NSDF are shown in Figure 10-2. The responsibility for overall safe operation of the NSDF rests with the FA. The responsibility for day-to-day operations rests with the Manager Waste Management Operations with some responsibilities delegated to the Operations Section Leader as specified in the Facility Specific Conduct of Operations Procedures.

The ultimate responsibility for the safety of CNL nuclear facilities rests with the President of CNL. The authority for nuclear operations is delegated to the ERM Vice-President. In addition, the Nuclear Laboratories Operations, Vice-President Operations and Chief Nuclear Officer is the CRL Site Licence Holder with oversight responsibility of the CRL site activities that impact the requirements and conditions defined by the site licence. This responsibility is discharged through the company line management and a Facility Authority is designated for each Nuclear Facility to be accountable for the safe operation and use of the Facility, in compliance with the conditions of licences, permits, applicable laws, and regulations.

The primary responsibilities of the Facility Authority, Facility Manager, Operations Manager, Operations Section Leader, and Operations Supervisor are listed in the Management System Manual [10-5] and the Conduct of Operations [10-7].

The Facility Manager, Operations Manager and Operations Section Leader ensure that the operation of the NSDF Facility is in accordance with the approved documentation. The Operations Manager and the Operations Section Leader manage the operation of the NSDF Facility. The Operations Section Leader is assisted by the Operations Supervisor, Operations Specialist, Direct Operating Staff, and by the support staff through operational control exercised by the Operations Manager. The Operations Manager and Operations Section Leader inform the Facility Manager and Facility Authority of operational and safety matters.

The Operation Specialist and Direct Operating Staff are responsible for safely operating the Facility in accordance with established policies and procedures, and inform supervision of options to improve the operation including suggestions for revising procedures.

Operating Staff members are trained and qualified to perform the duties of operating positions in the NSDF Facility. Staff from other branches, which include the Group 1 qualified Radiation Surveyors and Contamination Monitors, Heavy Equipment Operators, Facility Safety Representative, Facility Quality Representative, Licensing Representative, and Training Representative, as well as support staff from other divisions, provide operational support. The support staff takes direction from the Operations Section Leader and/or Operations Supervisor for work scheduling and matters of operational safety, but report to their respective managers for the technical aspects of their functions.

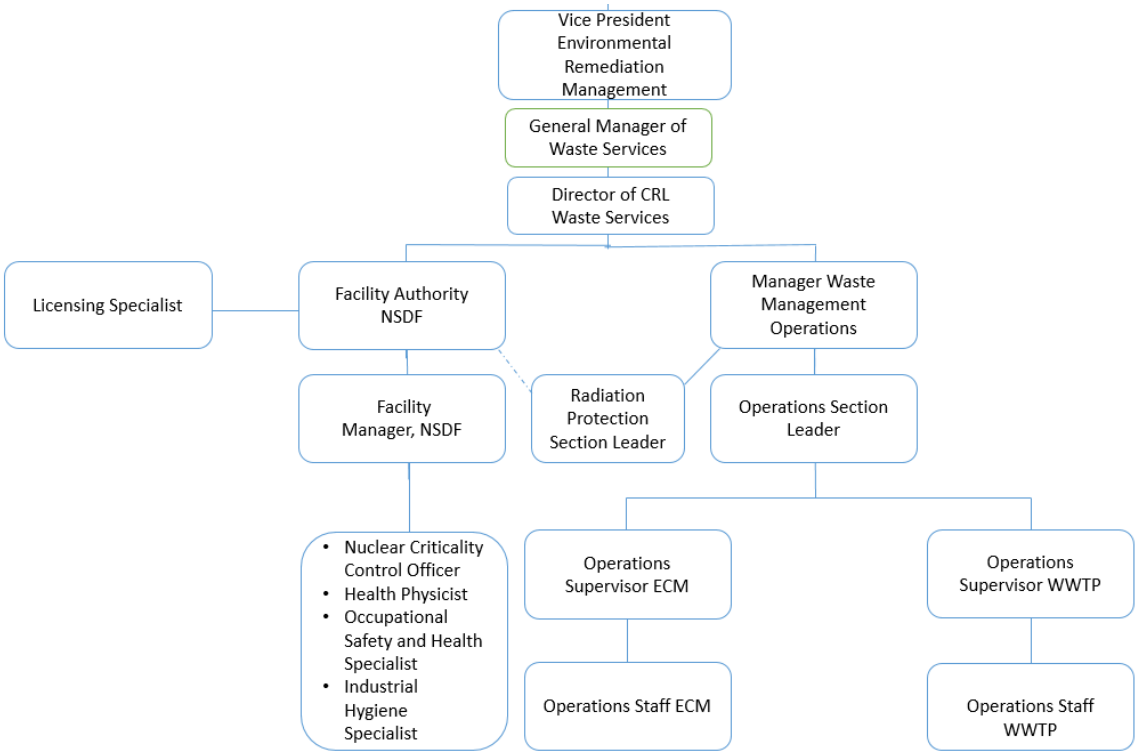

Figure 10-2 NSDF Operations Organization Chart

10.5 Minimum Staffing Requirements

The minimum number of qualified workers for the safe operation of the NSDF will be derived from the NSDF operation procedures that will be prepared prior to Facility operations. The minimum staffing will meet the requirements of Minimum Staff Complement, REGDOC-2.2.5 [10-15].

10.6 Fitness for Duty

The shift schedule for the NSDF (ECM and WWTP) will be derived from the NSDF operation procedures that will be prepared prior to Facility operations. The shift schedule will meet the requirements in the Canada Labour Code [10-16] and Fitness for Duty: Managing Worker Fatigue, REGDOC-2.2.4 [10-17].

10.7 Training

This section will describe the training requirements for staff involved in the operation of the NSDF Facility. Training requirements will be determined as part of the NSDF Staffing and Training Plan, developed according to Training and Development [10-18].

The total number of NSDF staff is anticipated to be 55 - 65 persons.

Specific training is required for all personnel to operate and maintain equipment within each NSDF Facility, which includes continuing training appropriate to their positions and qualifications.

Facility specific training is provided to support staff to enable them to perform assigned tasks effectively and safely. The Facility Manager is responsible for the development and implementation of the training program and for its effectiveness. Recruitment and training for the NSDF Staff follows CNL procedures. The recruitment selection criteria of the following positions will be detailed in the NSDF Staffing and Training Plan: Operations Section Leader, Operations Supervisor, Operations Specialist, Waste Management Technical Officer, and Mechanical Service Attendant. Personnel, selected to operate the NSDF, are qualified when the training program has been successfully completed and the individuals have demonstrated the skills and ability to perform the job.

The Training and Development Program focuses on three main areas for any Nuclear Facility and associated support staff:

- Fundamentals - to provide the theoretical knowledge required to understand technical concepts, the principles of equipment operation, and the policies and procedures for controlling nuclear materials at CNL.
- Safety Training - to provide the knowledge and skills in the areas of RP and industrial safety as appropriate to the hazards and conditions that are encountered in a specific job position.
- Facility Specific - to provide familiarization with NSDF operation policies and procedures, the Safety Related Systems, criticality and emergency procedures, and the knowledge and skills required to operate the NSDF Facility.

10.8 Near Surface Disposal Facility Site Access

Access to NSDF is controlled taking into account the security requirements specified by the CRL Security Program. Only authorized personnel will be allowed access to the NSDF. The NSDF Facility shall develop Facility Specific Conduct of Operations to control access including entry, exit and movement of people and equipment.

The NSDF shall have security measures as required by the NSCA [10-19] and the Nuclear Security Regulations [10-20]. Information related to security arrangements, equipment, systems and procedures, and the route or schedule to transport nuclear material is prescribed information.

10.9 Emergency Procedures

Emergency procedures are developed using the Building Emergency Procedures Template for CRL [10-21], to address potential emergencies including fires, flood, minor spill, major spill, natural gas/carbon monoxide leak, loss of power, earthquake, tornado, criticality response, high radiation, radiological contamination, bomb threat/suspicious package, hold and secure and stay-in. Checklists are also created for evacuation and floor plans and assembly area locations are also defined.

10.10 Document Control and Records

Documents related to the NSDF are controlled to ensure they are prepared and accepted by qualified staff, reviewed for adequacy, approved for use, and distributed to the required personnel, as required by CNL's company-wide procedure, Creation, Capture and Use of Information Assets [10-22].

Essential and non-essential records are identified, controlled, filed, and maintained in accordance with company-wide procedures including the following:

- Project documentation.
- Operating and maintenance procedures.
- Work records.
- Waste acceptance records.
- Waste data records.
- Waste placement records.
- Regulatory correspondence.
- Non-conformance reports.

10.11 Work Control

All work at the NSDF is performed in accordance with CNL's Integrated Work Control [10-23].

Operation of the Facility is conducted according to:

- Operating procedures for normal operation and for responding to abnormal situations.
- Emergency procedures for response to emergency conditions.
- Commissioning procedures when new equipment is being tested.
- Return to service of equipment or systems after any maintenance, repair, calibration, inspection, or tests shall be carried out as per the documents listed in the NSDF main Governing Documentation Index (to be developed).
- Temporary procedures as required for non-standard operation of a system because of equipment failure, maintenance or modification.
- Non-routine and infrequently-performed high-hazard activities shall be subject to the same standard of review, approval and authorization.

Work is performed by qualified personnel using approved operating procedures, maintenance procedures, work plans, and/or clearances/permits issued under the Integrated Work Control [10-23] or the WP system [10-24]. Procedures and work plans are approved documents which are reviewed by subject matter experts in disciplines relevant to safety (e.g. RP, industrial hygiene, operations), as necessary. Work not incorporated in standard operating procedures is authorized through the Integrated Work Control [10-23] or the WP system [10-24], which requires the identification of hazards, requirements for mitigation of hazards (e.g. PPE&C), radiation survey, pre-job briefs, and approval by the WP authorizer.

10.12 Operations and Maintenance Plan and Procedures

The NSDF Operations and Maintenance Plan [10-11], provides a listing of the operation procedures and maintenance procedures that will be developed to support the O&M of the NSDF systems. The O&M manuals will include sections applicable to the ECM, WWTP, decontamination facilities, and other support facilities as applicable [10-11].

A comprehensive operating manual will be developed prior to the start of NSDF operations [10-11] in accordance with Operating Procedures and Operating Manuals [10-25].

A comprehensive maintenance manual will be developed prior to the start of NSDF operations [10-11]. The maintenance manual will be developed in accordance with CRL Site Maintenance Work Planning and Control [10-26].

The NSDF operations procedures that will be developed prior to the start of NSDF operations will be developed using the following categories [10-11]:

- Administrative.
- Waste Acceptance and Inspection.
- Waste Placement.
- Decontamination.
- Leachate Collection and Monitoring.
- Leak Detection.
- Contingency and Emergency Response.
- WWTP and Laboratory Operations.
- Vehicle Decontamination Facility.
- Environmental Monitoring.
- Exfiltration Gallery.

10.13 Control of Modifications

The control of modifications to the Facility, will be in accordance with CNL's ECC Process [10-27].

10.14 Review and Audit

The NSDF is operated under the NSDF Facility Authorization [10-3] and is subject to regular review and audit, as required by the Compliance Program Requirements Document [10-28].

Oversight is provided through self-assessments, internal audits, regulatory inspections and independent reviews.

10.15 References

[10-1] CNSC, *Nuclear Research and Test Establishment Operating Licence Chalk River Laboratories*, NRTEOL-01.00/2028, 2018 March 28.

[10-2] CNSC, *Licence Conditions Handbook for Chalk River Laboratories*, NRTEOL-LCH-01.00/2028 (CRL-508760-HBK-002), Revision 1, 2019 February 25.

[10-3] *Facility Authorization for the Operation of the Near Surface Disposal Facility at the Chalk River Laboratories*, 232-00583-FA-001, Revision 3, 2020 October.

[10-4] *Quality,* 900-514200-PDD-001, Revision 0, 2019 July.

[10-5] *Management System Manual*, 900-514100-MAN-001, Revision 1, 2020 August.

[10-6] *Management System Governing Document Index*, 900-514100-GDI-001, Revision 1, 2018 March.

[10-7] *Conduct of Operations*, 900-508200-PDD-001, Revision 3, 2019 December.

[10-8] *Site Licences, Certificates, Permits, Building/Facility Contacts & Licence Representatives*, 900-514300-LST-001, Revision 9, 2020 July.

[10-9] *Developing Facility Specific Conduct of Operations,* 900-508200-MCP-009, Revision 1, 2020 January.

[10-10] *CRL Site Maintenance Work Planning and Control*, 900-508230-MCP-005, Revision 0, 2017 December.

[10-11] *Operations and Maintenance Plan*, 232-508220-PLA-006, Revision 0, 2019 September.

[10-12] *Radiation Protection Plan*, 232-508740-RWP-001, Revision 1, 2018 August.

[10-13] *Ageing Management Program,* 900-508222-STD-001, Revision 0, 2018 February.

[10-14] CNSC, *Fitness for Service: Aging Management*, REGDOC-2.6.3, 2014 March.

[10-15] CNSC, *Minimum Staff Complement*, REGDOC-2.2.5, 2019 April.

[10-16] *Canada Labour Code*, R.S.C., 1985, c. L-2.

[10-17] CNSC, Fitness for Duty: Managing Worker Fatigue, REGDOC-2.2.4, 2017 March.

[10-18] *Training and Development,* 900-510200-PDD-001, Revision 3, 2020 March.

[10-19] *Nuclear Safety and Control Act*, S.C. 1997, c.9.

[10-20] *Nuclear Security Regulations*, SOR/2000-209.

[10-21] *Building Emergency Procedures Template for CRL*, 900-508730-TMP-002, Revision 2, 2018 October.

[10-22] *Creation, Capture and Use of Information Assets*, 900-511300-STD-003, Revision 2, 2019 October.

[10-23] *Integrated Work Control,* 900-514100-STD-002, Revision 3, 2020 February.

[10-24] *Work Permit*, 900-510400-MCP-032, Revision 0, 2017 December.

[10-25] *Operating Procedures and Operating Manuals*, 900-508200-MCP-006, Revision 3, 2020 September.

[10-26] *CRL Site Maintenance Work Planning and Control*, 900-508230-MCP-005, Revision 0, 2017 December.

[10-27] *Engineering Change Control,* 900-508130-MCP-001, Revision 2, 2019 July.

[10-28] *Compliance Program Requirements Document*, 900-514300-PRD-001, Revision 2, 2020 March.

11. RADIATION PROTECTION

Measures described in CNL's Radiation Protection Requirements [11-1], and procedures given in the RP Governing Document Index [11-2], are used in the NSDF Facility to monitor and control radiation, radioactive contamination and worker exposure. Compliance with the NSCA [11-3] and associated Regulations, ensure appropriate RP and provide a system of dose limitation. The RP Program [11-4], is designed to utilize OPEX and information from international organizations including ICRP, National Council on Radiation Protection and Measurements (NCRP) and IAEA. The ICRP recommendations are followed where required.

As stated in the RP Program Description Document [11-4], the fundamental objectives of the CNL RP process are:

- Compliance with the RP Program requirements, licensing commitments and/or legal requirements.
- Upholding the safety of CNL personnel or the public.
- Preventing any unmonitored release of radioactive material to the environment.
- Maintaining worker exposures that are below dose acceptance criteria, CNL's Action Levels; and are ALARA.

Canadian Nuclear Laboratories applies the ALARA principle in all activities involving the use of ionizing radiation. All radiation doses to personnel or members of the public must be justified, in accordance with the ALARA principle and be maintained below regulatory limits. The RP and surveillance program includes:

- Zoning work areas, based on levels of radiation fields and contamination, to indicate the level of precaution required.
- Limiting access to areas of radiation hazard.
- Monitoring ambient radiation fields to detect any changes that might have occurred.
- Maintaining contamination control by measuring contamination levels.

11.1 Radiological Work Controls

External radiation hazards associated with the NSDF are managed by radiation shielding, zoning and access control, and hazard monitoring. Contamination hazards associated with the NSDF are managed by confinement/containment of radiological contamination, radiological safety zoning and access control, and PPE&C.

Radiation exposure within the NSDF due to any release of radioactive material from the NSDF and their associated operations is kept ALARA and below prescribed limits in all operational states; radiation exposures due to accidents shall be mitigated.

Radiological Work Assessments and planning are used in combination with Dose Control Points (DCP) to limit doses to workers and to ensure these are managed in accordance with the RP Regulations [11-5], the CNL RP Program and are ALARA.

Radiological work assessment and planning is the identification of radiological aspects, evaluation of radiological concern and significance. This includes the review and selection of hazard controls and protective measures that will prevent, control, and/or minimize radiological exposure and risk. These measures are implemented for non-routine or high hazard activities related to operation and maintenance of the NSDF.

Dose Control Points are assigned to each worker in accordance with [11-6]. Dose Control Points shall be reviewed at least annually and adjusted as necessary according to the needs of the work expected. Exceeding the DCP shall trigger a management review of the employee's activities to ensure doses were justified and ALARA. The DCP assignments exceeding 5 mSv shall be reviewed by a Group 1 qualified Health Physicist. Additionally, significant deviations from the DCP will trigger an ALARA assessment [11-1] and [11-6].

11.2 Radiological Monitoring

Radiological monitoring will be in accordance with CNL's external [11-7] and internal [11-8] dosimetry, and Radiation Protection Instrumentation [11-9] with the following requirements:

- Near Surface Disposal Facility personnel will wear a Thermoluminescent Dosimeter or a photo-badge, personnel in certain areas may wear Personal Alarming Dosimeters (PAD), and all personnel will participate in the internal dosimetry program.
- The Integrated Work Control [11-10] forms the basis for the control of work.
- All work that meets the requirements of the WP [11-11], will be performed under an approved WP [11-11] and will follow the requirements of Radiological WP [11-12].
- Abnormal situations, where the potential or estimated dose is likely to exceed CNL's Administrative Control Levels, require a formal, approved work plan and specific RP Program Approvals [11-1].
- New and non-routine work, require a formal, approved work plan and specific RP Program Approvals [11-1].

11.2.1 Radiation Monitoring

Routine radiation and contamination monitoring within the NSDF will be performed to identify and trend radiation hazard levels in accordance with RP Requirements [11-1]. Area radiation monitoring is provided in all areas within the NSDF where there is potential for accessible dose rates in excess of the prescribed limits [11-1] from normal operations or unplanned events.

The number of gamma radiation monitors, their physical location, and the annunciation philosophy are based on an evaluation of radiation hazards, expected radiation levels, equipment layout, and operational and maintenance activities expected in the area. The monitoring system conforms to the RP Requirements [11-1], and includes both fixed and portable monitors.

When a fixed radiation alarm system is out of service, a temporary alternative program that provides equivalent protection shall be implemented and maintained [11-1]. The temporary alternative program shall be documented and approved by a Group 1 qualified Health Physicist [11-1].

11.2.1.1 Dose Rates

The dose rate limits and the means of handling and transferring that shall be applied to the bulk and packaged waste at the NSDF are presented in Table 11-1.

Table 11-1
Dose Rate Limits and Means of Handling and Transferring

Radiation Type	**Dose Rates**	**Means of Handling and Transferring**
Total gamma and neutron	≤0.5 mSv/h near contact <u>and</u> ≤0.01 mSv/h at a distance of 1 metre.	Manual or mechanical means.
Total gamma and neutron	>0.5 mSv/h to ≤2 mSv/h near contact <u>and</u> >0.01 mSv/h to ≤0.1 mSv/h at a distance of 1 metre.	Mechanical means.
Total gamma and neutron	>2 mSv/h near contact <u>or</u> >0.1 mSv/h at a distance of 1 metre.	Handling and transferring is subject to RP Program controls, Infrequently Performed Operations [11-13], and assessment approval by the NSDF Facility Authority.
Beta	<10 mSv/h near contact	Based on total gamma and neutron dose rates.

The gamma and beta dose rate limits in Movement of Non-Waste Equipment and Material [11-14], have been used as guidance in the development of the dose rate limits and the means of handling and transferring waste in Table 11-1. The gamma and beta dose rate limits in [11-14] that have been used as guidance are:

- "Total gamma (and neutron if applicable) dose rates on package exteriors should not exceed 2 mSv/h (200 mrem/h) on contact with the package or 0.1 mSv/h (10 mrem/h) at a distance of 1 m from the package for packages to be transferred primarily by mechanical means".
- "Total gamma (and neutron if applicable) dose rates on package exteriors should not exceed 0.5 mSv/h (50 mrem/h) on contact with the package or 0.01 mSv/h (1 mrem/h) at a distance of 1 m from the package for transfers that are to be primarily handled manually".
- "Beta radiation dose rates shall not exceed 10 mSv/h (1 rem/h) on contact with the package."

In addition, the beta dose rate limit of 10 mSv/h is applied directly from CNLs RP Program Documentation, ALARA Review and Assessment – Planning and Control of Radiation Work [11-15]. This RP document sets the Hazard Level for beta dose rates at <u>Low</u> if less than

10 mGy/h, which means that the hazard lies well inside the level of work approval for CNLs' Group 1 RP Staff. Beta dose rates will be reduced via packaging, but the limit is specified to ensure that excessive shallow/skin doses are not encountered on packages that may simply comprise a bagged/double bagged contaminated item.

11.2.1.2 Surface Contamination

The maximum non-fixed surface contamination on the outer surfaces of each waste package and or transport container, averaged over 300 cm^2, must be less than 3.7 Bq/cm^2 beta gamma, and less than 0.37 Bq/cm^2 alpha.

11.2.2 Radiation Monitoring Equipment

Radiation monitoring equipment is used in the Facility to protect the workers and public as well as contamination control and compliance monitoring. The radiation monitoring equipment used in the Facility may include:

- Area radiation monitors.
- Continuous air monitors.
- Radiation survey instrumentation (e.g. gamma survey meters, beta survey meters).
- Personnel contamination monitors (e.g. friskers, hand and foot monitors).
- Surface contamination monitors (e.g. pancake detectors).
- Tritium monitor.

There are three whole body monitors in the Facility, which are used for monitoring of personnel and visitors exiting the Facility. Two whole body monitors are located in the OSC, and one whole body monitor is located in the WWTP.

The radiological monitoring equipment used in the NSDF meets the CNL site standard, and the radiological monitoring regime is based on RP Program Requirements [11-1] and associated Radiation and Contamination Work Place Monitoring Routines [11-16]. This monitoring regime is subject to regular review to verify adequacy, and if necessary, the monitoring frequency will be changed to better capture trends. Any trends that are observed will result in a review of the monitoring requirements and possibly in the operations and activities being carried out. This is to ensure that all radiological consequences are controlled and Facility personnel do not receive unnecessary exposure to radiation.

Radiation monitor locations include:

- Equalization Tanks secondary containment sump.
- Filter press enclosure (CAM).

11.3 Personnel Contamination Monitoring

Personal surface contamination monitoring equipment is in the form of whole-body monitors (e.g. walk-through, stand-in), hand and foot monitor and/or portable contamination monitoring instrumentation ("friskers") [11-17]. Persons shall monitor for radioactive contamination in the following situations:

- After working or handling unsealed radioactive material.
- When suspecting personal contamination.
- When leaving an area that may be contaminated.
- When exiting from a higher Contamination Zone to a lower Contamination Zone.
- When exiting a CA where the potential for contamination exists.
- When asked to do so by a supervisor or Group 1 qualified Employee.

11.3.1 Skin and Clothing Contamination

All radioactive contamination of skin and clothing is to be immediately reported to a Group 1 qualified Radiation Surveyor. The instructions of the Group 1 qualified Radiation Surveyor are followed for the skin and clothing contamination event. Radioactive contamination of skin and clothing events are reported promptly to the WP Authorizer, Operations Supervisor, Group 1 qualified Health Physicist, Facility Manager, and FA, and are documented using the ImpAct process [11-18].

11.4 Vehicle Contamination Monitoring

All vehicles used within the perimeters of the NSDF, are to be checked clean of contamination, by RP Staff upon departure from all access CAs. All material or equipment that is retrieved from, or used in, the NSDF is to be bagged or wrapped in plastic prior to it being loaded into a vehicle. The only exceptions involve equipment that is verified to be free of radioactive contamination by RP staff before being loaded onto the vehicle.

11.5 Workers

Near Surface Disposal Facility workers are provided with RP training appropriate to their roles. All radiological work is performed by qualified workers with RP Group 3 training using approved procedures and/or WP. Workers are made aware of all radiological hazards, controls, and risk reduction measures necessary to ensure their safety and the safe NSDF operation.

The NSDF staff use several methods of protection against the radiological hazards including radiation surveys, work control, PPE&C, personnel dosimetry, and contamination monitoring. During operations with potential for contamination hazards, operating personnel wear appropriate PPE&C as directed by RP to minimize internal and external doses. Application of RP procedures and ALARA practices minimize doses to the operational personnel.

11.5.1 Estimated Dose Control Points Near Surface Disposal Facility Staff

A DCP is an estimated annual limit of radiation exposure for an individual set by the Facility Manager in consultation with a Health Physicist, based on past experience and future planned work. All DCPs for the NSDF staff are set conservatively low and adjusted as experience is gained with the operations at NSDF [11-19]. Past experience with DCPs at other CRL Class I nuclear facilities and information gathered during disposal facility benchmarking, was used to estimate annual DCPs as shown in Table 11-2 [11-19]. The summation of the estimated DCPs for all NSDF staff yields a very conservative collective dose for 52 employees at 191 mSv [11-19].

Table 11-2
Near Surface Disposal Facility Staff Estimated Dose Control Points [11-19]

Number of Staff at each Position (#)	Estimated DCP	Description of Responsibilities
(2) Operations Manager / Facility Manager	1 mSv	ECM and WWTP tours, troubleshooting, event investigation.
(1) Administrative	1 mSv	Occupancy in the Administration building. Rare tour of ECM and WWTP.
(1) Health Physicist	1 mSv	ECM and WWTP tours, oversight, event investigation.
(1) ECM/VDF Facility Supervisor	3 mSv	Oversight of all ECM and VDF operations. Cross trained as WWTP Facility Supervisor.
(1) WWTP Supervisor	3 mSv	Oversight of all WWTP operations. Cross trained as ECM/VDF Facility Supervisor.
(3) S&L/NCCO, Training Specialist, ½ person year OSH, and ½ person year Industrial Hygiene	1 mSv	Mostly office work with short duration visits to the field.
(5) ECM Technicians	1 - 5 mSv	(2) @ 1 mSv – waste shipment planning and tracking, Kiosk operation. (3) @ 5 mSv – offloading ramp operations, sort and segregation facility operation.
(4) WWTP Technicians	3 mSv	Routine WWTP operations, cleaning of filter press, changing out resins, and annual cleaning of Equalization Tanks.
(5) Operating Engineer (Hoisting and Heavy Equipment)	3 - 5 mSv	(1) @ 3 mSv – working lead hand. (4) @ 5 mSv – ECM heavy equipment, hoisting.
(14) Trades	3 - 8 mSv	(1) @ 3 mSv – working lead hand. (3) @ 5 mSv – Mechanic assisted by Millwrights. (2) @ 3 mSv – drivers for waste transport, water trucks, snow removal and grass cutting. (4) @ 8 mSv – Mechanical Service Attendants, sort and segregation facility operation, macroencapsulation, offloading ramp operations, and waste transport. (2) @ 5 mSv – Carpenters, grouting, forming, controlled low strength material batch plant operation.

		(2) @ 3 mSv – Electrician and pipefitter working mostly in WWTP.
(4) Engineering	2 mSv	Civil engineer working in office with frequent visits to the ECM. Process, electrical and chemical engineers working in office with frequent WWTP tours.
(8) Radiation Protection	5 mSv	(4) RP Surveyors and (4) Contamination Monitors working in sort and segregation, ECM, WWTP, VDF and Kiosks.
(3) Lab Technicians	2 mSv	Collect samples in WWTP and around ECM, analyze samples and write reports.

11.6 Public

Radiological exposure to a member of the public from NSDF operations, can occur due to an airborne release and or water effluent from the Facility. Indirect exposure to the public from treated effluent releases to groundwater and/or surface water would be insignificant. Airborne and surface water releases are monitored by CNL's EnvP Program, to ensure compliance with release limits and to identify potential areas for improvement. Doses to the public from NSDF operations are expected to be negligible, less than 10 µSv/y.

11.7 Radiation Shielding

The amount of shielding required to protect against different types of radiation is commensurate with the energy (radiation) including:

- Shielded flasks, overpacks and packages are used for the transfer of materials to the NSDF.
- A shielded enclosure is provided for storage of radioactive sources used for source checking radiation monitors.
- Lead blankets may be used to provide temporary shielding over very radioactive items.

When the dose rates exceed a certain level and providing shielding is impractical, NSDF Staff may develop special handling and transport methods in consultation with the Group 1 qualified RP Staff.

11.8 Radiological Safety Zones

The CNL RP Requirements [11-1] have established guidelines for dose rates within the general environment of nuclear facilities and in the workplace. The NSDF is designated as a CA and is also subject to Radiological Zoning requirements of [11-1]. The NSDF is subdivided into radiological safety zones in accordance with the requirements of [11-1], [11-2] and [11-20]. Radiological areas and safety zones control the spread of contamination and indicate the degree of hazard from external radiation. The designation of radiological safety zones are based upon the level of radiation and contamination hazards present. Segregation of areas into zones assists with ensuring the effective management of radiological hazards at the NSDF and helps keep doses to persons ALARA [11-15]. The general (accessible) whole-body dose levels for the Radiation Zones and the general (accessible) removable surface contamination levels for the Contamination Zones, are defined in Radiological Areas and Zones [11-20].

Table 11-3 lists the predicted Radiological Safety Zone, Radiation Zone and Contamination Zone designations for the NSDF structures and areas. The Radiological Safety Zone designations in Table 11-3 are subject to change based on radiological survey results. The frequency for conducting radiological surveys is defined in Radiation and Contamination Work Place Monitoring Routines [11-16]. The records of radiological surveys are compiled and can be obtained by contacting the NSDF Supervisor.

The maximum average accessible whole-body dose rate levels for the Radiation Zones are [11-16]:

- ≤0.5 µSv/h for Radiation Zone 1.
- >0.5 µSv/h and ≤10 µSv/h for Radiation Zone 2.
- >10 µSv/h and ≤1.0 mSv/h for Radiation Zone 3.
- >1.0 mSv/h and ≤100 mSv/h for Radiation Zone 4.
- >100 mSv/h for Radiation Zone 5.

Table 11-3
Predicted Radiological Safety Zones

Area	Radiological Safety Zone	Radiation Zone	Contamination Zone
ECM			
Inactive disposal cells	2	2	1
Active open disposal cell including TSWRPA	3	3	3
WWTP			
Filter press enclosure	3	3	2
Pre-treatment and residuals management area	3	3	2
Decontamination rooms and vestibules	2	2	1
Laboratory and control room	2	2	1
Maintenance shop	2	2	1
Other support areas	1	1	1
VDF			
Vehicle decontamination hall	2	2	2
Decontamination room and vestibule	2	2	2
Other support areas, including maintenance hall	1	1	1
OSC			
Radiation protection monitoring portal, decontamination room, first aid room and RP office	2	2	1

Other support areas	1	1	1
Other Areas			
Kiosks, weigh scales	1	1	1
Administration Office	1	1	1
Perimeter Fence	2	2	1

11.9 As Low As Reasonably Achievable

The NSDF Project ALARA assessment [11-21], was completed to ensure that the NSDF design, is selected so that implications for occupational and public radiation safety are ALARA, and that the planning and control of radiation work at the NSDF will provide optimized RP.

As Low As Reasonably Achievable is achieved in the development of the NSDF through integration of design and safety activities. The NSDF development follows an iterative design process, whereby, results of the safety analyses are taken into account in the development of the design to ensure adherence to ALARA [11-21].

The ALARA principle in the NSDF is achieved by implementing zoning and access control measures, by providing adequate shielding for structures and waste packages with high radiation fields, by providing process equipment segregation, radiation alarms in place, continuous monitoring, and worker training and approved procedures [11-21]. Further reduction in operating staff doses is achieved by minimizing releases through periodic inspection and preventive maintenance of equipment [11-21].

The NSDF design and operations have been developed to meet the regulatory requirements of ALARA and minimizes radiation exposures to workers, the public, and the environment based on the following design and safety aspects [11-21]:

- The completed Facility Design Checklist in [11-21], documents and demonstrates that the NSDF design conforms to the RP Program requirements documented in Design and Modification Considerations [11-22].
- The completed ALARA Design and Review Questionnaires in [11-21], document that the NSDF design/process control options conforms to the RP Program requirements documented in Design and Modification Considerations [11-22].
- Radiation sources have been identified and their use justified for the design and proposed operation of the NSDF.
- The estimated worker radiation exposures and radiological consequences during normal operations are below the dose acceptance criteria and the CNL dose Action Levels.
- The NSDF design of the ECM and WWTP includes two physical barriers to provide containment of radioactive materials to prevent the release of radioactive materials and or spread of contamination.

- Containment of radioactive material in the ECM is provided by the base liner system and the cover system. The base liner system includes the primary liner system and the secondary liner system.
- Primary containment of radioactive material in the WWTP is provided by the tanks and piping, and secondary containment is provided by the concrete containment and the WWTP active drain system.
- The WWTP filter press enclosure limits access to the filter press and reduces worker radiation doses, since the enclosure provides a radiation level outside the enclosure meeting Radiation Zone 2 requirements of <10 μSv/h.
- The WWTP ventilation system is designed to prevent the escape of contamination to the work area and to ensure that the flow of air is from areas of lower contamination potential to areas of higher contamination potential. The WWTP active ventilation includes HEPA filtration to limit the release of radioactive or other hazardous material to the environment.
- Accessible locations in the Facility are segregated into radiological safety zones as per Radiological Areas and Zones [11-20], based upon routine radiation dose rates and contamination levels expected in the area.
- Provisions are provided in the design for personnel contamination monitoring equipment at appropriate locations.
- Access control to the Facility is provided to prevent or reduce the likelihood of unauthorized or inadvertent access.

11.10 References

[11-1] *Radiation Protection*, 900-508740-PRD-001, Revision 3, 2018 June.

[11-2] *Radiation Protection Governing Document Index*, 900-508740-GDI-001, Revision 2, 2018 June.

[11-3] *Nuclear Safety and Control Act*, S.C. 1997, c. 9.

[11-4] *Radiation Protection*, 900-508740-PDD-001, Revision 0, 2017 March.

[11-5] *Radiation Protection Regulations*, SOR/2000-203.

[11-6] *Dose Control Points*, 900-508740-MCP-007, Revision 0, 2017 June.

[11-7] *External Dosimetry*, 900-508740-MCP-022, Revision 0, 2018 October.

[11-8] *Internal Dosimetry*, 900-508740-STD-002, Revision 0, 2018 January.

[11-9] *Radiation Protection Instrumentation*, 900-508740-MCP-002, Revision 1, 2019 December.

[11-10] *Integrated Work Control*, 900-514100-STD-002, Revision 2, 2019 June.

[11-11] *Work Permit,* 900-510400-MCP-032, Revision 0, 2017 November.

[11-12] *Radiological Work Permit*, 900-508740-STD-003, Revision 1, 2019 July.

[11-13] *Infrequently Performed Operations,* 900-508200-MCP-008, Revision 1, 2019 November.

[11-14] *Movement of Non-Waste Equipment and Material,* 900-508740-MCP-037, Revision 0, 2018 December.

[11-15] *ALARA Review and Assessment – Planning and Control of Radiation Work,* 900-508740-MCP-026, Revision 0, 2017 June.

[11-16] *Radiation and Contamination Work Place Monitoring Routines,* 900-508740-FID-001, Revision 0, 2018 November.

[11-17] *Personnel Contamination Monitoring*, 900-508740-MCP-031, Revision 0, 2018 November.

[11-18] *Processing Internal and External Operating Experience*, 900-514000-MCP-001, Revision 0, 2017 March.

[11-19] *NSDF Staffing Levels and Estimated Dose Control Points for ALARA Assessments*, 232-508740-021-000, Revision 0, 2018 September.

[11-20] *Radiological Areas and Zones*, 900-508740-MCP-027, Revision 2, 2019 December.

[11-21] *Near Surface Disposal Facility ALARA Assessment*, 232-508740-ASD-001, Revision 1, 2020 March.

[11-22] *Design and Modification Considerations*, 900-508740-STD-005, Revision 0, 2019 February.

12. COMMISSIONING

The NSDF Commissioning Plan [12-1], outlines the strategy for commissioning the NSDF. Commissioning will be completed in accordance with the CNL's Commissioning Program documentation [12-2] and [12-3]. Commissioning starts with planning the commissioning scope, phases, and control points [12-2]. Commissioning ends with the Commissioning Completion Assurance process [12-2]. The ultimate objective of commissioning is to obtain a building or Facility whose systems function in all respects according to design intent and to meet the needs of the occupants [12-2].

A detailed commissioning plan will be developed that defines specific commissioning procedures and commissioning specifications and objectives [12-1]. The sequence of activities are inactive commissioning, licencing, Facility hand-over to Operations and then active commissioning.

12.1 Commissioning Plan

The purpose of the NSDF Commissioning Plan [12-1], is to establish methods for ensuring accountability in addition to the preparation, review, and approval and revision control of the components of NSDF commissioning. The NSDF Commissioning Plan [12-1] sets out a process and methodology for the commissioning and outlines the requirements for:

- Commissioning organization.
- Stakeholder interfaces.
- Commissioning documentation.
- Training requirements.
- Commissioning/training schedules.
- Commissioning procedures.
- Pre-requisite testing and documentation.
- Equipment start-up testing and verification.
- System performance verification.
- Facility full and partial turnover to CNL/NSDF Operations.
- Operational monitoring.
- As-built drawing production.
- Operating and Maintenance manuals.

12.2 Commissioning Organization, Roles and Responsibilities

The commissioning team is made up of the CNL commissioning/engineering representatives, CNL operations representatives, commissioning agent, Engineer of Record, and construction contractor personnel [12-1]. The commissioning agent is responsible for the inactive commissioning and CNL is responsible for the active commissioning.

12.2.1 Canadian Nuclear Laboratories Commissioning/Engineering Representatives

The CNL commissioning/engineering representatives are responsible for [12-1] and [12-2]:

- Preparing commissioning documentation and/or reviewing commissioning documentation prepared by commissioning agencies.
- Observing, witnessing, reporting progress and certifying results of commissioning activities.
- Submitting commissioning results to the Design Authority designate for concurrence of acceptability, as applicable.
- Participating in in-active commissioning activities to prepare for the active commissioning phase after turnover from construction.
- Assuming leadership in active commissioning phase during the operations phase.
- Processing all identified non-conformances from the commissioning agent.

12.2.2 Canadian Nuclear Laboratories Operations Representatives

The CNL operations representatives are responsible for [12-1]:

- Participating in the inactive commissioning process to get trained and in ready state for operations during active commissioning.
- Participating in system commissioning as subject matter experts.
- Performing the day-to-day operation and maintenance of the new Facility during active commissioning.
- Taking a leading role during active commissioning, in the operation phase and beyond.

12.2.3 Commissioning Agent

The commissioning agent is responsible for [12-1] and [12-2]:

- Assuming overall responsibility for the inactive commissioning of the Facility and providing Single Point of Contact with CNL.
- Co-ordinating, planning, and executing all inactive commissioning activities in collaboration with CNL representatives, the Construction Contractor and the Engineer of Record, through the engagement with CNL.
- Ensuring that all inactive commissioning activities are carried out to ensure the delivery of a fully operational project complete in every respect.
- Performing a design basis review, from a commissioning point of view, for identification of design functional and operational requirements of the overall project and an assessment regarding the adequacy of the design to meet design, functional and operational requirements.
- Preparation of commissioning documentation, including detailed commissioning plans, commissioning specifications and objectives, commissioning procedures, and reports.

- Obtaining approval for deviations from procedures.
- Reporting issues encountered during the conduct of commissioning activities.
- Submitting commissioning results to CNL Commissioning Team for review and acceptance.
- Revising, refining and updating the commissioning plans and procedures during the construction and commissioning phase as necessary to reflect arising changes.
- Reviewing commissioning system performance, accessibility, maintainability, operation efficiency under all conditions of operation.
- Ensuring commissioning agent's commissioning specialists have supervisory role to confirm and record the commissioning test results and produce reports.
- Managing and implementing the commissioning tests in accordance with commissioning specifications and commissioning procedures.
- Providing Commissioning Completion Assurance documentation.
- Performing integrated system commissioning tests with simulants.
- Operating under the construction contractor's HSSE Program.

12.2.4 Construction Contractor

The construction contractor is responsible for [12-1]:

- Performing oversight on the contractor's qualified commissioning interface, subcontractors, suppliers/manufacturers and other support disciplines.
- Ensuring the construction/installation is in accordance with the contract documents.
- Preparing and submitting overall construction and commissioning schedule in coordination with the commissioning agent.
- Preparing and submitting functional performance test scripts that will be used to demonstrate, verify and validate system/equipment performance against specified acceptance criteria with input from manufacturers and sub-trades.
- Implementing all commissioning activities required by the specifications, including demonstrations, training and testing under the direction of the commissioning agent.
- Supplying all trades that will be directly operating and adjusting the equipment and systems to help execute commissioning tests.
- Ensuring that the pre-requisites for the commissioning have been satisfied and that pre-functional tests such as system flushing, functional checks, logic checks, interlock checks, and system integrity checks have been completed based on the checklists generated by the commissioning agent.
- Providing simulants to verify the WWTP process systems' performance for 24-hour run for each treatment train.
- Providing for storage and disposal of all simulants used in commissioning.

- Incorporating activities in the project schedule for the execution of the commissioning tests under the direction of the commissioning agent.
- Preparing and submitting system/equipment specific forms.

12.2.5 Engineer of Record

The engineer of record is responsible for [12-1]:

- Performing oversight on the designer's commissioning specialist, discipline leads and construction oversight staff.
- Ensuring that the Facility design meets the Client's functional and operational requirements.
- Monitoring inactive commissioning activities, witnessing and reviewing the accuracy of the reported results.
- Supervising and witnessing testing, adjusting and balancing, and other tests during inactive commissioning.

12.3 Pre-Commissioning Process

Pre-commissioning of the NSDF is carried out through ongoing visual inspections during construction, and testing of systems/components during or prior to installation.

Prior to turnover to the Commissioning Team, all systems/components within the scope of the Facilities will undergo various systems/components level verification tests, performed to ensure that the installation and performance align with the design/construction documentation [12-1]. These tests shall be documented by the manufacturers/suppliers and shall be included as part of the turnover documents [12-1].

Pre-commissioning activities include [12-1]:

- Factory Acceptance Testing.
- Certified instrument calibration records.
- "Meggering" of wires to verify integrity of insulation.
- Technical Standards & Safety Authority (TSSA) witnessing leak-testing of pressure boundaries.
- Leak testing including piping and ducting.
- Testing of electronic LDSs.
- Pre-commissioning functional equipment point to point checks.
- Interlock and logic testing.

12.4 Turnover to Commissioning

Commissioning activities are carried-out subsequent to the completion of construction checks and tests, and the turnover of systems. Upon turnover, equipment ownership and terminal points are tagged prior to conducting commissioning activities in order to ensure safety, and configuration management during the commissioning phase.

12.5 Commissioning Execution Process

Commissioning of the NSDF will be carried out by the commissioning team following approved commissioning procedures. The commissioning procedures will be specific to the system/equipment being commissioned.

There are two distinct NSDF areas for the NSDF commissioning [12-1]:

- ECM and support facilities.
- WWTP and Support Buildings.

The commissioning process is separated into inactive commissioning and active commissioning [12-1]. The inactive commissioning phases are [12-1]:

- Equipment level commissioning activities using clean water as a medium.
- System level commissioning activities using clean water as a medium.
- Facility level commissioning activities using a representative simulated contaminated wastewater (brine solution) to simulate the expected leachate.

The active commissioning phase is the WWTP Facility level commissioning. The WWTP active commissioning utilizes radioactive wastewater/leachate, once sufficient volume of wastewater/leachate is available in the Equalization Tanks, the produced wastewater/leachate is utilized for final commissioning and Facility handover.

The commissioning activities include [12-1]:

- Deficiencies identification.
- Pre-commissioning documentation.
- Performance verification testing of individual components or instruments of a system.
- Visual monitoring requirements by commissioning team personnel.
- Independent verification of commissioning activities.
- Site Acceptance Testing.
- System functional performance testing to assess the overall system performance compared to the system design requirements.
- Sign-offs required.

Deficiencies identified during the testing and commissioning process, will be documented in the system specific commissioning procedure, and corrective action will be recorded and taken prior to the completion of commissioning activities [12-1]. For the issues encountered during commissioning activities, re-testing will be performed and, if necessary, additional commissioning procedures may be developed in order to provide appropriate objective evidences that the issues were successfully resolved [12-1].

12.5.1 Engineered Containment Mound

The construction of the ECM has inspection and testing requirements, and the testing results support the ECM commissioning. The ECM SSCs that require inspection and testing are [12-1]:

- Compacted clay liner (CCL).
- HDPE geomembrane.
- Geosynthetic clay liner.
- Geogrid.
- Geotextile.
- Leachate collection and removal system.

12.5.1.1 Compacted Clay Liner

The ECM CCL inspection and testing includes [12-1]:

- Moisture content of the clay.
- Percent moisture content during nuclear density machine testing.
- Soil compaction testing - density and compaction.
- Critical moisture content component, also includes lab testing and test pad construction.
- Material sample testing - grain size, Atterberg limits and plasticity limits.
- Subgrade proof roll documentation.
- Nuclear density machine testing, Shelby tubes testing and permeability testing.

12.5.1.2 High-Density Polyethylene Geomembrane

The ECM HDPE geomembrane inspection and testing includes [12-1]:

- Non-destructive testing on field seams, patches, and repair welds.
- Destructive testing on all field seams. Destructive testing may be done on all patches and repair bonds as required by the engineer.
- Sampling seam length, at least one sample per day.
- Testing field samples for shear and peel strength. Failure of either test will result in the sample location weld being rejected.
- Quality control testing following technical specifications.
- Quality assurance testing following the Construction Quality Assurance Plan [12-4].

12.5.1.3 Geosynthetic Clay Liner, Geogrid and Geotextile

The ECM GCL, geogrid and geotextile inspection and testing includes [12-1]:

- Quality control testing following technical specifications.

- Quality assurance testing following the Construction Quality Assurance Plan [12-4].

12.5.1.4 Leachate Collection and Removal System

The ECM leachate collection and removal system inspection and testing includes [12-1]:

- Leak testing of pumping system.
- Contact water pumping stations and LDSs.
- Force main LDS.
- Video of leachate piping to ensure no plugging or localized collapses.
- Testing of drainage system.
- Verification of pump capacity and delivery system.

12.5.2 Waste Water Treatment Plant

The WWTP and support buildings systems/components that require commissioning based on six design areas include the following [12-1]:

- Civil – WWTP, force mains, storm drainage system, and contact and leachate water pumping systems.
- Architectural – overhead powered/manual doors, access hatches, entry/exit doors, windows, electric hoists; and truck weigh scales.
- Mechanical – domestic hot and cold water, compressed air, sanitary drainage, storm water, HVAC equipment, supply air, inactive exhaust ventilation, active exhaust ventilation, motorized dampers, unit heaters, fire protection systems, radiation monitoring systems and vehicle decontamination systems.
- Building automation and control systems.
- Electrical – incoming power and switchgear, high voltage transformers, auto transfer switch, low voltage 600V distribution, low voltage below 120-280V distribution, diesel generator and Class III Power distribution, fire alarm system; security system, ground grids, non-emergency lighting, emergency lighting (including exit lights), lightning protection system, Class II uninterruptable power equipment, fire detection system, I&Cs/SCADA Systems, and voice/data communication.
- WWTP processes – tanks, pressure vessels, mixers, piping, pumps, level indication and alarms, membrane filter package system, filter press, and chemical addition systems.

12.6 Documentation

The pre-commissioning and commissioning activities will follow the documentation hierarchy in accordance with CNL's Commissioning Program [12-2] and [12-3].

The commissioning documentation consists of [12-2]:

- Commissioning Specifications and Objectives.
- System Commissioning Plans.
- Commissioning Procedures.
- Commissioning completion assurance record.
- Commissioning Report.

Commissioning procedures will be developed for all commissioning activities and the results from execution of the procedures will be recorded in the commissioning reports. A detailed commissioning and training schedule will be developed by the Commissioning Agent in accordance with specifications [12-1]. Pre-commissioning and commissioning forms will be developed by the Commissioning Agent as part of the detailed commissioning plan [12-1].

Forms will be used to document results of the commissioning activities and will be collated in the commissioning reports. Pre-commissioning and commissioning forms include [12-1]:

- Factory acceptance testing results.
- Site acceptance testing results.
- Installation/Start-Up Check Lists – installation details and point to point checks verification. Informs the Commissioning Team, which systems are ready for commissioning.
- Performance verification report forms – used for all components, sub-systems and systems. The testing and commissioning results are recorded on this form.
- Process verification forms – verification of the delivery, installation and performance of process components, sub-systems and systems.
- Training forms – to demonstrate that training has been provided for the equipment or system.
- Manufacturer/vendor supplied installation, start-up and functional verification forms – supplied from manufacturer/vendor as required.
- System functional performance testing – testing of the dynamic function and operation of equipment/systems to verify or validate that the performance meets the acceptance criteria specified in the design.
- Commissioning report – summarizing the commissioning objectives, commissioning results, and identified deficiencies either resolved or outstanding.

12.7 Turnover to Operations

The Facility will be turned over to NSDF Operations after completion of inactive commissioning activities and acceptance of the inactive commissioning by NSDF Operations.

12.8 References

[12-1] AECOM, *Commissioning Plan*, 232-505250-PLA-001, Revision 1, 2018 December.

[12-2] *Commissioning*, 900-505250-PDD-001, Revision 1, 2019 January.

[12-3] *Commissioning*, 900-505250-PRD-001, Revision 0, 2017 March.

[12-4] AECOM, *Construction Quality Assurance Plan,* 232-508244-QAP-001, Revision 2, 2019 September.

13. OPERATING EXPERIENCE

The CNL WMAs have been operating for more than 60 years without any significant adverse safety or environmental impact. This is indicative of the safe operating procedures followed in Facility operations and the reliability of the equipment used.

The design of the NSDF adopted nationally and internationally accepted best practices, identified through OPEX and LLD. Table 13-1 shows that CNL and AECOM, the design consultant, have designed and/or operated similar near surface waste facilities.

Table 13-1
CNL and AECOM Similar Near Surface Waste Facilities

Country	Name and Location	Organization	Role
Canada	Port Granby Waste Management Facility (PGWMF), Clarington, Ontario	AECOM	Engineer of record
		CNL	Operator and licensee
	Port Hope Waste Management Facility (PHWMF), Port Hope, Ontario	CNL	Operator and licensee
United States	Energy Solutions, Clive, Utah	AECOM	Technical advisor to regulator
	Waste Control Specialists, Andrews, Texas	AECOM	Design and engineer of record
	Maxey Flat, Fleming Country, Kentucky	AECOM	Design and engineer of record
	Environmental Management Waste Management Facility (EMWMF) at UCOR, Oak Ridge, Tennessee	AECOM	Design, engineer of record and operator
	Idaho Comprehensive Environmental Response, Compensation, and Liability Act Disposal Facility, Idaho Falls, Idaho	AECOM	Operator

A review of major hazards and OPEX was completed for the NSDF Project. The systematic review was completed to identify major hazards, initiating events and OPEX that is applicable to the NSDF during the pre-closure period. This review included:

- A review of all hazard assessments performed for the CRL WMAs.
- A review of OPEX using CNL’s internal OPEX and Improvement Action (ImpAct) database.
- A review of US NRC and US DOE OPEX.
- A review of events and hazards that have been identified and assessed in safety and hazard reports for “like” Facilities.
- A review of records of past incidents occurring in “like” Facilities.
- A compiled list of credible major hazards and initiating events applicable to the NSDF.

A number of NSDF hazard analysis were conducted during the NSDF design, to identify hazards and optimize the design to ensure protection of workers, public and the environment. Past incidents that occurred at CNL and internationally were reviewed to identify events that occurred in similar waste disposal facilities, or in other industries that utilized similar equipment or processes to those proposed for the NSDF. The OPEX review included:

- Reviewing the results of previous OPEX searches documented in CNL safety reports for "like" Facilities which are, CNL's Waste Management Areas Hazard Identification Report [13-1] and CNL's Waste Treatment Centre Hazard Analysis Plan [13-2].
- Database searches for more recent OPEX reports. Database searches included CNL's internal OPEX and Improvement Action (ImpAct) database; and US NRC and US DOE OPEX databases.

Table 13-2, provides a summary of the OPEX relevant to the NSDF during the construction, operations and closure phases. The OPEX in Table 13-2 is grouped into the following categories:

- Ageing management.
- Chemical handling.
- Configuration management
- Conventional safety.
- Criticality.
- Dropped waste package.
- Earthquake.
- ECM Fault.
- Environmental release.
- External Natural Hazards.
- Fire.
- Heavy equipment impact/near miss.
- Human error.
- Liquid containment failure.
- Loss of services/utilities.
- Loss of shielding.
- Procedures.
- Radiological contamination.
- Radiation exposure.
- Safety-related systems.
- Waste inventory/characterization.
- Waste package failure.

Canadian Nuclear Laboratories will continue to review internal and external OPEX and incorporate improvements into the Facility operations as necessary.

Table 13-2
OPEX Review

Hazard	Event Description	Location	Year	Source	Event ID
Ageing Management					
Degradation of SSC	Long-Term Operations: ageing management of concrete structures affected by alkali-silica reaction		2018	OPEX	OPEX-18-0341
	Deterioration of cover tarps.	CNL	2016	OPEX	D&WM-16-0034
	Acid splash to face - Aged and degraded container allowed liquid to pool into secondary transport container		2018	OPEX	OPEX-18-0733
Chemical Handling					
Unanticipated Chemical Reaction	Unanticipated Chemical Reaction During Waste Load-Out. The reaction was the result of the fogging agent used for airborne radioactivity control coming into contact with dried residual chemicals on the floor.	Hanford	2016	OPEX	2016-RL-HNF-0007
	Unanticipated Reaction between a Spilled Chemical and the Spill Absorbent. While the manufacturer's labeling on the GREEN STUFF states that it is tested to be compatible with over 300 chemicals, this should not lead to the assumption that it is compatible with all chemicals.	Brookhaven National Lab	2016	US DOE	2016-BNL-Spill-0001
	Chemical incompatibility: Incidents reflect hazards of inadvertently mixing incompatible chemicals. After transferring waste organic solvents into a satellite container in a fume hood, a technician in a commercial Research & Development lab emptied a bottle of 30 percent hydrogen peroxide into the same container, causing a violent reaction that filled the lab with smoke and prompted evacuation. At another commercial lab, a technician poured two bottles of nitric acid into a waste container and later added a small quantity of acetic acid, causing a violent reaction that sprayed material on her lab coat and clothing.	Pacific North West National Lab	2012	US DOE	
Poisonous Gas	A Boat Maintenance Crew Supervisor Dies of Carbon Monoxide Poisoning While Using a Gasoline-Powered Pressure Washer.	Washington State	2012	NIOSH	
	An early warning system alarm was triggered, indicating that elevated levels of hydrogen sulphide gas were present. Hydrogen sulphide is a typical by-product of wastewater collection and treatment processes. Upon hearing the alarm, all personnel followed procedure and exited the building immediately. As a precaution, two workers sought medical evaluation.	PGWMF	2017	Port Hope Area Initiative Public Disclosures	-
	PHAI - Off gas generated during regular clean by outside contractor on the Membrane Bioreactor at new Port Granby WWTP. During a routine Membrane Bioreactor cleaning performed by GE (an outside contractor) at the Port Granby Water Treatment Plant there was a considerable amount of off-gas (chlorine) generated, resulting in some minor irritation to operators eyes and the area smelt of chlorine gas fumes.	PHAI	2015	OPEX	D&WM-15-1975
	PGWWTP - Hydrogen Sulphide Alarm	PGWMF	2017	OPEX	D&WM-17-0193
	Work Accident in Water Treatment Plant due to Ingress of Chlorine Gas into the Venting Pipes		2019	OPEX	OPEX-19-0025
Incorrect Flammability Classification of Tank	Incorrect Flammability Classification on Tank 22 - Incorporation of the heat load attributed to the solids inventory into the WCS database changed the Tank 22 classification, a status based on flammability characteristics, from "very slow" to "slow"	Savannah River	2014	US DOE	2014-SR-SRR-02
Chemical Leak/Release	Issue Identified With A Vendor Chemical Tote Nozzle at H Tank Farm. The vendor nozzle dimensions to be different than the standard tank farm nozzle/dimensions. This difference created an interference in the mating surfaces and prevented the nozzle from proper connection with the sealing surface on the hose. This issue could have resulted in a leak and possibly exposed personnel or the environment to the contents of the tote, which at the time was 13% Nitric Acid.	Savannah River	2013	US DOE	2013-CTS-001176

Hazard	Event Description	Location	Year	Source	Event ID
	Consider the Worst-case Scenario When Selecting Personal Protective Equipment - acid droplets ran off the nitrile glove, through the gap between the glove and Tyvek coverall, and onto the researcher's bare forearm.		2017	US DOE	LL-2017-LLNL-5
	Diesel Fueling Nozzle Automatic Cut-off Failure at the Paducah Gaseous Diffusion Plant (PGDP). If an operator at any fueling station places absolute reliance upon the commercially provided and acceptable cut-off valves and should they leave the fueling operation unattended for an extended period of time, then large quantities of fuel could be spilled	Paducah Gaseous Diffusion Plant	2011	US DOE	2011 – URSMSLL - 005
	Disconnection of Fittings Sprays Caustic. Venting of systems is paramount when attempting to disconnect fittings. Pressurized systems have been found to be extremely dangerous, and accidents/fatalities have been the result of exposure to pressurized systems.	Hanford	2013	US DOE	WRPS-IB-13-020
	Flammable cabinet venting - The vents should be installed when the cabinet is indoors and removed when the cabinet is outdoors.	USA	2010	US DOE	RPP-WTP-SB-070710
	Inspect Chemical Glove Prior to Use - Reusable chemical gloves must be inspected for integrity before each use and replaced regularly.	Hanford	2012	US DOE	2012-ANL-011
	Nitric Acid Tank Over Fills causing an estimated 150 gallons of nitric acid solution to overflow from the tank and flow into the tank off-gas piping, scrubber and filter housing	Bechtel Jacobs	2009	US DOE	B-2009-OR-BJCWM-1002
	Safety Shower and Eyewash Reminder - worker failed to remove contaminated clothing resulting in burns	Livermore	2013	US DOE	LL-2013-LLNL-21
	Port Granby Waste Management Facility - On December 1, one of the waste loads contained a partially degraded drum with unknown chemical constituent. The waste load was subsequently placed into the cell and spread by the bulldozer operator. During spreading activities the drum was ruptured causing the chemical to flow out of the drum. The operator of the excavator in Cell 1 complained of eye and respiratory irritation and nausea at approximately 10 am. He was taken to hospital for assessment at approximately 12:30 pm, and ultimately released and back at site by the end of the work day.	PGWMF		OPEX	S-EFDR # 4
	Ferric Chloride Leak from Chemical Metering Pump at Port Granby Waste Management Facility	PGWMF	2012	OPEX	D&WM-12-7758
	Ferric Chloride Leak at Port Granby Waste Management Facility	PGWMF	2012	OPEX	D&WM-12-8178
	Waste Treatment Center (WTC) Operator sprayed with cleaning solution during rubber pipe failure	CRL	2010	OPEX	OPS-10-9643
	Port Granby Project - Noxious Vapours Encountered During Waste Excavation. Two workers were exposed to unknown hazard suspected to be Ammonia liquid and vapours.	PGWMF	2016	OPEX	D&WM-16-7033
	PGWMF - Cracked PVC Fitting on HCl Acid Pump	PGWMF	2012	OPEX	D&WM-12-10122
	PGWMF - Port Granby Waste Management Facility - Hydrochloric Acid Leak	PGWMF	2015	OPEX	D&WM-15-8607
	PGWWTP - Phosphoric Acid Leak from Storage Tank for Evaporator/Slurry Dryer CIP Systems	PGWMF	2015	OPEX	D&WM-15-1732
	PGWWTP - Methanol Leak from Back Pressure Valve	PGWMF	2015	OPEX	D&WM-15-5998

Hazard	Event Description	Location	Year	Source	Event ID
	Near Miss: PGWWTP - Phosphoric Acid Leak Due to Unexpected Pump Start	PGWMF	2015	OPEX	D&WM-15-7453
	Chemical Spill Due to Faulty Fitting	PHAI	2016	OPEX	D&WM-16-5714
	PWGSC Contractor Event - Hydrochloric fumes found in chemical storage room during delivery	PGWMF	2014	OPEX	D&WM-14-7535
	Contractor personnel splashed with sodium hydroxide	Embalse	2018	OPEX	EB-18-18
	HWP - PH LTWMF- Worker splashed with Pro Guard Mag Dust Suppressant	PHAI	2019	OPEX	D&WM-19-0288
Configuration Management					
Configuration Errors	B240 power accidently disconnected due to inaccurate drawings	CRL	2008	OPEX	ISS-08-08006
	Configuration Management - labeling incorrect on 200 amp electrical panel	CRL	2012	OPEX	D&WM-12-6533
	Improper labelling of valves in B240. Valve numbers were marked on wall instead of having valve tags.	CRL	2008	OPEX	D_WM-08-05746
	Lack of control of master drawings at the WTC.	CRL	2009	OPEX	D_WM-09-04701
	Waste Treatment Center does not have a well-established jumper process.	CRL	2009	OPEX	D_WM-09-05162
	WTC Abnormal Configuration - Suppressed B240 Tank 2 Alarm	CRL	2012	OPEX	OPS-12-6206
	MEL does not exist for B574	CRL	2013	OPEX	OPS-13-1499
	WTC Abnormal configuration for B574 commissioning	CRL	2013	OPEX	OPS-13-5958
	Historic water line exposed and severed during digging of trench to place PVC ducts for THA 31 construction trailer.	CRL	2010	OPEX	D&WM-10-8048
	Inconsistent Labelling of pumps in WTC Bituminization Process Drawings	CRL	2016	OPEX	ENG-16-2422
	Overhead beams in WTC are not all marked with load rating capabilities.	CRL	2008	OPEX	D_WM-08-09818
	No Area Available Within WMA B to Dump Snow Removed From Security Compound	CRL	2010	OPEX	D&WM-10-2592

Hazard	Event Description	Location	Year	Source	Event ID
	Ventilation Concern. Recent changes to Facility ventilation allowed supply air to blow down in the vicinity of the west port, creating air turbulence in an area that high risk tasks are performed.		2011	OPEX	OPS-11-2777
Conventional Safety					
Unauthorized Entry	Entering Work Area without Proper Notification	Fluor BWXT Portsmouth	2012	US DOE	Y-2012-FBPORTS-0501
Working at Heights	Employee Falls from Utility Pit Ladder - While climbing a fixed vertical ladder to exit the utility pit, the pipefitter's left foot began to slip during, or directly after, transitioning the right hand from the final ladder rung to the vertical post of the handrail located outside the pit. The transition from the ladder to the exterior handrail, the extended reach needed to grip the exterior handrail, as well as the muck on the bottom of his shoes, caused his left foot to slip 'very unexpectedly' on the ladder rung.		2016	US DOE	Y-2016-CNS-Y12-10372
	Employee falls into bunker during waste emplacement	CRL	2011	OPEX	D&WM-11-3969
	OPEX Review - PHAI - EB-15-25, EB-15-26 Fukushima Workers fatally injured while working at heights	PHAI	2015	OPEX	D&WM-15-1107
	PGWWTP - Safety Guards for Work around open septic tanks required	PGWMF	2015	OPEX	D&WM-15-1738
Blasting	Fatal Injury from Blast Rock. Worker was approximately 1 200 feet from the blast area.	USA	2016	MSHA	
Biological Hazard	Racoon and Rodent Feces in WMA(Waste Management Area) Bunker	CRL	2009	OPEX	D&WM-09-31797
	Biological Hazard - Hantavirus - The deer mouse is the major reservoir for Sin Nombre virus.		2011	MSA	
	PHAI-MO Insect Bites	PHAI	2010	OPEX	D&WM-10-9483
	PHAI Employee Injury - Wasp sting at Port Granby	PHAI	2012	OPEX	D&WM-12-7851
	Avoiding Problems with Wasps	Livermore	2012	US DOE	LL-2012-LLNL-09
	PHAI - Employee Receives Poison Ivy Exposure at PGWMF	PHAI	2013	OPEX	D&WM-13-7700
	Review of OPEX Alert: Employee comes into contact with Poisonous Tussock Caterpillar at CNL IB-15-31	PHAI	2015	OPEX	D&WM-15-5851
Noise	Hearing Protection with Communication Capabilities Proposed for Power Plant Workers	Los Alamos National Lab	2018		LANL-2018-1487
	Noise meter failed post-test calibration check.		2015	OPEX	D&WM-15-4364

Hazard	Event Description	Location	Year	Source	Event ID
Hoisting & Rigging Worker Fatality/Injury	Lifting, Rigging, and Material-Handling Concerns. Workers were lifting an electrical cable reel with a nylon sling installed through the center of the reel. The weight of the load was not confirmed to be within the sling lifting limit.	WL	2011	OPEX	D&WM-11-3453
	Lifting and rigging injury. Minor injury to worker's wrist and shin as a result of a motor slipping on a sling during a lift.	CRL	2011	OPEX	OPS-11-4880
	Pipe Safety Alert - Since 2008, six miners have died as a result of accidents related to handling large diameter pipe.	USA		MSHA	
Line of Fire	Fatal fall Accident. Victim was standing on top of the drive belt guard signaling the excavator operator when he was hit with the excavator bucket.	USA	2014	MSHA	MAI-2014-30
	OPEX: PHAI Review of OPEX ImpAct D&WM-12-5665 "Near Miss: Relief Valve Discharges into Employees Face" on PGWMF operations	PGWMF	2012	OPEX	D&WM-12-7471
	HWP - PH WWTP - Irritant Splashed Into Left Eye	PHAI	2019	OPEX	D&WM-19-0276
	Overhead Object Falls from Bridge Crane Striking Worker Below	Fluor BWXT Portsmouth	2019	OPEX	OPEX-19-0037
	CNL - Overhead Door Malfunction Leads to Discovery of Unsafe Condition		2018	OPEX	OPEX-18-1215
Arc Flash	PGWWTP - 600 V Disconnects do not have Arc Flash Incident Energy Ratings	PGWMF	2016	OPEX	D&WM-16-0902
Confined Space	PGWWTP - Operations Staff unaware of Confined Space Entry re-designation for Bioreactors	PGWMF	2016	OPEX	D&WM-16-1076
Criticality					
Criticality	Receipt of Fissionable Material without required documentation.	CRL	1992	CRL	UER-COB-92-04
	Violation of criticality approval CA-131B-R5 storage limits	CRL	2000	OPEX	PER-WMA-00-02
	Spent fuel assemblies placed into storage casks before require five-year cooling time	USA	2000	US Nuclear Regulatory Commission	MR Number: 3-00-0038
	High-enriched uranium security limit exceeded	CRL	2005	OPEX	ENF-NFFF-05-06R
	Received 022 flask with wrong amount of fissionable material	CRL	2006	OPEX	ENF-FMC-06-08
	Incorrectly labeled fissionable material	CRL	2006	OPEX	ENF-9100-06-04
Dropped Waste Package					

Hazard	Event Description	Location	Year	Source	Event ID
Dropped Load	How to keep winch cable attached to waste container	Hanford	2015	US DOE	RCCC-2014-0023
	Shielded Box slides off forklift tines following encounter with unstable soil.	Washington Closure Project	2015	US DOE	RCCC-2015-0014
	Roll On/Roll Off Disposal Container Tips During Dumping Process	River Corridor Closure Project	2016	US DOE	RCCC-2011-0016
	Roll-off truck winch failure. The hook at the end of the winch cable failed and recoiled over a high voltage powerline.	USA		MSHA	
	Failure of a reeving cable during unloading of a full roll-on/roll-off container caused the container to partially drop, coming into contact with an adjacent container. Neither container sustained damage.	River Corridor Closure Project	2011	US DOE	RCCC-2011-0027
	Flask slipped and fell off the trailer	CRL	1993	CRL	UER-TB-93-01
	Flask F-003 cable break	CRL	2002	OPEX	PER-WMA-02-03
	Radioactive waste bag falls off WMA waste wagon	CRL	2009	OPEX	D_WM-09-08569
	OPEX - PHAI - Assessment of ImpAct OPS-13-4462 "Chain Hoist Fails While Lifting Concrete Slab" on PGWMF Operations	PHAI	2013	OPEX	D&WM-13-6142
	B-25 Bin Tips During Loading at WMA	CRL	2018	OPEX	D&WM-18-3987
	Safety: drum lifter removed from service		2010	OPEX	D&WM-10-0967
Earthquake					
Earthquake	WTC Response to Earthquake	CRL	2010	OPEX	OPS-10-5631
ECM Fault					
Damaged SSC	Unstable Soil Conditions Result In Tipped Dump Truck. During the process of raising the bed of the trailer, and with simultaneous shifting of the weight of the soils in the trailer, the left rear wheels of the trailer to slide into a depression which had been partially covered by disturbed soils during the initial site preparation activities resulting in the cab and trailer tipping over on its side.	Hanford	2010	US DOE	2010-RL-HNF-0036
	Trucks loads generated greater than allowed ground pressures, causing depressions in the compacted soil-bentonite admix layer of base liner	River Corridor Closure Project, Richland, Washington, USA	2008	US DOE	RCCC-08-014
	Sink hole discovered over buried sand trench in WMA B	CRL	2012	OPEX	D&WM-12-5969

Hazard	Event Description	Location	Year	Source	Event ID
	Sink Hole Discovered In WMA B	CRL	2013	OPEX	D&WM-13-6337
Slips, Trips and Falls	Dangerous walking conditions in WTC patrol area during winter conditions	CRL	2008	OPEX	D_WM-08-06890
Erosion	Large washout discovered at north end of WMA tile array	CRL	2013	OPEX	D&WM-13-8263
Environmental Release					
Contamination – Airborne Release	Air Monitoring TSP Exceedance	PHAI	2014	OPEX	D&WM-14-3241
	High TSP Concentration at Port Granby East and South HiVols (2016 May 30)	PGWMF	2016	OPEX	D&WM-16-4215
	High TSP Concentration at Port Granby East HiVols (2016 May 31)	PGWMF	2016	OPEX	D&WM-16-4738
	High TSP Concentration Port Granby East HiVol (2016 July 13)	PGWMF	2016	OPEX	D&WM-16-5125
	TREND - High Dust Levels at the PG LTWMF Project	PGWMF	2016	OPEX	D&WM-16-5134
	High TSP Concentration, Port Granby South Hi-Vol (2016-August-09)	PGWMF	2016	OPEX	D&WM-16-5686
	High TSP Concentration, Port Granby South Hi-Vol (2016-Sept-01)	PGWMF	2016	OPEX	D&WM-16-5795
	Contamination discovered outside WMA B fence.	CRL	2008	OPEX	D_WM-08-06756
	Contamination discovered outside WMA B fence.	CRL	2008	OPEX	D_WM-08-07376
	TREND - Air Effluent Exceedances of I-131 at a Number of Facilities Across the Chalk River Site in Early October 2013	CRL	2013	OPEX	OPS-13-10427
	Exceedance of tritium oxide administrative level at B570 WTC E11 sample point.	CRL	2009	OPEX	D_WM-09-05915
	High TSP Concentration Port Granby East Hi-Vol (2016 July 26)	PGWMF	2016	OPEX	D&WM-16-5607
	PHAI - Off gas generated during regular clean by outside contractor on the Membrane Bioreactor at new Port Granby Waste Water Treatment Plant	PHAI	2015	OPEX	D&WM-15-1975
Contamination – Liquid Release	Unplanned Water Discharge - Insufficient Oversight and Lack of Communication Contribute to Unplanned Water Discharge. Upon investigation, it was found that the compression fitting was not fully clamped onto the backflow assembly pipe, allowing them to separate after personnel left the job site.	Hanford	2011	US DOE	IB-11-007

Hazard	Event Description	Location	Year	Source	Event ID
	CNSC issues an Order to MOECC to cease any remediation activities that could increase environmental risk from sediment cleanup work at the Young's Creek Area project (at the decommissioned Deloro mine).	Deloro Mine Site, Ontario	2015	CNSC Hearing	CMD-16-M6/16-M6.A
	A break in a shallow underground pipe occurred during construction activities at the Port Granby LLRW Management Facility. A small quantity of untreated water entered the treated effluent discharge system. Within 30 hours of detection, the source of untreated water was identified and repairs were made.	PGWMF	2016	Port Hope Area Initiative Public Disclosures	-
	Exceedances during spring 2014 groundwater monitoring at Port Hope Long Term Waste Management Facility (LTWMF)	PHAI	2014	OPEX	D&WM-14-7322
	Environmental parameter (uranium concentration in standing water in catch basin) exceeds investigative threshold	Low-Level Radioactive Waste Management Office (LLRWMO)	2014	OPEX	D&WM-14-8395
	Pine Street Extension Consolidation Site (PSE CS) groundwater well 93-6-II dissolved uranium exceedance of investigative threshold	LLRWMO	2013	OPEX	D&WM-13-7223
	Port Granby Equalization Pond Level Height Above the Maximum Operating Height	PGWMF	2017	OPEX	D&WM-17-0626
	Port Granby West Gorge Reservoir Overflow - approximately 2.5 to 7 m^3 of water discharged from the West Gorge Reservoir (WGR) to the surrounding environment but did not leave the licensed site. The WGR was constructed in the 1970s as part of the legacy water collection and treatment system, it is known to have overflowed on a seasonal basis and due to this, the West Gorge has legacy related contamination. The gorge will be remediated as part of the Port Granby Project (PGP)	PGWMF	2018	OPEX	D&WM-18-0289
	OPEX: IB-10-23 Waste Treatment Center Tank 2 Leak & Response	CRL	2010	OPEX	P&NO-10-5613
	Water pumped from manholes to drainage ditch outside the boundary of the Welcome WMF.	PHAI	2014	OPEX	D&WM-14-3639
	Overflow of Primary Containment for Radioactive Solution due to Siphoning	CRL	2018	OPEX	R&D-18-3081
	PHAI - PGWMF - Toxicity Failure of Total Interceptor Discharge - 23 January 2013	PHAI	2013	OPEX	D&WM-13-1516
	Sewage Treatment Plant Temporary Storage Site (STP TSS) west groundwater well dissolved uranium exceedance of investigative threshold	PHAI	2013	OPEX	D&WM-13-7218
	PHAI - Action level exceedance at WWMF	PHAI	2013	OPEX	D&WM-13-7323
	PGWWTP - Unintended discharge of 10% Lime Solution	PGWMF	2016	OPEX	D&WM-16-4892
	Conductivity exceeded Internal Investigation Level (IIL) at WTC_LWE monitoring point for 2010 March	CRL	2010	OPEX	OPS-10-4543

Hazard	Event Description	Location	Year	Source	Event ID
	Mercury Site License Limit Exceedances in WTC Liquid Waste Evaporator (LWE) Distillate	CRL	2010	OPEX	OPS-10-12931
	Phenolics Concentration Exceeded the AECL guideline limit at WTC	CRL	2011	OPEX	OPS-11-2394
	Total Organic Carbon Concentration Exceeded the IIL limit at WTC	CRL	2011	OPEX	OPS-11-7703
	TREND - Conductivity Exceeded Limit at WTC_B205	CRL	2012	OPEX	OPS-12-3559
	Chloroform Concentration Exceeded the IIL limit at WTC	CRL	2012	OPEX	OPS-12-3561
	Chemical Oxygen Demand Concentration Exceeded the IIL limit at WTC	CRL	2012	OPEX	OPS-12-3565
	Dissolve Organic Carbon Concentration Exceeded the IIL limit at WTC	CRL	2012	OPEX	OPS-12-4381
	Total Organic Concentration Exceeded the IIL limit at WTC	CRL	2013	OPEX	OPS-13-0978
	Contaminated water discovered in storm water ditch at PG LTWMF	PGWMF	2017	OPEX	D&WM-17-0153
	Hole discovered in (possibly active) fume hood plastic exhaust duct.	WL	2008	OPEX	D_WM-08-00225
Leaks and Spills	Hydraulic Spill - Construction area of SMAGS - July 14, 2010 *Duplicate ImpAct of ImpAct D&WM-10-8506*	CRL	2010	OPEX	D&WM-10-8494
	Transmission fluid from mobile crane leaks onto ground at WMA B	CRL	2014	OPEX	D&WM-14-1489
	Small hydraulic oil spill discovered on gravel within WMA B	CRL	2018	OPEX	D&WM-18-1881
	EW1 Contractor reported a Hydraulic Fluid Spill	PHAI	2016	OPEX	D&WM-16-6069
	EW1 small diesel spill	PHAI	2016	OPEX	D&WM-16-6674
	HWP - SSS - Metro Fuel Spill	CRL	2019	OPEX	D&WM-19-0336
	Small Transmission Fluid Leak From Mobile Crane Within WMA B	CRL	2013	OPEX	D&WM-13-4956
	WL EnvP - Hydraulic fluid spill of approximately 5 litres in WMA - Not Reportable	WL	2016	OPEX	D&WM-16-4008

Hazard	Event Description	Location	Year	Source	Event ID
	WL Environmental Protection - hydraulic fluid spill was reported in the WMA at soil sorting location.	WL	2014	OPEX	D&WM-14-3020
External Natural Hazards					
Endangering Wildlife	Bollards and Fence Posts with Open Tops Have Led to Bird Entrapment and Mortality	Los Alamos	2013	US DOE	LANL-ADESH-2013-2696
	Birds Nest with Live Hatchlings found inside a Bobcat Skidsteer	Idaho National Lab	2010	US DOE	2010-ID-AMWTP-0011
	Summertime Pests & Animal Encounters - what to do		2011	MSA	
	Preventing Human-Wildlife Conflicts: Canada Geese	Livermore	2013	US DOE	LL-2013-LLNL-03
	Protecting migratory birds	Pacific Northwest	2013	US DOE	
Freezing	Inadequate Implementation of Freeze Protection Strategies resulted in Sprinkler Activation	CRL	2018	OPEX	OPEX-18-1098
	B574 Heat Trace Failed	CRL	2017	OPEX	OPS-17-4314
	B574 - Failed Heat Trace	CRL	2019	OPEX	OPS-19-0146
Ice Storm	Improper Sign Off of FPS (THRR) Project Construction Electrical Inspection & Test Plans (ITP's). Due to freezing rain trees and branches have fallen at the Port Granby Waste Management Facility property. The East gate cannot be accessed because the roadway is covered with trees and branches.	PGWMF	2014	OPEX	D&WM-14-0157
	OPEX EmP - Toronto Ice Storm 2013 December		2014	OPEX	OPS-14-0013
Severe Precipitation	Potential for Flooding at Brewery Pond on AECL-owned land located at 228 Cavan Street Port Hope Ontario	LLRWMO	2014	OPEX	D&WM-14-4949
	Erosion at Pine Street Extension Roadway	LLRWMO	2014	OPEX	D&WM-14-5788
	Outer Area Road Wash-out	PHAI	2010	OPEX	OPS-10-2689
	Uncontrolled discharge at PGP from East Gorge Reservoir Sump - On 2017 June 23 the region around Port Granby received significant rainfall in a very short period of time. Localized flooding, road closures were occurring at the time. Based on the weather forecast, mitigating steps to control water levels at the East Gorge Reservoir had been taken in advance. Initially, the East Gorge Sump / water management was keeping up with the accumulating rain water by pumping directly to the WWTP. At approximately 9 am, workers noticed the pump could not move the water at the required rate to keep the Gorge water levels from rising / potentially over flowing. Due to the amount of rainfall the WWTP had to throttle the inlet to the plant as the WWTP could not handle the inflow rates; and the valves were realigned so that the East Gorge Reservoir water could be pumped into the Equalization Pond. During this	Port Granby	2017	OPEX	D&WM-17-2973

Hazard	Event Description	Location	Year	Source	Event ID
	period a small amount of the water overtopped the EGR sump and an estimated 2 to 5 m^3 of water went into the East Gorge standpipe overflow, which terminates before the lake (note: the standpipe was installed in the 1970s to mitigate / provide dam protection).				
Severe Wind	Hurricane Preparedness		20118	US DOE	
	Storm Ripped the LLRWMO PSE TSS Pad 2 Tarp	LLRWMO	2015	OPEX	D&WM-15-8757
	No flow chart recordings due to strong wind		2014	OPEX	D&WM-14-1022
Fire					
Fire	Heavy equipment vehicle fires and suppression systems. Three fire events and a TSR violation involving fire suppression systems at Environmental Management (EM) sites have occurred since 2014 associated with diesel powered heavy equipment vehicles.	Hanford	2017	US DOE	EM-SR--SRNS-CPWM-2017-0003
	Haul Truck Electrical Fire	Energy Solutions	2011	US DOE	2011-MB-002
	Spontaneous combustion of waste in Waste Storage Bunker CD-77	CRL	1987	CRL	Fire Investigation Report No. 63
	Minor vehicle fire – crane in WMA “B	CRL	1997	CRL	ASR-1
	WMA D Fire, welders cutting up a marine container with a Broco torch	CRL	2012	OPEX	D&WM-12-5499
	Fire at Fort McMurray Long-Term Waste Management Facility Resulting in Burn of Vegetation on Top of Mound	For McMurray	2016	OPEX	D&WM-16-3303
	WMA D Compound Fire	CRL	2012	OPEX	D&WM-12-7523
	UPS Battery Fire During Testing Activities	Taishan	2019	OPEX	OPEX-19-0104
Heavy Equipment Impact / Near Miss					
Collisions/Struck-by	Overhead Power Line Strike at PGWMF	PGWMF	2017	OPEX	D&WM-17-0281
	Bulldozer blade ruptured a 16-inch diameter high-pressure natural gas transmission line	USA		MSHA	
	A power line was pulled and separated at the hydro pole near Port Hope Area Initiative Facility due to PWGSC excavation activities.	Welcome Waste Management Facility	2013	CNL	D&WM-13-5776

Hazard	Event Description	Location	Year	Source	Event ID
	Auxiliary natural gas line struck during excavation activities.	Argonne National Lab	2015	OPEX	2015-ANL-010
	Backhoe carrying culvert on-site access road drives into work van at speed exceeding limits.	Port Hope WWTP Access Road	2014	CNL	D&WM-14-8963
	An excavator with the boom raised was driven through a power line. This caused the electrical poles to snap and the line to droop.	PGWMF	2017	CNL	D&WM-17-0281
	HWP - PH-LTWMF - Property damage - excavator 750 scratch beam of the on-site waste portal	PHAI	2018	OPEX	D&WM-18-1454
	PH-LTWMF Rock Truck Operator contacted the side rails of the inbound scale, for off-site waste, with the front right wheel of equipment.	PHAI	2018	OPEX	D&WM-18-2034
	HWP - PH LTWMF - Excavator contact with mobile pump	PHAI	2018	OPEX	D&WM-18-2618
	HWP - PH LTWMF - Pick-Up Truck Contact with Rock Truck 2018-Aug-26	PHAI	2018	OPEX	D&WM-18-3170
	HWP - PH LTWMF - Aggregate delivery truck contact with parked equipment	PHAI	2018	OPEX	D&WM-18-3172
	Cell 1 (EW1) construction - rock truck mirror damaged while parking	PHAI	2017	OPEX	D&WM-17-1670
	PH-EW1 Heavy Equipment contact	PHAI	2017	OPEX	D&WM-17-2257
	Equipment Contact incident LTWMF	PHAI	2017	OPEX	D&WM-17-4896
	LTWMF - Port Hope. Packer backed into fueling pickup truck	PHAI	2017	OPEX	D&WM-17-4969
	HWP - PG WMF - Minor Accident Involving UTV at Port Granby WMF Site	PGWMF	2018	OPEX	D&WM-18-0660
	Minor Motor Vehicle accident at WMA B	CRL	2015	OPEX	OPS-15-3049
	Near accident on roadway to WMA C	CRL	2015	OPEX	OPS-15-6252
	Traffic Accident Occurs On Plant Road in Front of WMA B	CRL	2010	OPEX	P&NO-10-4793
	Tractor Trailer Jack Knife in front of 457 B	CRL	2019	OPEX	P&NO-19-0209
	PGP Near Miss: rock truck struck de-energized suspended line	PHAI	2016	OPEX	D&WM-16-5571

Hazard	Event Description	Location	Year	Source	Event ID
	Unexpected Crane Movement with an Attached Load	IDAHO National Lab	2019	OPEX	OPEX-19-0174-002
	There has been a trend of traffic/heavy equipment related incidents recently at the Port Hope and Port Granby construction sites.	PHAI/PGWMF	2016	OPEX	D&WM-16-6272
	5 Electrical Lines Severed During Excavation For FPS Construction - 4 Live & 1 Dead	CRL	2011	OPEX	OPS-11-5604
	4800 V line pulled and separated at the hydro pole near PHAI Facility due to PWGSC excavation activities in construction Island	PHAI	2013	OPEX	D&WM-13-5776
Rollover/Tipping	A non-fatal accident occurred when a bulldozer over-turned on an embankment, rolling onto a bench below. Low temperatures and frozen ground created the condition, which lead to the accident.	USA		MSHA	
	Excavator Dig-Face Slide-Off During Exhumation Operations, the edge sloughed off of an adjacent open 21-foot deep pit causing the excavator to slide into it	Fluor Idaho	2017	US DOE	FID-2017-1924
	Front-End Loader Tip Over. When stockpiling materials using a front-end loader, ensure that the dirt or gravel ramp is relatively uniform, has adequate compaction, and is wide enough to safely accomplish the task at hand.	Hanford	2011	US DOE	2011-RL-HNF-0051
	A waste vehicle was left unattended with the motor running. The vehicle rolled into a waste cell and sustained minor damage.	Environmental Management Waste Management Facility	2011	US DOE	Y-2011-OR-BJCEMWMF-0701
	Truck transporting a waste container drove off of road due to operator error, rolled and spilled waste contents.	River Corridor Closure Project	2012	US DOE	RCCC-2012-0006
	WL Equipment - WMA: Loader slides into ditch while snow clearing	WL	2017	OPEX	D&WM-17-5286
	Rock Truck Box Rolls Over (Erosion Control by External Contractor at WMA A & PRB Project)	CRL	2014	OPEX	OPS-14-7583
	EW1 Water wagon tipped over from becoming unstable in the Cell 1 footprint	PHAI	2016	OPEX	D&WM-16-6087
	Water tractor tipped over on its side, no injuries	PHAI	2016	OPEX	D&WM-16-6769
	EW1 Dozer slides off the berm due to surface ice on the clay, causing no injuries.	CRL	2016	OPEX	D&WM-16-6811
	On 2012 November 8, at between 8:00 and 8:30 am, an incident involving heavy equipment at the Elliott Road construction site did not get reported to PHAI-MO management until about 11:00 am. The incident involved a dump truck delivering a load of gabion stone to the Port Granby Project's Elliott Road site. The delivery was with a tractor trailer-type dump truck with a capacity of about 25 tonnes. The load of stone was being dumped and when the dump box reached its maximum extension, the box suddenly tipped sideways, broke off the trailer frame and fell to the ground, spilling its load of stone.	PHAI	2012	OPEX	D&WM-12-8854
	Riding mower accidentally slips into South Settling pond at Welcome site	PHAI	2016	OPEX	D&WM-16-3497

Hazard	Event Description	Location	Year	Source	Event ID
	HWP- Port Hope LTWMF - Vehicle box roll-over while working on Ponds Expansion	PHAI	2017	OPEX	D&WM-17-5162
	HWP - PG WMF - Port Granby Heavy Equipment Near Miss Incident - AMECFW Subcontractor Rock Truck Box Tilted	PGWMF	2018	OPEX	D&WM-18-1143
	HWP - Trend Identified on Increase in Rock Truck Tipping Incidents at Port Hope and Port Granby Projects	PHAI	2018	OPEX	D&WM-18-1407
Struck-By	Grade Checker Severely Injured When Backed Over by Grader	Washington State Department		SHARP	71-142-2015s
	CAT excavator models 345C, 345CL, 345D, and 345DL need valve inspection, the main hydraulic control valve may stick causing the machinery to move unexpectedly which could result in serious injury or death.	River Corridor Closure Project	2009	US DOE	RCCC-09-018
	Skid Steer Loader Operator Fatally Crushed	Washington State Department	2017	NIOSH	71-166-2018s
	SMAGS Construction Island - Contractor Injury. While a General Contractor's" sub" was unloading an office trailer, the load bindings hit him in the leg as he was releasing the pressure from the bindings. It was suspected that he sustained a fracture of his right leg below the knee.	CRL	2010	OPEX	D&WM-10-5087
	PHAI - OPEX - Assessment of ImpAct D&WM-12-6444 "Near Miss Trailer Hitch Uncouples During Loading" on PGWMF Operations	PHAI	2012	OPEX	D&WM-12-9771
	OPEX - External Safety Event - Construction Worker Struck and Killed While Acting as Site Traffic Control Person	Milton, ON	2014	OPEX	D&WM-14-7275
	HWP - TSS STP - Spotter Contact with Reversing Truck	PHAI	2019	OPEX	D&WM-19-0125
	HWP - PG LTWMF - Subcontractor Injures leg during bin roll off	PGWMF	2019	OPEX	D&WM-19-0080
	HWP - TREND - Increase in number of incidents relating to heavy equipment contact	PHAI	2019	OPEX	D&WM-19-0130
	Contractor Injured when Trapped between Forklift and Railing		2018	OPEX	OPEX-18-1185
Speeding	AECL Vehicle Observed Speeding on the Welcome Waste Management Facility Road.	PHAI	2013	OPEX	D&WM-13-5247
	Driving speed exceeded the posted site limits	PHAI	2013	OPEX	D&WM-13-6412
Human Error					
Human Error	Leak Detector Response Inadequately Performed - certain assumptions (bases) were not met (amount of waste) to validate the leak. In this particular case, a small leak tripped the leak detector before the radiation levels were present as modelled in the radiological monitoring plan.	Richland Operation	2013	US DOE	WRPS-IB-13-028

Hazard	Event Description	Location	Year	Source	Event ID
	WMA “G” canisters not monitored as required	CRL	1991	CRL	ASR-5
	Incomplete flask transfer form	CRL	1999	CRL	PER-FMC-99-04
	Irradiated material transferred between facilities without proper paperwork	CRL	2000	CRL	PER-UC-00-06
	PGWWTP - Slurry Dryer Door Near Miss, a slurry dryer door was inadvertently opened while the drain wand was still in the drain port in the door. No injury or equipment damage occurred.	PGWMF	2015	OPEX	D&WM-15-1760
Liquid Containment Failure					
Containment Failure	CH2MHill Plateau Remediation Company, Hanford Site (CHPRC) - A four inch diameter schedule 80 PVC pipe ruptured scattering pieces of PVC pipe to multiple locations within the room. There was no damage to other operating equipment, no release of sludge (mixture of organics and water) outside the containment area and no injuries to personnel. Three factors combined causing the failure and subsequent rupture of the piping; increased internal pipe pressure caused by decomposition of organic matter, damage to PVC piping during Facility construction, and possible inadequate support of isolation valves.	HANFORD		OPEX	2014-RL-HNF-0007
	IX Column becomes unattached during THIS De-watering Skid Removal Operation	CRL	2011	OPEX	D&WM-11-5993
	Leak in the basement of B243, confirmed that a leak was coming from the gasket on the strainer.	CRL	2009	OPEX	D_WM-09-00516
	B574 MX-1A leaking	CRL	2014	OPEX	OPS-14-4473
	Water found in secondary containment of temporary active drain hose-in-hose assembly before installation	CRL	2011	OPEX	OPS-11-4631
	PGWMF - Cracked PVC Fitting on HCl Acid Pump	PGWMF	2012	OPEX	D&WM-12-10122
	PGWMF - Port Granby Waste Management Facility - Hydrochloric Acid Leak	PGWMF	2015	OPEX	D&WM-15-8607
	Welcome Waste Management Facility (WWMF), Port Hope Outfall Pipeline/Diffuser Findings	PHAI	2010	OPEX	D&WM-10-10058
	Welcome Waste Management Facility (WWMF), Port Hope East Outfall Pipeline Visible on Surface of Lake Ontario	PHAI	2010	OPEX	D&WM-10-10060
	PGWMF - Broken Effluent Pipe at the Port Granby Waste Management Facility (PGWMF)	PGWMF	2016	OPEX	D&WM-16-2387
	Chemical Spill Due to Faulty Fitting	PHAI	2016	OPEX	D&WM-16-5714
	CNL - Overflow of Primary Containment for Radioactive Solution due to Siphoning		2018	OPEX	OPEX-18-1206

Hazard	Event Description	Location	Year	Source	Event ID
Loss of Services / Utilities					
Loss of Service	Loss of Class III and Class IV Power in MPF	CRL	2019	OPEX	OPS-19-0754
	Heating System Failure in Environmental Laboratory Building		2014	OPEX	D&WM-14-10334
	B240 exhaust fan without belt	CRL	2014	OPEX	OPS-14-2459
	OPEX: Class III Power Failure reviewed at PHAI	PHAI	2012	OPEX	D&WM-12-4310
	Diesel generator located at B562 (WMA-B) failure	CRL	2008	OPEX	ISS-08-01830
	Loss of PLC power in B574	CRL	2013	OPEX	OPS-13-6635
	Natural Gas Leak at LLRWMO Office at 196 Toronto Road, Port Hope	LLRWMO	2014	OPEX	D&WM-14-10370
	Natural Gas Leak at LLRWMO Office	LLRWMO	2014	OPEX	D&WM-14-10370
	WTC Server Failure	CRL	2011	OPEX	OPS-11-3446
Loss of Shielding					
Loss of shielding	Shielded spent nuclear fuel carrier door opens unexpectedly	United States DOE	2000	DOE LL	Y-2000-OR-BJCX10-0801
Procedures					
Inadequate Procedure	Facility Emergency Plan does not include plans for propane and diesel emergencies	PHAI	2015	OPEX	D&WM-15-4775
	Inadequate contamination control measures in place for work on Port Granby WTP Mixing Tanks	CRL	2012	OPEX	D&WM-12-5817
	Loss of Contamination Control - Contamination control techniques associated with the aliquot handling process and rinsing of the excavator implements were less than adequate. Contingency planning for applying the fixative when conditions change was not clearly defined.	Washington Closure Project	2016	US DOE	RCCC-2016-0003
	Implement Powered Equipment Inventory Control - The plan's lack of scissor lift-specific hazard analysis and controls was not detected and the work was authorized to begin. Only after one of the scissor lifts tipped over and seriously injured one of the workers did the Accident Investigation Board determine that the subcontractor lacked experience with the use of scissor lifts for this application and failed to follow the manufacturer's warnings. These warnings were not incorporated into safety and health plans. The scissor lift had been used in a manner beyond its design capacity.	Strategic Petroleum Reserve	2013	US DOE	2013-HQ-FE7-0001

Hazard	Event Description	Location	Year	Source	Event ID
	Manufacturer’s Operating Instructions May Be Insufficient to Protect Workers	Savannah River	2014	US DOE	2013-SR-SWPF-030
	Lessons Learned on Waste Disposal Facilities. DOE facilities should periodically review and update their operating procedures to address changes in requirements and technologies.	DOE		OPEX	EM-53
	Requirements for Operational Control Limits are not clearly defined in Contractor Plan or PHAI's Dust Management Requirements document	PHAI	2013	OPEX	D&WM-13-5072
	Suggested improvements for Dust Management and Requirements Plan (4500-509200-PLA-001)	PHAI	2016	OPEX	D&WM-16-1467
Procedure Non-Adherence	Proper Storage and Maintenance of Records - multiple regulatory-required logbooks associated with underground storage tanks were mistakenly removed and thrown in the building’s dumpster. These logbooks contain multiple years’ of monitoring data and meet the criteria for being a record.	Livermore	2014	US DOE	LL-2014-LLNL-17
	Programmatic Warehouse Control of Spare Parts - spare parts inadvertently disposed of.	Oak Ridge	2017	US DOE	B-2017-OR-UCORNHHO-1101
	Groundwater Sampling Conducted Incorrectly - never assume processes and control procedures will be consistently executed as written	B&W Pantex	2012	US DOE	2012-PTX-LL-0402
	All inspections required under Environmental Code of Practice for Aboveground and Underground Storage Tank Systems Containing Petroleum and Allied Petroleum Products, PN1327, are not being performed at the PG WWTP	PGWMF	2015	OPEX	D&WM-15-4821
	PHAI MO - Observed PWGSC hired contractor backing up dump truck without a spotter.	PHAI	2011	OPEX	D&WM-11-7033
	During waste drum processing activities, sample handling and equipment decontamination processes were not performed correctly, leading to spread of contamination beyond control points.	River Corridor Closure Project, Richland, Washington, USA	2016	US DOE	RCCC-2016-0003
	VEHICLE EXITED WASTE MANAGEMENT AREA H, A CA2 AREA, WITHOUT BEING MONITORED BY RP	CRL	2009	OPEX	D_WM-09-08312
Radiological Contamination					
Contamination	Prevent Spread of Contamination from Fixatives to Soil - When applying fixatives in areas with potential for environmental contamination, assess whether environmentally-friendly products can be used, and take measures to prevent cross-contamination of soil and water.	Separations Process Research Unit	2014	US DOE	PMML-2014-SPRU-Lower Level Land Area-03
	Loose contamination found on shipment of radioactive waste	CRL	1999	OPEX	PER-WM&D-99-01
	Bulldozer contamination in south swamp area	CRL	2000	OPEX	PER-WMA-00-01
	Fixed contamination on truck tire.	CRL	2001	OPEX	PER-WMA-01-01

Hazard	Event Description	Location	Year	Source	Event ID
	Unanticipated behavior of the active ventilation system during a loss of Class IV power	CRL	2004	OPEX	ENF-NPF-04-21
	Received empty Cobalt shipping flasks with loose contamination on them	Bruce	2004	CANDU Owners Group	B-2004-04319
	Nuclear operator’s hand contaminated while receiving empty waste disposal flasks	CRL	2006	OPEX	ENR-MPF-06-58
	Utility worker skin contamination event @ large compound (B-455B) WMA-B	CRL	2010	OPEX	D&WM-10-12186
	Vehicle Tire Contamination at Port Granby Site	CRL	2014	OPEX	D&WM-14-0532
	Contaminated package received at WMA B	CRL	2018	OPEX	D&WM-18-1251
	Footwear contamination by radon - for trending purposes	CRL	2013	OPEX	D&WM-13-7518
	Radon Hand Contamination event at Port Granby	CRL	2013	OPEX	D&WM-13-8902
	Elevated radon gas concentrations identified in Electrical Manholes (EMH) at the Port Hope Waste Water Treatment Plant Construction Site	CRL	2014	OPEX	D&WM-14-4201
	Radon Contamination on AECL Contracted Grass Cutter's Hand	CRL	2014	OPEX	D&WM-14-5332
	High Radon Levels in groundwater monitoring well located on the PHAI Pine Street Extension site.	CRL	2015	OPEX	D&WM-15-2882
	Personal Clothing Contamination detected in B701	CRL	2014	OPEX	OPS-14-10056
	OPEX: Spread of Contamination during movement of IX column	CRL	2011	OPEX	D&WM-11-7617
Radiation Exposure					
Radiation Exposure	Unplanned exposure while handling pressure tube waste container	Point Lepreau	2009	CANDU Owners’ Group	09-1131
	WL - WMA: Unidentified Waste Drum With Dose Rate Exceeding 2.5 mrem/h	WL	2017	OPEX	D&WM-17-1309
	Radiation dose(s) received in excess of the specified Action Level	CRL	2018	OPEX	DWM-18-3694
Systems Important to Safety					

Hazard	Event Description	Location	Year	Source	Event ID
Failure/Unavailability of SRS	Laboratory Tests Indicate Conditions that Could Potentially Impact Certain Type of HEPA Filter Performance	USA	2013	HSS DOE	OE-3 document
	Momentary Electrical Power Loss Causes Loss of Retrieval Contamination Enclosure Ventilation	Idaho	2014	US DOE	2014-ID-AMWTP-006
	Fire sprinkler head leak	CRL	2005	OPEX	ENF-DFO-05-04
	Firewater Check Valve Found Installed in the Wrong Direction During Inspection	External	2018	OPEX	OPEX-18-0373
	Radiation Monitoring system is N/C to document THRR-106131-DR-003 requirements	CRL	2011	OPEX	D&WM-11-3204
	B222X HEPA #2 failed	CRL	2017	OPEX	OPS-17-2247
	Informer unit failed in B591	CRL	2010	OPEX	D&WM-10-9467
	PHAI OPEX Review: Fire Doors Propped Open	PHAI	2012	OPEX	D&WM-12-6248
	B574 Fire Alarm Impairment	CRL	2012	OPEX	OPS-12-7681
	Repeat event - New Fire Alarm Monitoring System failure	CRL	2012	OPEX	OPS-12-8614
	FME Plug Discovered in Safety Valve Vent Port - Dearator #2	CRL	2015	OPEX	OPS-15-7981
	Security Equipment Malfunction	CRL	2019	OPEX	P&NO-19-0177
	RFFL fire suppression system nozzle and delay time did not match design specifications	CRL	2012	OPEX	R&D-12-4766
	PSVS on refrigerant piping adjacent to roof mounted condenser (B570) are capped and exposed to possible freeze-up in cold weather	CRL	2009	OPEX	SM-09-02230
	Emergency Power Generator #2 Declared Unavailable during Routine Test		2019	OPEX	OPEX-19-0034
	No emergency shower within building if worker gets splashed with chemicals or gets contaminated	CRL	2009	OPEX	D_WM-09-02423
	B215 Fume Hood alarms and Tritium in air monitor alarms sound the same	CRL	2019	OPEX	R&D-19-0191
	B240 Annual Emergency Light PMM not on WTC maintenance schedule	CRL	2016	OPEX	OPS-16-1342

Hazard	Event Description	Location	Year	Source	Event ID
	PMR 606815 was not on WTC Facility Maintenance Schedule	CRL	2014	OPEX	OPS-14-8162
	HEPA filters not leak tested annually as per RPM-7.7	CRL	2014	OPEX	D&WM-14-2958
	All Ventilation System Hazards Must Be Analyzed During Safety Basis Development	Fluor	2006	US DOE	2006-RL-HNF-0026
	WTC Safety Related Equipment Not Being Monitored	CRL	2011	OPEX	OPS-11-2116
	Durable and Redundant Markings Necessary to Denote Radiological Status of Heavy Industrial Equipment	LATA Environmental Services of Kentucky	2014	US DOE	2014B-LL-LATA-1041
Waste Inventory / Characterization					
Errors/Uncertainties in Waste Inventory	Waste profile document received with inadequate information to support conclusions.	EMWMF, Oak Ridge, Tennessee, USA	2008	US DOE	Y-2008-OR-BJCWM-0801
	Increased Oversight of Material Labels for Drums Stored Outside - Material labels and tagging sufficient for initial mild indoor storage locations may be insufficient when material is subsequently moved outdoors or to more severe storage locations.	Hanford	2013	US DOE	WRPS-WF-2013-005
	Process or Material Change Requires New Waste Characterization. Sometime after the original waste characterization, the lubricant used in the compressor was changed from petroleum-based to a synthetic lubricant. The change from petroleum-based to synthetic oil invalidated the original waste characterization.	Livermore	2009	US DOE	LL-2009-LLNL-06
	Sealed* Radioactive Source Found in Ordinary Metal Waste Dumpster - a 15 milliCurie Ni-63 sealed* source, was tossed into a metals dumpster.	Brookhaven National Lab	2013	US DOE	2013-BNL-Medical-0003
	Waste Characterization/Classification - SRNS developed a process to allow generators to use the legacy contaminated waste containers as a part of the waste form. The weight of the entire waste stream including the container could be used to calculate radionuclide concentrations and can, in some cases, help classify a waste stream as LLW versus transuranic (TRU) waste.	Savannah River	2011	US DOE	EFCOG Best Practice #102
	Missing solid radioactive datasheet for waste after being picked up from WAF by WMA B	CRL	2016	OPEX	D&WM-16-2161
	Loss of Waste Data Tracking System data during an ATOM system upgrade	CRL	2019	OPEX	D&WM-19-0017
	Waste Data Tracking System issues since conversion to ATOM	CRL	2019	OPEX	P&NO-19-0507
	WMA C surface stored drums. The drums are not properly labelled, not identifying generator or waste material. All drums stored in a WMA must be labels as per operating procedures and externally generated drums must be labelled as per TDG requirements.	CRL	2008	OPEX	D_WM-08-07996
	Bulging Hazardous Waste Drum Discovered in Staging Area		2018	OPEX	OPEX-18-0927
	Errors in Obtaining and Interpreting Waste Characterization Data		2018	OPEX	OPEX-18-0283

Hazard	Event Description	Location	Year	Source	Event ID
Waste Package Failure					
Waste Package Failure	Corrosion in Drums in Long Term Storage - Facilities which are storing waste in filtered drums without climate control should be alert to conditions which increase the potential for internal corrosion over time.	Hanford	2014	US DOE	2014-RL-HNF-0025
	Degraded Storage Container - Containers being used for outside storage must be periodically inspected to evaluate the container's integrity for its intended use. Holes formed on the top of a container due to corrosion and precipitation had accumulated in the container.	Oak Ridge LLC	2016	US DOE	B-2016-OR-UCORNSE-0902
	Inadequate Containment for Long-term Storage of Contaminated Waste Items. After remaining in storage for nine years, a disposal path for the glovebox was determined. While the Radiological Technician was performing a characterization survey of the glovebox in preparation for shipment, high levels of contamination were detected underneath the glovebox. Further investigation found that one section of the tape holding plastic over the bottom port had come loose and the temporary containment was compromised. This resulted in a release of radioactive material into the surrounding area.	Oak Ridge LLC	2017	US DOE	B-2017-OR-UCORNHHO-1001
	Leaking Drum at K-1420 - a Transportation employee had been sprayed with liquid coolant contained within a 55-gallon drum that had developed a leak along a seam during work operations for securing the drum on the transport truck for transportation and disposal.	Oak Ridge LLC	2013	US DOE	B-2013-OR-UCORWD-0701
	Degradation and failure of stored radiological material containers and packages, build-up of pressurized flammable gases	DOE	2004	DOE LL	HG-EH-2004-01
	A waste drum was found to have a hole in it, resulting from corrosion and mechanical forces. Several workers who had worked in the area of the drum received minor uptakes of alpha contamination.	Hanford Waste Receiving and Processing Facility	2004	US DOE	2004-RL-HNF-0020
	Tearing of Flexible Overpack During Hoisting Operations at WMA H	CRL	2019	OPEX	D&WM-19-0256
	Corrosion Discovered On Sides of Some of the LLRWMO Bins Stored in B563	LLRWMO	2012	OPEX	D&WM-12-4335
	Torn active asbestos bag received at WMA B	CRL	2014	OPEX	D&WM-14-10667
	Port Granby Waste Management Facility - On December 1, one of the waste loads contained a partially degraded drum with unknown chemical constituent. The waste load was subsequently placed into the cell and spread by the bulldozer operator. During spreading activities the drum was ruptured causing the chemical to flow out of the drum.	PGWMF		OPEX	S-EFDR # 4
	URS CH2M Oak Ridge Inadequate Containment for Long-term Storage of Contaminated Waste Items	URS CH2M Oak Ridge	2017	OPEX	EB-17-455

13.1 Lessons Learned

Lessons Learned from CNL's Port Hope and Port Granby Projects have been reviewed and recommendations have been incorporated into the design as applicable. The greatest operational challenge at both sites is water management. The NSDF leachate, contact water and non-contact water systems have been designed to collect and convey the volume of water that will accumulate from back-to-back, 100-year, 24-hour storm events. The NSDF Equalization Tank design capacity will provide sufficient storage to prevent the release of untreated water into the environment. Lessons learned associated with project management, construction, commissioning and operations will be incorporated into NSDF Project plans accordingly. Lessons learned are documented in the Port Hope and Port Granby benchmarking report [13-3].

Chalk River Laboratories WMA C is a 5 ha, low-level radiological waste landfill (sand trenches). Waste emplacement commenced in 1963 and ceased in 2006. An impervious engineered cover and surface water drainage system, similar to the one proposed for the NSDF, was installed over WMA C in 2013. The steep reduction of tritium in the groundwater plumes immediately downgradient of WMA C is indicative of the covers performance. A field inspection of the engineered cover was performed in 2015 and observations led to minor repairs of the cover's surface layer in areas where erosion from surface water drainage had occurred [13-4].

Low Level Waste Facilities at Hanford, Washington, and Clive, Utah have demonstrated successful confinement of contaminants. These facilities experience low water infiltration due to being located in semi-arid climates. More than 30 years of OPEX has resulted in LLD with regards to leachate and wastewater management.

At the LLW disposal Facility at Maxey Flat, Kentucky, which operated from 1963 to 1977, it was discovered that leachate was seeping into an adjacent, newly constructed trench. In response, a water management program was begun, which involved pumping of leachate out of the trenches into aboveground tanks and treating the leachate. Following closure, a flexible membrane liner was installed to reduce water infiltration. Grading and surface drainage were also improved. This was found to significantly reduce the migration of radioactive contaminants due to surface influences.

In response, the design of the NSDF includes a leachate collection and LDS to ensure the collection of all wastewater within the ECM. Furthermore, a final cover system is installed on filled cells to minimize the total infiltration into the ECM.

A LLW disposal Facility at West Valley, New York, where precipitation is moderately high, was operational from 1963 - 1975. The Facility consisted of a series of trenches excavated in successive segments. During operations, a section of the trench would be exposed before installation of the covers. Although water that accumulated at the floors of the trenches was routinely pumped out, a significant amount remained as standing water following emplacement of the covers. Cores from test holes drilled near the trenches following closure, contained tritium, indicating migration from the sides of the trenches. To reduce the residual quantities of water which will have infiltrated the open cells of the NSDF ECM during operation, the LCS will remain operational for up to 30 years following installation of the final cover. Compared to the West Valley trenches, which were surrounded on the sides by existing fine-grained till, the ECM base liner and final cover include natural and synthetic barriers to confine the contaminants.

A Facility at Beatty, Nevada, was operational from 1962 until 1992. In 1997, a monitoring program discovered unexpectedly high levels of tritium below the Facility boundary. Improper disposal of liquid waste is thought to be the root cause, resulting in transport to the aquifer below the waste Facility. The original cover was a mixture of earth and gravel, several feet thick, which is anticipated to have contributed to water infiltration. In 2015, following a large rainfall event, a crater developed at the edge of the Facility, allowing rainwater to come into contact with metallic sodium waste, resulting in the ejection of non-radiological material from a trench through the cover. Investigations revealed, in addition to the crater, the existence of linear cracks near the edge of trenches, sinkhole-type openings, and areas of subsidence. A site action plan is currently being implemented, but differential settlement between wastes within the trench is an initial hypothesis for the cracks.

The NSDF is designed to avert OPEX events like those that have occurred at Beatty, Nevada. The WAC have been developed to prevent the emplacement of liquid wastes, and adherence to the WAC is strengthened through the Waste Generator Certification Program. The ECM final cover is designed to accommodate rain events and minimize infiltration due to sloping, stormwater management, and a synthetic membrane. To prevent damage from differential settlement, the waste emplacement procedures require adjacent waste columns to have similar potential for long term settlement. The final cover is also designed to accommodate some differential settlement. A post-closure care plan details the steps for detecting and repairing any damage to the final cover during the ICP.

The results of an independent Technical Review of the Hanford Environmental Restoration Disposal Facility and other NSDFs throughout the United States, was published by the US DOE [13-5]. These facilities are similar to the NSDF, featuring one or more disposal cells, a double liner system consisting of a clay liner, primary and secondary composite geosynthetic liners, a LDS, LCS, wastewater treatment system, and multilayer final cover system. The common LLD that emerged from this review are listed below along with a brief explanation (shown in italics) of how the LLD has been addressed in the NSDF design:

- Accurate waste forecasting is a critical aspect of cost-effective disposal operations. Site managers should optimize their waste stream as much as possible. Waste Characteristics and expected quantities of each waste type have been updated throughout the iterative design process of the NSDF [13-6] and [13-7].
- Final cap cover will be the most important engineering factor affecting the long-term viability and performance of the waste disposal Facility, so much attention should be paid to its design. The performance of the NSDF ECM base liner system and final cover system have

been evaluated and the design is considered optimized as documented in the Base Liner and Final Cover Evaluation and Optimization document [13-8].

- Settlement of waste induced by collapse of voids (e.g. containers or vessels) are prevalent and problematic. Strategies such as dynamic compaction or smaller cell size should be considered. The NSDF Waste Acceptance Criteria [13-9], includes limits on void ratios on bulk waste, and voids inside and between waste packages. Containerized waste shall either have the void space filled with compacted waste or grout. This will reduce the possibility of container collapse, and subsequent ECM settlement. Waste compaction requirements are specified for each waste type in the Waste Placement and Compaction Plan [13-10].
- Sumps should be located to one side of the cell versus centrally located. The sumps are located at the downgradient edges of the NSDF ECM.
- Automated processes should be considered where practical. System automation has been included in the design to the extent practical.

Lessons learned from European LLW Facilities, such as those in Spain, France and Belgium, are not included in this report. Their design utilizes above ground engineered concrete vaults in comparison to an ECM for the NSDF. Their waste packaging/placement and leachate management operations are entirely different than the NSDF approach. Searches for LLD for these facilities included web searches of public documents of Dessel, Centre de l'Aube and El Cabril, a review of LLW conference papers, and a review of benchmarking reports prepared by CNL staff who visited these three facilities in the past. The information searched did not contain LLD. Near Surface Disposal Facility Project staff assessed the need for pursuing the search and decided their LLD would not have a significant impact on the NSDF due to differences in the design, construction methods, waste packaging, waste placement methods, and for cell closure.

13.2 References

[13-1] *Waste Management Areas Hazard Identification Report*, WMA-508770-REPT-001, Revision 0, 2013 August.

[13-2] *Waste Treatment Centre Hazard Analysis Plan*, WTC-508770-PLA-001, Revision 0, 2014 October.

[13-3] *Port Hope and Port Granby Benchmarking Activity Report*, 232-508120-041-000-0001, 2016 October.

[13-4] *Inspection Report: Waste Management Area C Engineered Cover*, WMA-106110-REPT-002, Revision 0, 2015 September.

[13-5] US Department of Energy (US DOE), *Lessons Learned on Waste Disposal Facilities*, EM-53 Lessons Learned Bulletin, 2015 October.

[13-6] *Waste Characterization*, 232-508600-REPT-002, Revision 4, 2020 February.

[13-7] *Near Surface Disposal Facility Reference Inventory,* 232-50860-REPT-003, Revision 3, 2020 April.

[13-8] *Base Liner and Final Cover Evaluation and Optimization*, 232-508600-TN-002, Revision 1, 2019 January.

[13-9] *Near Surface Disposal Facility Waste Acceptance Criteria*, 232-508600-WAC-003, Revision 2, 2020 September.

[13-10] *Waste Placement and Compaction Plan*, B1550-508600-PLA-001, Revision 2, 2019 October.

14. SAFETY ANALYSIS

The NSDF Operation includes construction of disposal cells, waste placement, temporary waste storage, wastewater processing, inspection, maintenance, and monitoring.

This section presents the NSDF safety analysis and provides:

- An overview of the safety analysis methodology.
- Identification and characterization of hazards and events.
- Classification of the events into the following classes of events: AOOs, DBAs, BDBAs including DECs, and conventional health and safety.
- Evaluation of the Facility hazards and events with respect to radiological consequence to on-site workers, the public, and the surrounding environment.
- Assessment of risk.
- Identification of the safeguards in place to minimize or mitigate these radiological consequences.
- If necessary, identification of suggested further mitigation of radiological consequences.
- Conclusion of the analyses.

This safety analysis examines the potential hazards that could result from normal operations and the consequences of abnormal events and accidents.

The main consequences of the accidents resulting from the NSDF operation are:

- Worker exposure to radiation, and
- Radioactive releases to environment, resulting in radiological consequences to the on-site receptors and the off-site receptors, and to non-human biota.

Hazards arising from the operation of the NSDF Facilities are radiological and chemical in nature, although some industrial type of hazards do exist from day to day operations. Although, there are conventional non-radiological industrial workplace hazards, this report is focused on the radiological hazards and associated radiological consequences to the on-site receptors, workers, and off-site receptors, members of the public. Conventional, occupational, non-radiological hazards were evaluated only to the extent of determining their ability to initiate or contribute to accidents; otherwise such hazards are adequately covered by the OSH Program [14-1]. Chemical hazards are assessed on the basis that the consequence of the associated non-radiological hazard has an impact on radiological consequences.

14.1 Safety Analysis Methodology

The systematic and comprehensive methodology followed in this safety analysis to identify all hazards and accident scenarios included:

1. Hazard identification.
2. Identification of major hazards and PIE associated with the NSDF design and operations.

3. Hazard analysis of the consolidated list of major hazards and PIE for the NSDF Facilities.
4. Failure Mode Effects and Criticality Analysis (FMECA) of the WWTP.
5. Safety analysis of normal operation, AOOs, DBAs, and BDBAs including DECs, using credible/relevant scenarios.

14.1.1 Hazard Identification

The hazard identification was conducted based on the 30% design [14-2]. The objective of the hazard identification was to list characteristics associated with SSCs with the potential for radiological or chemical harm to people or the environment [14-2].

The hazards posed by the NSDF Facility, with the exception of the WWTP, were identified based on the safety analysts' engineering judgement, and were recorded on the Safety Hazards Checklist and documented in Hazard Identification [14-2]. Also, the Safety Hazards Checklist was used to record relevant details and safeguards for the identified hazards [14-2].

Detailed information on the hazard identification is available in Hazard Identification [14-2].

14.1.1.1 Preliminary Failure Modes and Effects Analysis

The WWTP hazard identification involved completing a preliminary Failure Modes and Effects Analysis (FMEA) for the WWTP components and subcomponents based on the 30% design Piping and Instrumentation Diagrams [14-2]. The preliminary FMEA for the WWTP components, was developed to identify failure modes and effects based on the safety analysts' engineering judgement [14-2]. The WWTP preliminary FMEA is documented in Hazard Identification [14-2] and includes the following aspects:

- Component.
- Subcomponent description and function.
- Failure or error mode.
- Potential root cause.
- Effects on other components.
- Effects on whole system.

Detailed information on the preliminary FMEA is available in Hazard Identification [14-2].

14.1.2 Identification of Major Hazards and Initiating Events

Following the hazard identification described above, a systematic and comprehensive approach was used to identify the major hazards and initiating events associated with the design and operations of the NSDF. Table 14-1 is the consolidated list of hazards and initiating events as documented in "What-If" Hazard Analysis for the Near Surface Disposal Facility [14-3] and Hazard Analysis for the Near Surface Disposal Facility Waste Water Treatment Plant and Associated Systems [14-4].

The NSDF consolidated list of hazards and PIEs in Table 14-1, was developed using the following documents:

- NSDF Hazard Identification and Analysis [14-5].
- Design of Reactor Facilities: Nuclear Power Plants, REGDOC -2.5.2 [14-6].
- NSDF Human Factors Report (relevant OPEX) [14-7].
- The Safety Case and Safety Assessment for the Predisposal Management of Radioactive Waste [14-8].
- Waste Management Areas – Hazards Identification Report [14-9].
- Waste Treatment Centre – Hazard Analysis Plan (relevant for the WWTP) [14-10].

Table 14-1
List of Major Hazards and Postulated Initiating Events

Postulated Initiating Event / Hazard	Potential Scenarios and Applicable NSDF System	Corresponding Event Grouping in Table 14-9
Containment Failure	1. Liner failure (Applicable to ECM). 2. Rupture of waste container (Applicable to ECM, WWTP). 3. Failure of piping or tank - internal flooding, over pressurization, sediment accumulation, and blockage (Applicable to ECM, WWTP and VDF). 4. Cover failure on closed disposal cell (Applicable to ECM). 5. Leak from vehicle (Applicable to all NSDF systems).	A.3.1, A.4.1, B.3.1
Contamination	1. Contamination on waste packages and bulk waste (Applicable to ECM). 2. Contamination (airborne) released during waste emplacement and compaction (Applicable to ECM). 3. Elevated airborne releases exceed administrative level (Applicable to ECM and WWTP). 4. Failure to monitor facilities as required by procedures (Applicable to ECM, WWTP, and VDF). 5. Worker falls into partially filled open disposal cell (Applicable to ECM). 6. Contamination transfer by wildlife (Applicable to ECM). 7. Worker contaminated or exposed during pump-out of water in facilities/sumps (Applicable to ECM, WWTP and VDF). 8. Contamination on transport vehicle (Applicable to VDF).	A.3.3, A.4.2, A.5.1
Corrosion	1. General deterioration of SSCs (Applicable to ECM, WWTP, and VDF). 2. Corrosion of waste containers (Applicable to ECM). 3. Corrosion of chemical containers (Applicable to WWTP).	No events
Crane Failure	1. Crane failure during transfer waste emplacement – suspended load (Applicable to ECM and WWTP).	B.2.1, B.3.2

Postulated Initiating Event / Hazard	Potential Scenarios and Applicable NSDF System	Corresponding Event Grouping in Table 14-9
Dropped Load	1. Dropped waste package due to mechanical failure or malfunction of lifting/hoisting equipment (Applicable to ECM and WWTP). 2. Dropped chemical container due to mechanical failure or malfunction of lifting/hoisting equipment (Applicable to WWTP). 3. Crane failures: electrical failure or mechanical failure. No hazard if single-failure proof hoist used (Applicable to ECM and WWTP). 4. Dropped waste package due to human error (Applicable to ECM and WWTP). 5. Dropped chemical container due to human error (Applicable to WWTP). 6. Waste package(s) fall off of transport vehicle during transport and breached (Applicable to ECM). 7. Chemical container(s) fall off of transport vehicle during transport and breached (Applicable to WWTP). 8. Dropped shielded waste package could cause a partial loss of shielding (Applicable to ECM).	A.3.2, A.4.3, B.2.1, B.3.2
Explosion (deflagrations and detonations)	1. With or without fire, with or without secondary missiles (Applicable to all NSDF systems). 2. Burning combustible material in Facility (Applicable to all NSDF systems). 3. Facility/equipment (Applicable to all NSDF systems). 4. Adjacent buildings (Applicable to all NSDF systems). 5. Passing vehicle (Applicable to all NSDF systems). 6. Hydrogen sulfide explosion in WWTP.	See Fire events.
External Hazard (Natural)	1. Earthquake (seismic activity) (Applicable to all NSDF systems). 2. Extreme meteorological conditions – temperature, snow, freezing rain, wind, drought, and rain (Applicable to all NSDF systems). 3. Ground subsidence, soil erosion or frost heave (Applicable to all NSDF systems). 4. Flooding – precipitation, dam failure, snow melt, and rise in water table (Applicable to all NSDF systems). 5. Wildland fire (Applicable to all NSDF systems). 6. Tornados and microbursts (with or without projectiles) (Applicable to all NSDF systems). 7. Lightning (Applicable to all NSDF systems). 8. Biological phenomena (e.g. algae, fauna and flora invasion and biological contamination) (Applicable to ECM and WWTP). 9. Intrusion of non-human biota (e.g. animals such as fox, bear, deer, geese, etc.) (Applicable to all NSDF systems).	A.1, A.1.1, A.1.2, A.1.3, A.3.6 B.1, B.1.1, B.1.2, B.1.3, B.1.4 C.1, C.2, C.3
External Hazard (Human induced)	1. Aircraft crash (Applicable to all NSDF systems main hazard is ECM). 2. Transport infrastructure (Applicable to all NSDF systems). 3. Vehicle or person, damage to power supply (Applicable to all NSDF	A.3.5, C.4

Postulated Initiating Event / Hazard	Potential Scenarios and Applicable NSDF System	Corresponding Event Grouping in Table 14-9
	systems).	
Damaged Structure	1. Structural collapse (Applicable to all NSDF systems). 2. Collapse or damage of structures during waste emplacement and compaction (Applicable to ECM).	A.3.7, A.3.9, B.2.4
Fire	1. Internally caused fire within ECM (waste fire, vehicle fire, flammable gas generation from disposed waste). 2. Internally caused fire within ECM - Temporary waste storage area. 3. Internally caused fire within ECM – operating disposal cell. 4. Internally caused fire within WWTP. 5. Internally caused fire within VDF. 6. Vehicle fire (Applicable to all NSDF systems). 7. Spontaneous combustion (Applicable to ECM).	B.2.6, B.3.5, B.4.1
Hazardous Reaction	1. Chemical reaction hazards – applicable to the ECM and WWTP, insufficient or incorrect mixing between wastes and conditioning materials, incompatible chemicals, chemical addition wrong sequence, or wrong chemical. 2. Loss of control process (applicable to the WWTP).	D.1.2.3, D.2.2.2
Loss of Services	1. Loss of Facility power due to natural phenomena events (e.g. rain, lightning, freezing weather) and certain external events, (e.g. vehicle impacts with critical components outside the Facility) where initiating events were separately assessed as "common cause initiators" (Applicable to all NSDF systems). 2. Interruption of electrical power/loss of Class IV power (Applicable to all NSDF systems). 3. Loss of Facility support systems (e.g. Heating Ventilation Air Conditioning (HVAC), service water, and inert gas supply) will have little impact because of the lack of need for active safety function performance during and after a loss of HVAC, power, or inert gas supply (Applicable to all NSDF systems). 4. Loss of air and breathing air (Applicable to WWTP). 5. Loss of natural gas (Applicable to WWTP and associated facilities). 6. Loss of active drain (Applicable to WWTP). 7. Loss or malfunction of emergency equipment (Applicable to all NSDF systems).	A.2, A.2.1, A.2.2, .2.3
Loss of Shielding	1. Damage to shielded package, leading to worker exposure (Applicable to ECM). 2. Loss of shielding, leading to worker exposure (Applicable to WWTP).	No events
Loss of Ventilation	1. Failures in ventilation system, including failure or malfunction of High-Efficiency Particulate Air filter, fan and duct (Applicable to WWTP and VDF).	A.2.2

Postulated Initiating Event / Hazard	Potential Scenarios and Applicable NSDF System	Corresponding Event Grouping in Table 14-9
Radiation	1. Temporary waste storage area (Applicable to ECM). 2. Excessive dose rate encountered (Applicable to ECM and WWTP). 3. High radiation fields not identified (Applicable to ECM, WWTP and VDF). 4. High doses due to high fields and airborne contamination emanating from waste (Applicable to ECM, WWTP and VDF).	A.3.10, A.5.2, B.3.6
Unintended Contents	1. Waste does not meet WAC (Applicable to ECM). 2. Chemical hazards in waste not adequately treated (Applicable to ECM and WWTP). 3. Waste emplaced in disposal cell is retrieved due to not meeting the WAC (Applicable to ECM). 4. Bulk waste is stuck in ISO container being dumped into disposal cell (Applicable to ECM). 5. Unexpected increase in tank level (Applicable to WWTP). 6. Release of liquid effluent that does not meet discharge criteria (Applicable to WWTP).	A.3.4, B.2.2, B.2.5, B.3.3
Vehicle Collision	1. Collision of transport vehicles (Applicable to all NSDF systems). 2. Transport vehicle falls into disposal cell (Applicable to ECM). 3. Vehicle impact with structure (Applicable to all NSDF systems). 4. Snow removal equipment impacting structure (Applicable to all NSDF systems).	A.3.5, A.4.4, B.2.3, B.3.4
Equipment Failure	1. Incorrect setting on process control equipment (Applicable to all NSDF systems). 2. Loss or malfunction of instrumentation or equipment (Applicable to all NSDF systems). 3. Loss of control of process control equipment (Applicable to WWTP). 4. Maintenance or inspection deficiency (Applicable to all NSDF systems). 5. Aging of equipment (Applicable to all NSDF systems).	A.3.8

14.1.3 Detailed Hazard Analyses

The NSDF Hazard Analyses [14-2], [14-3], [14-4], and [14-5], were conducted to ensure that all possible hazards were represented and considered. The focus of the hazard analysis is on the potential accident conditions involving the hazards associated with the NSDF design and operations. In general, the hazard analysis process consisted of:

- Systematically evaluate hazards, develop accident sequences/scenarios, and identify administrative and engineered controls.

- Qualitatively assess the frequency and consequence/severity for the mitigated hazard or event.
- The frequency and consequence/severity is combined to determine the risk ranking of the mitigated hazard or event.

The "What-If" Hazard Analyses [14-3] and [14-4], analyzed the NSDF operation and 100% design, using the consolidated list of hazards, initiating events and AOOs documented in Table 14-1. These hazard analysis identified and evaluated the hazards/events/AOOs, causes, consequences of deviations, frequency, severity, associated risks, and the potential impacts to the environment, and persons, both workers and the public. The "What-If" Hazard Analyses [14-3] and [14-4] analyzed radiological, environmental and conventional industrial hazards.

The hazard analysis documented in NSDF Hazard Identification and Analysis [14-5], was based on 60% design with subsequent modifications to design details made by members of the detailed design project team until 2017 April. The hazard analysis in NSDF Hazard Identification and Analysis [14-5], only analyzed radiological hazards.

The risk matrix shown in Table 14-2, was used in the Hazard Analyses [14-3] and [14-4]. To ensure consistency with the event categories and their associated frequencies as identified in Table 14-6 the risk matrix shown in Table 14-2 is applied in this safety analysis. Note that the initial risk matrix, shown in Table 14-6, was used in [14-5] for the hazard analysis and FMECA.

The risk rankings used during the Hazard Analyses [14-3], [14-4] and [14-5] are based on a risk matrix combining qualitative assessments of event frequency and severity, reproduced in Table 14-2. The risks are described qualitatively in Table 14-3, Guidelines for Interpreting Risk Rankings [14-11] and [14-12], and are based on frequency ratings as shown in Table 14-4, Frequency Ratings, [14-11] and [14-13] and severity ratings as shown in Table 14-5, Severity Ratings [14-12] and [14-13]. Note that the Hazard Analysis and FMECA in [14-5], used the initial frequency ratings shown in Table 14-7and the initial severity ratings in Table 14-8.

These risk rankings are mitigated risks, taking into account safeguards and administrative controls that potentially lower the frequency and/or the severity of the event. Risk rankings R2 and R3, are unreasonable risk rankings, and require engineering solutions to achieve a reasonable risk ranking, which is a risk ranking of R0 or R1. For hazards with R0 risk ranking, the risk is negligible and no further action is necessary. For hazards with R1 risk ranking, the risk is tolerable and further protective measures are not essential but should be considered.

Where risk rankings were initially assessed as R2 and R3 [14-3], additional actions were identified and executed to reduce the risks to at least R1. The actions identified in the Hazard Analyses [14-3], [14-4], and [14-5], are tracked in the NSDF Safety Action Tracking Database [14-14].

The hazard analyses [14-3], [14-4], and [14-5], assume that the worker is trained and follows approved procedures, and that work in the Facility conforms to the requirements of the HSSE&Q Programs. The frequencies of the events as documented in [14-3], [14-4] and [14-5], are not implied to be absolute values, but rather to express an expected frequency range for the postulated scenario.

The Hazard Analysis [14-3] identified:

- 144 radiological safety consequences, 44 environmental consequences and 36 industrial safety consequences.
- 192 R0 mitigated risks, 31 R1 mitigated risks, two R2 mitigated risks and zero R3 mitigated risks.

The Hazard Analysis [14-4] identified:

- 11 radiological safety consequences, 35 environmental consequences and 49 industrial safety consequences.
- 82 R0 mitigated risks, 13 R1 mitigated risks, zero R2 mitigated risks and zero R3 mitigated risks.

Table 14-2
Risk Matrix

Frequency	S0	S1	S2	S3
AOO (Frequent or Occasional; ≥10^{-2}/y)	R0	R1	R2	R3
DBA (<10^{-2}/y and ≥10^{-5}/y)	R0	R0	R1	R2
BDBA (10^{-6}/y to <10^{-5}/y)	R0	R0	R0	R1

Table 14-3
Guidelines for Interpreting Risk Ratings

Risk Ranking	Definition
R0	The risk is negligible; no further action necessary.
R1	The risk is tolerable; further protective measures are not essential but should be considered[3].
R2	The risk is unreasonable; engineered solutions must be put in place to protect against the hazard.
R3	The risk is unreasonable; the proposed process or equipment is inherently unsafe, major modifications to the proposed design are required.

Table 14-4
Frequency Ratings

Frequency Class	Frequency Range (events/year)	Definition
F0	10^{-6} to $<10^{-5}$	Selected Beyond Design Basis Accident (BDBA) that is very unlikely to occur over the lifetime of the Facility. An accident less frequent and potentially more severe than a design-basis accident.
F1	$\geq 10^{-5}$ to 10^{-2}	Design Basis Accident (DBA) that is unlikely to occur over the lifetime of the Facility, but is considered plausible.
F2	$>10^{-2}$	An occasional event, Anticipated Operational Occurrence (AOO), upset condition, this event is expected to occur over the lifetime of the Facility but is not considered a normal operation.

[3] Further measures are typically additional administrative controls and/or simple design changes.

Table 14-5
Severity Ratings

Severity Rating	Definition
S0	**Industrial Consequences**: Consequences are negligible, minor injury requiring First Aid treatment which does not result in lost time from work (1). **Operational Consequences**: No operational impacts and Facility does not require a shutdown (e.g. for clean-up, etc.). **Radiological Consequences**: Effective doses up to 1 mSv (on-site) and/or 0.1 mSv (off-site). **Environmental Consequences:** Negligible release to the environment, impact may be measurable. Impacts to the environment are very small/negligible and localised (on-site)/short duration.
S1	**Industrial Consequences**: Consequences are minor, injury or an occupational disease requiring medical treatment by a medical practitioner(2) (other than CNL health centre nurse), a disabling injury resulting in a medical practitioner prescribing work restrictions (and modified work is offered by CNL)(3) or time off from work (lost time) of up to 5 days (4). **Operational Consequences**: Minor operational impact and Facility may require shut down for up to 1 day. **Radiological Consequences**: Effective doses in the range of 1 to 5 mSv (on-site) and/or 0.1 to 0.5 mSv (off-site). **Environmental Consequences:** Minor release to the environment, impact is measurable. Impacts to the environment are moderately extensive (on-site, may be off-site) and moderate duration.
S2	**Industrial Consequences**: Consequences are moderate, electric shock, toxic atmosphere, or oxygen deficient atmosphere that causes loss of consciousness. The implementation of rescue, revival or other similar emergency procedures. A disabling (non-permanent) injury/disease (to one or more workers) (5) resulting in a total lost time >5 days and up to 60 days (6). **Operational Consequences**: Moderate operational impact and Facility may require shut down for >1 to 5 days. **Radiological Consequences**: Effective doses in the range of 5 to 50 mSv (on-site) and/or 0.5 to 20 mSv (off-site). **Environmental Consequences:** Moderate release to the environment. Impacts to the environment are extensive (on-site and off-site) and long duration.
S3	**Industrial Consequences**: Consequences are severe, fatality, a disabling injury resulting in loss of a body member or a part thereof, or the complete loss of the usefulness of a body member or a part thereof, permanent impairment of a body function, a disabling (non-permanent) injury (to one or more workers)(5) resulting in a total lost time >60 days. **Operational Consequences**: Major operational impact and Facility shut down for greater than 5 days. **Radiological Consequences**: Effective doses >50 mSv (on-site) and/or >20 mSv (off-site). **Environmental Consequences:** Major release to the environment. Impacts to the environment are catastrophic.

Table Notes:

1. Minor cut treated at the CNL health centre (not requiring stitches).
2. Cut requiring stitches.
3. Doctor prescribes ‘no manual lifting’ for employee whose employment requires lifting.
4. Injury requiring medication to be prescribed which makes it unsafe to attend work.
5. One person injured or summation of lost time for multiple injured individuals.
6. Broken bones preventing return to work.

14.1.3.1 Initial Hazard Analysis Risk Rating

The initial hazard analysis risk ratings used in NSDF Hazard Identification and Analysis [14-5], were in effect when the hazard analyses were performed and align with the current Hazard Identification and Analysis [14-12]. The initial NSDF hazard analysis risk matrix, Table 14-6, does not align with the risk matrix in Safety Analysis for Decommissioning and Waste Management [14-11], shown in Table 14-3. In addition, the initial frequency ratings in Table 14-7 does not align with the frequencies in Table 3-4 Dose Acceptance Criteria for Accidents. The initiating events are categorized as an AOO, DBA or BDBA, based on their respective initiating event frequencies.

The hazard analysis and FMECA in NSDF Hazard Identification and Analysis [14-5] used the initial risk matrix, shown in Table 14-6, the initial frequency rating shown in Table 14-7 and the initial severity ratings shown in Table 14-8.

The Hazard Analysis [14-5] identified:

- 55 radiological safety consequences for the ECM and support buildings with 52 R0 mitigated risks, three R1 mitigated risks, zero R2 mitigated risks, and zero R3 mitigated risks.
- 59 radiological safety consequences for the WWTP with 56 R0 mitigated risks, three R1 mitigated risks, zero R2 mitigated risks, and zero R3 mitigated risks.

Table 14-6
Initial Risk Matrix for NSDF Hazard Analysis [14-5]

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

Table 14-7
Initial Frequency Rating for NSDF Hazard Analysis [14-5]

Frequency Class	Frequency Range (events/year)	Definition
F0	$<10^{-4}$ to 10^{-6}	A rare event that is very unlikely to occur.
F1	$<3 \times 10^{-2}$ to 10^{-4}	An event that is unlikely to occur over the lifetime of the Facility, but is considered plausible.
F2	3×10^{-1} to 3×10^{-2}	Upset condition, this event is expected to occur over the lifetime of the Facility but is not considered a normal operation.
F3	$>3 \times 10^{-1}$	Operational occurrence/frequent process upset, the event occurs on a regular basis during Facility operations.

Table 14-8
Initial Severity Ratings for NSDF Hazard Analysis [14-5]

Severity Class and Hazard Identification		On-site Workers	Off-site Public
S0	Radiological Consequence	Effective dose up to 1 mSv	Effective dose up to 0.1 mSv
S1	Radiological Consequence	Effective dose in the range of 1-5 mSv	Effective dose in the range of 0.1 – 0.5 mSv
S2	Radiological Consequence	Effective dose in the range of 5 – 50 mSv	Effective dose in the range of 0.5 – 20 mSv
S3	Radiological Consequence	Effective dose greater than 50 mSv	Effective dose greater than 20 mSv

14.1.3.2 Failure Modes and Effects Criticality Analysis

The preliminary FMEA for the WWTP presented in the Hazard Identification [14-2], was refined into the FMECA as documented in the NSDF Hazard Identification and Analysis [14-5]. The FMECA, identifies and assesses the hazards associated with the WWTP [14-5].

The FMECA [14-5] was developed based on the WWTP process and instrumentation drawings. Additionally, the FMECA [14-5] was augmented with internal events (e.g. human error) and external events (e.g. seismic, loss of Class IV power outage), which were analyzed for each applicable WWTP system. The FMECA assesses the effect of failure of WWTP process components, and the effect of the following external events on the WWTP systems [14-5]:

- Seismic events.
- Fire.
- Loss of Class IV Power.

- Tornado/high winds.
- Extreme temperatures.

The FMECA [14-5], includes mitigation, hazard, frequency, severity, risk classification and severity justification for each failure or error mode in addition to the aspects used in the preliminary FMEA [14-2].

The FMECA includes the following aspects [14-5]:

- WWTP Components and Subcomponents: Components are the stages of water treatment, subcomponents are the individual parts taken from Piping & Instrumentation Diagrams. Operating functions for each subcomponent are provided.
- Failure or Error Mode: The ways in which a component or subcomponent may fail.
- Potential Root Cause: The initiating event that resulted in the failure or error mode.
- Effects on other subcomponents and on the whole system: The consequences to other subcomponents and the system as a result of the failure or error mode. Consequences are generally in the context of a radiological exposure.
- Mitigation Measures: Inherent design features that reduce the likelihood or consequence of the event.
- Determine FMECA rating: Identify the hazard as either radiation or no significant radiation hazard, and estimate the frequency using Table 14-7, severity using Table 14-8 and risk using Table 14-6.
- Severity justification: Provide justification for the estimated severity.

The FMECA [14-5], examined the failure or error modes for a total of 144 WWTP sub-components and identified 59 failure or error modes with radiological consequences.

14.1.4 Hazards and Initiating Events Assessment

The hazards and events from the Hazard Analyses [14-2], [14-3], [14-4], and [14-5], are grouped based on type of accident as defined in Safety Analysis for Decommissioning and Waste Management [14-11]. Events are grouped under the following main headings:

Group A: Anticipated Operational Occurrences

Group B: Design Basis Accidents

Group C: Beyond Design Basis Accidents including DECs

Group D: Conventional Health and Safety

Groups A, B and C are events with radiological consequences and conventional events are excluded from these groups.

Group D events address conventional health and safety events with non-radiological consequences and are assessed qualitatively, describing the impact of the event and the features in place to mitigate the event. The Group D events are segregated into events with the frequency of AOOs and DBAs. The Conventional Safety Analysis [14-15], identifies conventional hazards, however, the hazard risk rating is not assessed. Group D events are derived from the Hazard Analyses [14-3] and [14-4] using hazards with conventional non-radiological consequences.

Events with a radiological consequence identified as being bounded by a similar, but more severe event, are assessed qualitatively with justification for the bounding event. Events with radiological consequences that are deemed to be a bounding event are analysed quantitatively as described in the Appendices A to L, to determine if the dose acceptance criteria for accidents [14-11] and shown in Table 3-4 are met. Table 14-9 provides the event groupings and the analysis approach being qualitative and or quantitative. Table 14-10 provides the event groupings, analysis approach and the mitigated risk rating for the identified events/hazards.

The assessment of the immediate worker accident consequences is based on the evaluation of waste handling scenarios, whose frequency is greater than 10^{-6}/y, which could be initiated by equipment failure or directly through human error by a worker performing the waste handling activity. The immediate worker is that individual directly involved with the waste handling operation for which the accident is postulated. Although procedures dictate that workers exit the area immediately, such accidents present an immediate risk due to the inhalation of airborne radionuclides to the worker performing the waste handling operation.

Table 14-9
Event Grouping and Analysis Approach

Event Grouping and Description		**Analysis Approach (Qualitative or Quantitative)**
Group A	**Anticipated Operational Occurrences**	
A.1	**External Events**	
A.1.1	Extreme Wind, Tornado and Microburst	
A.1.1.1	ECM	Qualitative
A.1.1.2	WWTP, Equalization Tanks and piping infrastructure	Qualitative
A.1.1.3	Building structures	Qualitative
A.1.2	Severe Precipitation	Qualitative
A.1.3	Extreme Drought	Qualitative
A.2	**Loss of Services**	
A.2.1	Loss of Class IV Power	Qualitative
A.2.2	Loss of ventilation	Qualitative
A.2.3	Loss of other services	Qualitative
A.3	**ECM**	
A.3.1	Containment failure	Qualitative
A.3.2	Dropped load	Quantitative
A.3.3	Contamination	Qualitative
A.3.4	Unintended contents	Qualitative
A.3.5	Vehicle collision	Qualitative

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)
A.3.6	Intrusion of non-human biota	Qualitative
A.3.7	Damage to structure	Qualitative
A.3.8	Higher flow	Qualitative
A.3.9	Ground subsidence or erosion	Qualitative
A.3.10	Radiation	Qualitative
A.4	**WWTP**	
A.4.1	Containment failure	Qualitative
A.4.2	Contamination	Quantitative
A.4.3	Dropped load	Qualitative
A.4.4	Vehicle collision	Qualitative
A.5	**VDF**	
A.5.1	Contamination	Quantitative
A.5.2	Radiation	Quantitative
Group B	**Design Basis Accidents**	
B.1	**External Events**	
B.1.1	Seismic activity	
B.1.1.1	ECM	Qualitative
B.1.1.2	WWTP, Equalization Tanks and piping infrastructure	Qualitative
B.1.1.3	Building structures	Qualitative
B.1.2	Wildland fire	Qualitative
B.1.3	Lightning	Qualitative
B.1.4	Extreme wind and tornado	
B.1.4.1	ECM	Qualitative
B.1.4.2	WWTP and Equalization Tanks	Qualitative
B.1.4.3	Building structures	Qualitative
B.2	**ECM**	
B.2.1	Dropped load	Quantitative
B.2.2	Unintended contents	Qualitative
B.2.3	Vehicle collision	Qualitative
B.2.4	Damage to structure	Qualitative
B.2.5	Misdirected flow	Qualitative
B.2.6	Internal fire	Quantitative
B.3	**WWTP**	
B.3.1	Containment failure	Quantitative
B.3.2	Dropped load	Qualitative
B.3.3	Unintended contents	Qualitative
B.3.4	Vehicle collision	Qualitative
B.3.5	Internal fire	Quantitative
B.3.6	Radiation	Qualitative
B.4	**VDF**	
B.4.1	Internal fire	Qualitative

Event Grouping and Description		**Analysis Approach (Qualitative or Quantitative)**
Group C	**Beyond Design Basis Accidents**	
C.1	Seismic activity	Qualitative
C.2	Flooding	Qualitative
C.3	Tornado	Qualitative
C.4	Aircraft crash	Qualitative/Quantitative
Group D	**Conventional Health and Safety**	
D.1	Anticipated Operational Occurrences	
D.1.1	ECM	
D.1.1.1	Impact/collision	Qualitative
D.1.1.2	Noise	Qualitative
D.1.1.3	Fall	Qualitative
D.1.2	WWTP, Equalization Tanks and piping infrastructure	
D.1.2.1	Fall	Qualitative
D.1.2.2	Spill/Leak	Qualitative
D.1.2.3	Hazardous reaction	Qualitative
D.1.2.4	Confined space	Qualitative
D.2	Design Basis Accidents	
D.2.1	ECM	
D.2.1.1	Impact/collision	Qualitative
D.2.2	WWTP	
D.2.2.1	Spill/Leak	Qualitative
D.2.2.2	Hazardous reaction	Qualitative
D.2.2.3	Dropped load	Qualitative
D.2.3	VDF	
D.2.3.1	Impact/collision	Qualitative
D.2.3.2	Spill/Leak	Qualitative

Table 14-10
Detailed Event Grouping Analysis Approach and Mitigated Risk Rating

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
Group A	**Anticipated Operational Occurrences**						
A.1	**External Events**						
A.1.1	**Extreme wind, Tornado and Microburst**						
A.1.1.1	**ECM**						
	ECM – potential for the interim cover to be displaced from the disposal cell during extreme wind resulting in increased precipitation infiltration.	Qualitative	RS	S0	F2	R0	[14-3]
	ECM – extreme wind resulting in the potential spread of contamination during waste placement in the disposal cell and waste storage in the TSWRPA resulting in potential radiological consequences to on-site and off-site receptors.	Qualitative	RS	S0	F2	R0	[14-3] [14-5]
A.1.1.2	**WWTP, Equalization Tanks and Piping Infrastructure**						
	Tornado or microburst cause potential damage to the Equalization Tanks' secondary containment resulting in potential release to the environment.	Qualitative	ENV	S1	F2	R1	[14-3]
	Potential Equalization Tank failure due to missiles generated by a tornado, resulting in the release of wastewater to the secondary containment and potential release to the environment.	Qualitative	ENV	S1	F2	R1	[14-3]
A.1.1.3	**Building Structures**						
	Tornado or microburst cause potential damage to the WWTP/VDF building structure resulting in the potential radiological consequences of spread of contamination and radiological consequences to on-site and off-site receptors.	Qualitative	RS	S0	F2	R0	[14-3]
A.1.2	**Severe Precipitation**						
	ECM – Severe precipitation results in an increase in water within the contact water storage area, an increase in the volume wastewater for the WWTP, the potential overflow of contact water within the disposal cell and the potential release of non-treated water to the environment.	Qualitative	ENV	S1	F2	R1	[14-3] [14-4]
	ECM – Severe precipitation causes potential erosion and or subsidence of the interim/final covers and waste layers, resulting in increased	Qualitative	RS	S0	F2	R0	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
	precipitation infiltration and increased leachate volume.						
	ECM – Severe precipitation results in potential water infiltration through the interim cover in the open disposal cell and increased leachate volume.	Qualitative	RS	S0	F2	R0	[14-5]
A.1.3	**Extreme Drought**						
	Extreme drought causes the loss of grass on the final cover, resulting in the potential erosion of the final cover.	Qualitative	RS	S0	F2	R0	[14-3]
	Extreme drought causes increased dry conditions within the ECM resulting in increased dust, increased airborne particulate material and the potential spread of contamination.	Qualitative	RS	S0	F2	R0	[14-5]
A.2	**Loss of Services**						
A.2.1	**Loss of Class IV power**						
	Loss of Class IV power results in the loss of the Equalization Tanks' heat tracing and loss of ventilation in WWTP.	Qualitative	RS	S0	F2	R0	[14-3
A.2.2	**Loss of ventilation**						
	Loss of ventilation results in WWTP airborne release in process area and potential radiological consequences to worker.	Qualitative	RS	S0	F2	R0	[14-3]
A.2.3	**Loss of other services**	Qualitative	RS	S0	F2	R0	[14-3]
A.3	**Engineered Containment Mound**						
A.3.1	**Containment Failure**						
	Heavy equipment impact with the waste package(s) due to human error causes containment failure resulting in the spread of contamination and the potential radiological consequences to on-site and off-site receptors.	Qualitative	RS	S0	F2	R0	[14-3]
	Degradation of waste packages due to corrosion results in an increase in leachate radionuclide activity concentration.	Qualitative	RS	S0	F2	R0	[14-3]
A.3.2	**Dropped load**						
	Potential damage to the waste package due to dropped load, resulting in the loss of shielding (dose rate >2 mSv/h near contact or > 1 mSv/h at 1 m), and radiological consequences to the worker.	Quantitative	RS	S2	F2	R2	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
	Dropped Load – Potential damage to the waste package (multiple) due to dropped load, resulting in the spread of contamination.	Quantitative	RS	S0	F2	R0	[14-3]
A.3.3	**Contamination**						
	There is excessive contamination on waste packages or handling equipment resulting in the spread of contamination (ECM and TSWRPA).	Qualitative	RS	S0	F2	R0	[14-3]
	Failure to monitor due to human error (transfer of contamination through worker, failure to monitor etc.) resulting in the spread of contamination (ECM and TSWRPA).	Qualitative	RS	S0	F2	R0	[14-3]
	There is cross contamination as a result of heavy equipment and vehicle movement resulting in the spread of contamination.	Qualitative	RS	S0	F2	R0	[14-5]
	There is increased dust at the ECM/disposal cell due to human error resulting in the spread of contamination.	Qualitative	RS	S0	F2	R0	[14-5]
A.3.4	**Unintended contents**						
	Unintended contents – waste does not meet waste acceptance criteria, resulting in potential radiological consequences to the worker (ECM and TSWRPA).	Qualitative	RS	S0	F2	R0	[14-3]
	Unintended contents – waste does not meet acceptance criteria, resulting in the potential increase in radioactivity in the leachate (ECM and TSWRPA).	Qualitative	RS	S0	F2	R0	[14-3]
A.3.5	**Impact/Collision**						
	Vehicle collision impact with the waste or another vehicle results in the potential spread of contamination (ECM and TSWRPA).	Qualitative	RS	S0	F2	R0	[14-3]
	Vehicle collision impact with the waste or another vehicle results in a potential vehicle fire, waste fire and environmental release (ECM and TSWRPA).	Qualitative	ENV	S0	F2	R0	[14-3]
A.3.6	**Intrusion of non-human biota**						
	Intrusion of non-human biota into the ECM resulting in radiological consequences to non-human biota and minor damage to the final cover.	Qualitative	ENV	S0	F2	R0	[14-3]
A.3.7	**Damage to Structure**						

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
	Side slope of the liner is damaged due to heavy equipment operation and human error during waste emplacement activities resulting in potential radiological consequences to the worker.	Qualitative	RS	S0	F2	R0	[14-3]
A.3.8	**Higher Flow**						
	Higher flow than anticipated of contact water due to human error leading to the overflow of contact water pump station #1 and resulting in a release to the environment.	Qualitative	ENV	S0	F2	R0	[14-4]
A.3.9	**Ground subsidence or erosion**						
	Ground subsidence or erosion results in the potential failure of the final cover and increased infiltration.	Qualitative	RS	S0	F2	R0	[14-3]
A.3.10	**Radiation**						
	Radiation – waste package has higher than anticipated dose rate due to human error, resulting in radiological consequences to the worker.	Qualitative	RS	S1	F2	R1	[14-5]
A.4	**WWTP**						
A.4.1	**Containment Failure**						
	Overflow of the Equalization Tank, piping or Equalization Tank failure (loss of primary containment) resulting in release of wastewater.	Qualitative	RS	S0	F2	R0	[14-3]
	Valve left open during sampling or drain valve left open during draining activity due to human error, resulting in spill/leak.	Qualitative	RS	S0	F2	R0	[14-3] [14-5]
	Loss of seal between filter press plates, resulting in spread of contamination and potential radiological consequences to the worker.	Qualitative	RS	S0	F2	R0	[14-3]
	Mechanical or freezing of the air valve on the effluent force main to Perch Lake (located at the high point of Perch Lake discharge line) leading to the potential for water hammering effect resulting in damage to the force main and release to the environment.	Qualitative	ENV	S1	F2	R1	[14-4]
A.4.2	**Contamination**						
	Contamination on equipment results in potential radiological consequences to the worker.	Qualitative	RS	S0	F2	R0	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
	Worker is splashed during sampling of the tanks, resulting in potential radiological consequences to the worker.	Quantitative	RS	S0	F2	R0	[14-3]
A.4.3	**Dropped Load**						
	Dropped load occurs in the WWTP due to human error, resulting in the spread of contamination and potential radiological consequences to the worker.	Quantitative	RS	S0	F2	R0	[14-3]
A.4.4	**Impact/Collision**						
	Vehicle collision impact due to human error damages structure, resulting to damage to Equalization Tank secondary containment or leachate extraction box.	Qualitative	RS	S0	F2	R0	[14-3]
A.5	**Vehicle Decontamination Facility (VDF)**						
	Exposure to greater than anticipated contamination on vehicle, or handling equipment resulting in potential radiological consequences to the worker.	Quantitative	RS	S1	F2	R1	[14-3]
	Radiation – higher than anticipated radiation fields from the vehicle resulting in potential radiological consequences to the worker.	Quantitative	RS	S1	F2	R1	[14-3]
Group B	**Design Basis Accidents**						
B.1	**External Events**						
B.1.1	**Seismic activity**						
B.1.1.1	**ECM**						
	Seismic activity (DBE) results in the potential displacement of waste and the spread of contamination in ECM disposal cell and/or TSWRPA.	Qualitative	RS	S0	F1	R0	[14-3]
	Seismic activity (DBE) results in the potential displacement of waste in ECM disposal cell and/or TSWRPA and potential release to the environment.	Qualitative	RS	S1	F1	R0	[14-3]
B.1.1.2	**WWTP, Equalization Tanks and Piping Infrastructure**						
	Seismic activity (DBE) causes potential piping failure at the Equalization Tanks resulting in release to the secondary containment and potential release to the environment.	Qualitative	ENV	S1	F1	R0	[14-3]
	Seismic activity (DBE) causes piping failure at Equalization Tank resulting in release to the	Qualitative	RS	S0	F1	R0	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk S	F	RR	Reference
	secondary containment and potential radiological consequences to the worker.						
	Seismic activity (DBE) causes damage to the piping and/or sediment box HDPE, resulting in the loss of containment and potential release to the environment.	Qualitative	ENV	S0	F1	R0	[14-3]
	Seismic activity (DBE) causes damage to the piping and/or leachate extraction box (HDPE), resulting in loss of containment and potential radiological consequences to the worker.	Qualitative	RS	S0	F1	R0	[14-3]
B.1.1.3	**Building Structures**						
	WWTP/VDF –Seismic activity (DBE) causes loss of services at WWTP and VDF including Class IV power, controls and ventilation.	Qualitative	RS	S0	F1	R0	[14-3]
B.1.2	**Wildland fire**						
	Wildland fire causes waste fire in the open disposal cell and or TSWRPA, resulting in release to the environment.	Qualitative	ENV	S0	F1	R0	[14-3]
	Wildland fire causes waste fire in the open disposal cell and or TSWRPA, resulting in radiological consequences to the on-site and off-site receptors.	Qualitative	RS	S1	F1	R0	[14-3]
B.1.3	**Lightning**						
	Lightning causes waste fire in the open disposal cell and or TSWRPA, resulting in release to the environment.	Qualitative	ENV	S0	F1	R0	[14-3]
	Lightning causes waste fire in the open disposal cell and or TSWRPA, resulting in radiological consequences to the on-site and off-site receptors.	Qualitative	RS	S1	F1	R0	[14-3]
B.1.4	**Extreme wind and Tornado**						
B.1.4.1	**ECM**						
	Extreme wind causes the interim cover to be displaced from the disposal cell resulting in increased precipitation infiltration.	Qualitative	RS	S0	F1	R0	[14-3]
	Tornado causes damage to the interim cover at the disposal cell resulting in the potential spread of contamination and potential radiological consequences to the on-site and off-site receptors.	Qualitative	RS	S0	F1	R0	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
	Extreme wind or tornado causes the potential spread of contamination at the TSWRPA and potential radiological consequences to on-site and off-site receptors.	Qualitative	RS	S0	F1	R0	[14-3]
B.1.4.2	**WWTP, Equalization Tanks and Piping Infrastructure**						
	Tornado causes potential damage to the Equalization Tanks' secondary containment resulting in potential release to the environment.	Qualitative	RS	S1	F1	R0	[14-3]
	Potential Equalization Tank failure due to tornado generated missiles resulting in release to the secondary containment and potential release to the environment.	Qualitative	ENV	S1	F1	R0	[14-3]
	Potential Equalization Tank failure due to missiles resulting in release to the secondary containment and potential radiological consequences to the on-site and off-site receptors.	Qualitative	RS	S0	F1	R0	[14-3]
B.1.4.3	**Building Structures**						
	Tornado causes potential collapse of the WWTP and the VDF building structures, resulting in the release of contamination and radiological consequences to the on-site and off-site receptors.	Qualitative	RS	S0	F1	R0	[14-3]
B.2	**ECM**						
B.2.1	**Dropped Load**						
	Equipment mechanical failure leads to dropped load and potential damage to the waste package(s) (multiple) resulting in the spread of contamination.	Qualitative	RS	S0	F1	R0	[14-3]
	Equipment mechanical failure leads to dropped load and potential damage to the waste package resulting in the loss of shielding and radiological consequences to the worker.	Qualitative	RS	S2	F1	R1	[14-3]
B.2.3	**Unintended Contents**						
	Unintended contents – waste does not meet acceptance criteria, resulting in a potential increase in chemical concentrations in the leachate.	Qualitative	RS	S1	F1	R0	[14-3]
	Unintended contents – waste does not meet acceptance criteria, resulting in a potential increase in radioactivity in the leachate and	Qualitative	RS	S0	F1	R0	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk S	F	RR	Reference
	potential radiological consequences to the worker.						
B.2.3	**Impact/Collision**						
	Vehicle collision due to mechanical failure leads to potential vehicle fire in the ECM/disposal cell resulting in waste fire and environmental release.	Qualitative	ENV	S0	F1	R0	[14-3]
	Vehicle collision due to mechanical failure leads to potential vehicle fire in the ECM/disposal cell resulting in waste fire and environmental release.	Quantitative	ENV	S0	F1	R0	[14-3]
	Vehicle impact leads to the vehicle falling into the disposal cell resulting in the potential spread of contamination.	Qualitative	RS	S1	F1	R0	[14-3]
	Vehicle impact results in the potential spread of contamination.	Qualitative	RS	S0	F1	R0	[14-3]
	Vehicle impact leads to potential vehicle fire resulting in waste fire and environmental release.	Qualitative	ENV	S0	F1	R0	[14-3]
B.2.4	**Damage to Structure**						
	Collapse or damage of the off-loading ramp leads to potential vehicle roll over, resulting in potential spread of contamination.	Qualitative	RS	S1	F1	R0	[14-3]
	Collapse or damage of the ECM waste structure (loss of mound stability) resulting in potential damage to the final cover.	Qualitative	RS	S0	F1	R0	[14-3]
B.2.5	**Misguided Flow**						
	Contact water in the ECM is transferred to the storm water system due to human error resulting in release to the environment.	Qualitative	ENV	S2	F1	R1	[14-4]
B.2.6	**Internal Fire**						
	Potential waste fire resulting in radiological consequences to on-site and off-site receptors, and release to the environment.	Quantitative	ENV	S0	F1	R0	[14-3]
			RS	S1	F1	R0	
B.3	**WWTP**						
B.3.1	**Containment Failure**						
	Loss of containment (tank failure) leads to spill of IX resin and/or GAC resulting in radiological consequences to the worker.	Quantitative	RS	S0	F1	R0	[14-3] [14-5]
	Loss of containment during the removal of spent resins/GAC leads to spill of IX resin and/or GAC, resulting in radiological consequences to the worker.	Quantitative	RS	S0	F1	R0	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
	Loss of containment due to mechanical failure leads to the loss of filter press containment resulting in spread of contamination.	Qualitative	RS	S0	F1	R0	[14-3]
	Loss of containment due to mechanical failure leads to the loss of secondary containment resulting in spread of contamination.	Qualitative	RS	S0	F1	R0	[14-3]
	Loss of containment – mechanical failure of piping and or valves, resulting in spill/leak and potential for the worker being splashed.	Qualitative	RS	S0	F1	R0	[14-3] [14-5]
	Loss of fume hood due to mechanical failure resulting in potential radiological consequences to the worker.	Qualitative	RS	S0	F1	R0	[14-3]
B.3.2	**Dropped Load**						
	Mechanical failure of handling equipment (crane) resulting in dropped load and the spread of contamination.	Qualitative	RS	S0	F1	R0	[14-3]
B.3.3	**Unintended Contents**						
	Unexpected increase in the Equalization Tank level resulting in potential overflow.	Qualitative	RS	S0	F1	R0	[14-3]
B.3.4	**Impact/Collision**						
	Vehicle collision impact due to mechanical failure damages structure, resulting to damage to Equalization Tank secondary containment or leachate extraction box.	Qualitative	RS	S0	F1	R0	[14-3]
B.3.5	**Internal Fire**						
	Flammable gas release, spontaneous combustion from chemical reaction, or electrical fire leads to an internal fire resulting in release to the environment and potential radiological consequences to the on-site and off-site receptors.	Qualitative	RS	S0	F1	R0	[14-3]
	Vehicle or electrical fire leading to potential minor damage to the building structure, resulting in release to the environment.	Qualitative	ENV	S1	F1	R0	[14-3]
	Fire in the processing area resulting in potential radiological consequences to the on-site and off-site receptors.	Quantitative	RS	S0	F1	R0	[14-3] [14-5]
B.3.6	**Radiation**						
	High radiation fields from the process system (filter press and IX resins) resulting in potential radiological consequences to the worker.	Qualitative	RS	S1	F1	R0	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
	Higher than anticipated radiation fields from the Equalization Tanks due to waste package(s) (Type 5 waste) failure in the ECM resulting in potential radiological consequences to worker.	Qualitative	RS	S0	F1	R0	[14-3]
B.4	**VDF**						
B.4.1	**Internal Fire**						
	Internal fire at VDF due to vehicle or electrical fire, resulting in release to the environment and potential radiological consequences to the on-site and off-site receptors.	Qualitative	RS	S0	F1	R0	[14-3]
Group C	**Beyond Design Basis Accidents including DECs**						
C.1	**Seismic activity**						
	Seismic activity, BDBE, results in potential liquefaction below the perimeter berm, damaging the perimeter berm, resulting in release to the environment and potential radiological consequences to the off-site receptor. Failure of the perimeter berm leads to failure of the interim cover and final cover.	Qualitative	RS	S1	F0	R0	[14-3]
			ENV	S3	F0	R1	[14-3]
	Seismic activity, BDBE, leads to potential displacement of waste in the disposal cell, resulting in the spread of contamination and release to the environment.	Qualitative	RS	S1	F0	R0	[14-3]
			ENV	S1	F0	R0	[14-3]
	Seismic activity, BDBE, leads to potential piping failure, loss of Equalization Tanks, and loss of secondary containment, resulting in release to the environment.	Qualitative	ENV	S3	F0	R1	[14-3]
	Seismic activity, BDBE, leads to the potential collapse of WWTP building structure, resulting in the release of contamination and radiological consequences to the on-site and off-site receptors.	Qualitative	RS	S0	F0	R0	[14-3]
	Seismic activity, BDBE, leads to potential WWTP internal fire, resulting in release to the environment.	Qualitative	ENV	S1	F0	R0	[14-3]
C.2	**Flooding**						
	Flooding due to the failure of dams on the Ottawa River has no consequence on the NSDF. The ECM is located above the above the Ottawa River flood elevation (a minimum of 160 mASL). The estimated flood level at the CRL site due to a	Qualitative	-	-	-	-	[14-3]

Event Grouping and Description		Analysis Approach (Qualitative or Quantitative)	CAT	Mitigated Risk			Reference
				S	F	RR	
	failure of both upstream dams on the Ottawa River is 122 mASL [SAB].						
C.3	**Tornado**						
	Beyond design basis tornado leads to potential damage to the rip rap and projectiles damage the perimeter berm, resulting in release to the environment and the spread of contamination.	Qualitative	ENV RS	S0 S0	F0 F0	R0 R0	[14-3]
	Beyond design basis tornado leads to potential damage to the final cover and gas vents, resulting in potential spread of contamination.	Qualitative	RS	S1	F0	R0	[14-3]
C.4	**Aircraft crash**	Qualitative/Quantitative	-	-	-	-	[14-3]
D	**Conventional Health and Safety – see** Table 14-18						

14.1.5 Quantitative Analysis Uncertainty

Uncertainties in the safety analysis and quantitative analysis can arise because of the limitations associated with the definition of the radiological inventory or source term, scenarios and available data. Uncertainties are accounted for in the safety analysis and quantitative analysis through:

- The adoption of conservative radiological inventory or source term. The NSDF source terms are defined in Waste Characterization [14-16], WWTP Material and Energy Balance Report [14-17], and the NSDF Reference Inventory [14-18].
- The quantitative analysis was completed following the appropriate methodology for the accident scenario and the methodology reference documents are provided in the reference sections for the quantitative analyses.
- The use of appropriate conservatism, engineering judgement and justified assumptions in the quantitative analyses, ensures that the radiological consequences estimates to the on-site and off-site receptors are conservative.
- Verification of calculations.
- Use of CNL approved codes; MicroShield Version 9.02 and RESRAD-OFFSITE Version 3.2.

14.2 Normal Operations

The normal operation is waste management activities including disposal of LLW and treatment of low-level wastewater, generated by the Facility. The NSDF operational activities include waste placement, waste processing, routine Facility inspections, radiological monitoring, surveillance, maintenance, and housekeeping.

The waste processing activities include:

- Waste reception and inspection.
- Waste temporary storage and staging at the TSWRPA.
- Waste processing (grouting) at the TSWRPA.
- Waste placement and compaction at the ECM disposal cell.
- Macro encapsulation and grouting of waste and waste layers at the ECM disposal cell.
- Management of contact and non-contact water in the ECM.
- Management of surface water.
- Treatment of low-level wastewater in the WWTP.
- Decontamination of vehicles and equipment in the VDF.

The fundamental safety functions that the NSDF must fulfill during normal operations are:

- Containment of radioactive materials.
- Control of operational discharges of radioactive and hazardous substances, as well as limitation of accidental releases.
- Monitoring of safety critical parameters to guide worker actions.

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

The hazards associated with the normal operation are radiological hazards, non-radiological hazards, chemical hazards, and conventional occupational hazards. Minor fugitive airborne emissions to the environment are an inherent aspect of normal operation for the NSDF.

Airborne effluents during normal operations are expected to occur during:

- Waste placement and compaction activities in the ECM.
- Filling and draining of the Equalization Tanks and the WWTP process tanks.
- Operation of the WWTP active ventilation exhaust.
- Stockpile storage of aggregate materials.
- Operation of heavy equipment and vehicles driving on unpaved roads.

Liquid effluents released during normal operations are:

- The discharge of WWTP treated effluent.
- The discharge of surface water and non-contact water.

14.2.1 Radiological Hazards

The radiological hazards during normal operations of the NSDF are direct radiation from the waste and contamination, and airborne emissions. Indirect exposure of on-site and off-site receptors to effluent releases to groundwater and surface water would be insignificant. The NSDF SSCs that are the primary sources of radiation are the ECM, and the WWTP. The primary sources of radiation at the NSDF include [14-19]:

- The bulk and packaged LLW disposed of in the ECM, including waste in the TSWRPA.
- Leachate and wastewater processed in the WWTP.
- Residuals including filter press dewatered solids and spent IX resins that are generated from processing wastewater in the WWTP.
- Radioactive sources used for checking instrumentation.

Workers in the ECM, WWTP and VDF are exposed to gamma radiation emanating from the waste. The Facility has various controls in place, which act to prevent, detect or mitigate the radiation hazards. The NSDF staff use several methods of protection against the radiological hazards, including radiation surveys, work control, PPE&C, personnel dosimetry, and contamination monitoring. During operations with potential for contamination hazards, operating personnel wear appropriate PPE&C as directed by RP to minimize internal and external doses. Application of RP procedures and ALARA practices minimize doses to the operational personnel. Dose control points are assigned to the workers and confirmed to be appropriate by the worker's manager. These DCPs can be adjusted by the manager and/or Group 1 qualified Health Physicist as necessary during the year.

The RP (and Dosimetry) Program and the EnvP Program are comprehensive monitoring and surveillance programs in place at CRL to monitor the dose received by members of the public and workers.

Routine radiation surveys of the various Facility areas are performed in accordance with the RP Program, and ensure that the spread of contamination is controlled and that the magnitude of hazard from external radiation and surface contamination is known. General site radiation levels are measured in the NSDF using a portable gamma-radiation dose rate survey meter held at waist level (~1 m from the ground).

Radiation fields in the NSDF are recorded on a scheduled basis. Radiation fields exceeding 0.025 mSv/h, are recorded and are posted in the appropriate area. This ensures that workers are well informed about radiation dose rates within the NSDF areas. Radiation surveys are performed by RP Staff before and during work within each Facility to ensure that radiation doses are planned and controlled. Temporary shielding may be used to reduce the dose rate if the RP personnel deem it to be necessary. Workers will use time, distance, alarming dosimetry, respirators, and PPE&C as specified in Radiological Work Assessments. Worker radiological exposure will be maintained ALARA.

Radioactive surface contamination at the NSDF are potential hazards. The Facility has various controls in place, which act to prevent, detect or mitigate the contamination hazards. Radiological areas and safety zones control the spread of contamination and indicate the degree of hazard from external radiation. The predicted radiological safety zone designations for the NSDF areas are documented in Table 11-3.

Waste packages and transportation containers must meet the external radiation fields as defined in Section 9.3.1.2, limiting the dose to the workers. The primary safeguards in place to mitigate the radiation hazard are barriers and RP oversight/surveillance. The disposal of waste in the NSDF shall be such that the dose rate at the NSDF perimeter fence shall not exceed 10 µSv/h.

The average effective dose from natural background radiation in Canada is approximately 1.8 mSv per year [14-20], which serves as a basis for comparison of NSDF radiation levels and the natural background level.

14.2.2 Worker Radiological Consequences

The radiological consequence to the workers performing work with radiological hazards during normal operations, is estimated by analyzing the radiological consequences to the following worker types:

- WWTP Worker.
- ECM Worker.

The radiological consequence to other NSDF workers (e.g. operations support staff), is expected to be low, and bounded by the estimated radiological consequence to the workers performing radiological work. Therefore, the radiological consequences to other NSDF workers during normal operations is not analyzed.

The radiological consequence to the worker is estimated based on:

- The expected exposure durations for the work tasks; and
- The estimated dose rates near the radiological hazard for the work tasks.

14.2.2.1 Waste Water Treatment Plant Worker Radiological Consequences

The total estimated radiological consequence to the WWTP worker is 5.65 mSv/y and detailed analysis is presented in Appendix A. Table 14-11 provides a summary of the WWTP worker radiological consequences, exposure duration and dose rate for the work tasks during normal operations. The work tasks contributing the most significant radiological consequence to workers are sampling the SAC IX resin and transfer of the dewatered residuals bin. The estimated radiological consequence to the WWTP worker is 5.65 mSv/y, which meets the CNL effective dose action levels of 6 mSv/4 weeks, and 20 mSv/y, presented in Table 3-2. The radiological consequence to the workers will be controlled using the estimated dose controls points listed in Table 11-2 and ALARA.

Table 14-11
Waste Water Treatment Plant Worker Normal Operations Radiological Consequence Analysis

Section	WWTP Process tank/component (number of tanks)	Operations or Maintenance Work Task	Duration (Hours per year)	Dose Rate (mSv/h)	Total Dose (mSv/y)
A.2.1	Equalization Tanks (3)	Equalization Tank maintenance	36	6.72E-04	2.42E-02
		Equalization Tank cleaning	36	6.72E-04	2.42E-02
A.2.2	Chemical Precipitation Tank (4)	Sampling and visual inspection of chemical precipitation	46.67	4.03E-04	1.88E-02
		Maintenance of motor and level instrumentation	96	4.03E-04	3.87E-02

A.2.3	Membrane Filter Feed Tank (2)	Maintenance of motor and level instrumentation	48	5.45E-04	2.62E-02
A.2.4	Membrane Filter Process Tank(2)	Maintenance of level instrumentation	24	4.14E-04	9.94E-03
A.2.5	Membrane Filter Skid (2)	Clean-in-place operation	11.67	4.14E-04	4.83E-03
A.2.6	pH adjust Tank (2)	Sampling of pH adjust tank at outlet of membrane filter	46.67	1.18E-04	5.05E-03
		Maintenance of motor and level instrumentation	48	1.18E-04	5.66E-03
A.2.7	Polishing System Feed Tank (2)	Maintenance of level instrumentation	24	1.59E-04	3.82E-03
A.2.8	IX and GAC tanks (6)	Sampling at outlet of each IX or GAC tank	46.67 (GAC) 46.67 (Zeolite) 46.67 (SAC)	2.54E-05 (GAC) 1.05E-04 (Zeolite) 5.69E-02(SAC)*	1.19E-03 (GAC) 4.90E-03 (Zeolite) 2.66E+00 (SAC)
		Replacement of GAC or IX resins	9 (GAC) 7 (Zeolite) 6 (SAC)	2.54E-05 (GAC) 1.05E-04 (Zeolite) 5.69E-02 (SAC)	2.29E-04 (GAC) 7.35E-04 (Zeolite) 3.41E-01 (SAC)
A.2.9	Final pH adjust Tank (2)	Maintenance of motor and level instrumentation	48	5.90E-06	2.83E-04
A.2.10	Final Effluent Release Tank (2)	Maintenance of level instrumentation	24	7.96E-06	1.91E-04
A.2.11	Residuals Storage Tank (2)	Maintenance of level instrumentation	48	7.88E-03	3.78E-01
		Removal of supernatant from tank	29	7.88E-03	2.29E-01
A.2.12	Filter Press Feed Tank (1)	Maintenance of motor and level instrumentation	24	1.27E-02	3.05E-01
A.2.13	Filter Press (1)	Operation of filter press	14.35	7.52E-03**	1.08E-01
		Filter press cleaning	58 operations	7.525E-03	4.36E-01
		Transfer of dewatered residuals bin	15	6.77E-02	1.02E+00
				Total Dose	**5.65 mSv/y**

*IX tank dose rate during sampling is half of the maximum dose rate, which exists during replacement.
The GAC dose rate is primarily the result of radionuclides in wastewater (rather than accumulated in the GAC), therefore, it is unchanged during GAC exhaustion.
** The filter press dose rate is estimated to be 1/9th the dose from the dewatered residuals bin.

14.2.2.2 Engineered Containment Mound Worker Radiological Consequences

The estimated radiological consequence to the ECM worker, based on work tasks, ranges from 0.8 mSv/y to 10.4 mSv/y, and detailed analysis is presented in Appendix A. Table 14-12 provides a summary of the ECM worker radiological consequences, exposure duration and dose rate for the work tasks during normal operations. The work task with the highest radiological consequence to workers is macro encapsulation of drummed waste. The highest radiological consequence to the worker is 1.3 mSv/4 week period and 10.4 mSv/y, which meets the CNL effective dose action levels of 6 mSv/4 weeks, and 20 mSv/y, presented in Table 3-2. The radiological consequence to workers will be controlled using the predicted DCPs listed in Table 11-2 [14-21], and the ALARA principle.

The ECM Worker works exclusively at the ECM performing tasks including waste placement, operating of heavy equipment, installing cover systems, and performing maintenance. The ECM worker receives a radiological consequence due to external radiation exposure to wastes, inhalation of dust, and inhalation of gaseous emissions (see Section 14.2.2.2.1).

The annual radiological consequence to the ECM worker was calculated using RESRAD-OFFSITE Version 3.2. The dose assessment using RESRAD-OFFSITE, models a disposal cell containing 150 000 m^3 bulk waste that is 10 m thick, and the worker is located on top for 1 120 hours/year. The exposure pathways includes external gamma, inhalation, radon, and soil ingestion. This radiological consequence estimate, conservatively excludes the distance and shielding provided by the heavy equipment to the worker. The peak radiological consequence to the ECM worker is 6.37 mSv/y, and this corresponds to a dose rate of approximately 5.69E-03 mSv/h. These radiological consequences estimates assume that there is no cover over the waste, and conservatively exclude the distance and any shielding provided by the heavy equipment to the receptor. The dose rate of 5.69E-03 mSv/h was used to estimate the worker dose in Table 14-12 for the activities: apply a daily cover to the LLW, move and grade LLW, and maintenance activities to the ECM. The highest annual exposure pathway contributions to the worker from the RESRAD-OFFSITE analysis are:

- 6.36 mSv from ground gamma.
- 1.24E-02 mSv from inhalation.
- 7.41E-07 mSv from radon.
- 4.27E-04 mSv from incidental soil ingestion.

Table 14-13 provides the estimated total annual radiological consequence for each ECM worker resource type, and the total annual radiological consequences per worker, if the worker (suggested resource), is expected to perform all specified work tasks listed in Table 14-12. The highest ECM worker estimated annual radiological consequence is 34.89 mSv or 8.72 mSv/worker (based on four RP staff workers). The highest estimated total annual radiological consequence per worker is 16.49 mSv/worker to the civil engineer, and this radiological consequences is likely overestimated, since the civil engineer works in an office with frequent visits to the ECM and is not likely present in the ECM during the work tasks.

However, the worker radiological consequence will be controlled using the CNL effective dose Action Level of 20 mSv/y or 6 mSv per four week monitoring period [14-22], presented in Table 3-2, and the worker assigned DCPs. The ECM worker annual radiological consequences will not exceed the CNL effective dose Action Level or the estimated DCP of 5 mSv. The ECM worker total annual radiological consequence that exceed the CNL effective dose Action Level, based on resource type, are not unreasonable, since more than one ECM staff will perform the specified work activities, and the total annual radiological consequence per worker is less than the CNL effective dose Action Level presented in Table 3-2 [14-19].

Table 14-12
Engineered Containment Mound Worker Normal Operations Radiological Consequences Summary

Section	Significant Tasks	Suggested Resources	Duration	Estimated Hours Near Source	Dose Rate (mSv/h)	Radiological Consequences	
						mSv/4 weeks	mSv/y
A.3.1	Unloading and placement of bulk low level waste (LLW) from shipment vehicle.	2 Waste Technicians, 1 Mechanical Service Attendant (MSA), 1 Driver, and 1 RP staff.	Work 8 hours in a 10 hour work day, 4 days per week for an 8 month season spending 50% of time near the waste.	560	4.72E-03	0.31	2.64
A.3.1	Packaged waste placement.	1 MSA, 1 Technician, 1 Driver, 2 RP staff, 1 Millwright, and 1 Hoisting Engineer	Work 8 hours per day, one day per week for an 8 month season spending 25% of the time near the waste package.	70	0.1	0.8	7.0
A.3.2	Grouting of packaged waste.	1 Civil Engineer, 1 Technician, 1 MSA, 2 Carpenters, 2 RP staff, 1 Contamination Monitor, 1 Millwright, and 1 Hoisting Engineer.	Work 8 hours/day, 2 days per month for an 8 month season spending 50% of the time near the packaged waste containment area.	64	9.514E-02	0.76	6.09

Section	Significant Tasks	Suggested Resources	Duration	Estimated Hours Near Source	Dose Rate (mSv/h)	Radiological Consequences	
						mSv/4 weeks	mSv/y
A.3.3	Macroencapulation of drummed waste.	1 Civil Engineer, 1 Technician, 1 MSA, 2 Carpenters, 2 RP staff, 1 Contamination Monitor, 1 Millwright, and 1 Hoisting Engineer	Work 8 hours/day, 1 day per month for an 8 month season spending 25% of the time near macro encapsulation containment area.	16	0.65	1.3	10.4
A.3.4	Apply a daily cover to the LLW.	2 Heavy equipment operators, and 1 RP staff.	Work 1 hour/day, 4 days per week for an 8 month season spending 100% of the time on the LLW.	140	5.69E-03	0.09	0.80
A.3.4	Moving and grading LLW.	2 Heavy equipment operators, and 1 RP staff.	Work 8 hours/day, 4 days per week for an 8 month season spending 100% of the time on the LLW.	1 120	5.69E-03	0.73	6.37
A.3.4	Maintenance activities to ECM.	2 Heavy equipment operators, and 1 RP staff.	Work 8 hours/day, one day per week for an 8 month season spending 100% of the time on the LLW.	280	5.69E-03	1.8	1.59

Table 14-13
ECM Worker Estimated Total Annual Dose

ECM Worker [a]	Total Annual Dose* (mSv)	Total Annual Dose* per worker (mSv/worker)
RP staff – surveyors (4)	34.89**	8.72
Mechanical Service Attendant (4)	26.13**	6.53
ECM Technician [b] (5)	26.13**	5.23
Millwright (3)	23.49**	7.83
Hoisting Engineer (2)	23.49**	11.75
Civil Engineer (1)	16.49 [c]	16.49 [c]
Carpenter (2)	16.49	8.25
Contamination Monitor (4)	16.49	4.12
Driver (2)	9.64	4.82
Heavy Equipment Operator (2)	8.76	4.38

[a] The number of staff for the ECM worker type [14-21] is provided in parentheses.
b Includes Technician and Waste Technician in Table 14-12.
c Civil engineer working in office with frequent visits to the ECM [14-21], the actual worker dose will be much lower.
* If the worker (suggested resource), is expected to perform all specified work tasks in Table 14-12.
** Total annual dose exceeds the CNL effective dose Action Level.

14.2.2.2.1 Gaseous Emissions

The ECM worker radiological consequences for the gaseous emissions, radon, tritium and Carbon-14, was assessed in Radon and Other Landfill Gas Modelling and Evaluation [14-23]. A summary of Radon and Other Landfill Gas Modelling and Evaluation [14-23], is provided in this section.

Radon gas production and transport during the operations period of the ECM, was modelled using methods developed by the U.S. Nuclear Regulatory Commission. Radon gas is produced by the decay of Ra-226. The model assumes that the Ra-226 source is uniformly distributed throughout the waste. Radon gas is created in the waste and a portion of the radon enters the interstitial pore spaces and is transported by gaseous diffusion. At the top of the waste, radon gas is released to the atmosphere. Ventilation is provided only by wind and natural processes outdoors.

The radon gas concentration in air was estimated from the radon flux from the top of the waste to the atmosphere. The following inputs and assumptions were used to estimate the ECM worker radiological consequences to the gaseous emissions during normal operations [14-23]:

- Ra-226 activity concentration in bulk waste is 2.16E-04 Bq/g.
- Ra-226 activity concentration in packaged waste is 0.529 Bq/g.
- The mass weighted average activity concentration of Ra-226 in bulk and packaged waste is 0.038 Bq/g.
- Waste density is 1.5 g/cm^3.
- Radon emanation coefficient is 0.25.
- All Ra-226 was conservatively assumed to be immediately available for transport through the waste mass. Waste packages do not limit radon gas emissions and no credit was taken for reduction in radon gas releases provided by the waste containers.
- The worker spends 1 024 hours per year in the ECM disposal cell placing waste packages, compacting bulk waste, grouting waste in place, placing other backfill materials around placed wastes, or other activities.
- The worker exposure time of 1 024 hours per year is based on an exposure time of 128 hours per month for eight months per year.
- The area of the largest disposal cell in the ECM, 15 000 m^2, was used.
- Radon was assumed to mix in the air to a height of 2 m to encompass the breathing zone of workers and to provide a conservatively low estimate of dilution.
- The residence time of radon in air in the NSDF is short, so there is little time for radon decay products to accumulate. It requires a couple of hours for the decay products to reach equilibrium. The radon dose, which is primarily from the radon decay products, is based on the assumption that the radon decay products in air are at 10% of their equilibrium

concentration. This is a conservatively high estimate, considering the ventilation provided by air movement in the outdoor environment.

- The LFG generated within the ECM is assumed to consist of approximately 50% methane (+/-5%) and 50% carbon dioxide (+/-5%) by volume, with very small amounts (fractional percent volume) of other gases, similar to LFG generated by decomposition of organic material in other landfills.
- Methane gas flux is 1.26E+05 m^3/year, from LandGem.
- Methane flux is 9.00E+07 g/year.
- Hydrogen flux is 2.25E+07 g/year based on ratio of atomic weights of hydrogen and methane.
- Carbon flux is 6.75E+07 g/year based on ratio of atomic weights of carbon and methane.
- Carbon-14 has a total inventory of 1.71E+12 Bq, equivalent to 10.7 g, and the C-14 concentration uniformly throughout the waste is 1.1E-11 g of C-14 per g of waste.
- Total waste mass is 9.57E+11 g.
- The worker inhalation dose from C-14 was evaluated assuming the ratio of C-14 to stable carbon in LFG is 1.1E-08 on a mass basis.
- Tritium has a total inventory of 8.91E+14 Bq, equivalent to 2.5 g of tritium, and the tritium concentration uniformly throughout the waste is 2.6E-12 g of tritium per g of waste.
- The analysis uses the non-decayed tritium inventory, as this value is higher and more representative of the operational period when gaseous releases may affect workers.
- The natural abundance of hydrogen in soil-like material is about 1 500 ppm or about 0.0015 g of hydrogen per gram of soil-like waste. Assuming this concentration of hydrogen is present in soil-like waste, tritium constitutes a fraction of 1.7E-09 of the total hydrogen on a mass basis.
- The worker inhalation dose from tritium was evaluated assuming the ratio of tritium to stable hydrogen in LFG is 1.7E-09 on a mass basis.
- Airborne radionuclides such as tritium, C-14, and radon in the post-closure period are bounded by the airborne emissions prior to the closure of the NSDF.
- Gaseous emissions of tritium and C-14 will decrease with time in the closure and post-closure phases, due to decomposition of organic substances during operations phase, resulting in decreased gas generation from organic material following the end of operations.

Table 14-14 shows the radioactive gas generation rates and the dose to workers during normal operations. The estimated radiological consequences to the ECM worker during normal operations from radon is 9.6E-04 mSv/y, from tritium is 1.6E-05 mSv/y and from Carbon-14 is 2.2E-06 mSv/y.

The estimated radon concentration of 0.5 Bq/m^3, in the disposal cell air:

- Is lower than the local background radon levels, and the current Canadian guideline of 200 Bq/m^3 for radon in indoor air for dwellings [14-24].
- Meets the Ontario Ministry of Labour workplace radon background level of <200 Bq/m^3 [14-25].

The Ontario Ministry of Labour classifies workplaces based on their average annual concentration of radon, and an average annual radon concentration of less than 200 Bq/m^3 is considered background and the program classification for radon in the workplace is unrestricted [14-25]. Workers may be exposed to elevated levels of radon gas in indoor environments, however, due to dilution in outdoor environments, the amount of radon gas is very small and does not pose a health risk [14-25].

Table 14-14
Radioactive Gas Generation Rates and Worker Radiological Consequences during Normal Operations

Parameter	Value
Radon gas production rate	3.0E-08 Bq/cm^3-sec
Radon flux to atmosphere, no cover	2.9E-02 Bq/m^2 /sec
Radon flux to atmosphere, final cover	6.4E-03 Bq/m^2 /sec
Radon concentration in NSDF cell	5.0E-01 Bq/m^3
Radon radiological consequence to the worker	9.6E-04 mSv/y
Tritium concentration in air	61 Bq/m^3
Tritium radiological consequence to the worker	1.6E-05 mSv/y
C-14 concentration in air	0.53 Bq/m^3
C-14 radiological consequence to worker	2.2E-06 mSv/y

14.2.2.3 Dose Rate at Near Surface Disposal Facility Fenceline

The estimated dose rate at the NSDF fenceline is 6.25E-04 mSv/h or 0.625 µSv/h, and detailed analysis is presented in Appendix A, Section A.4. The estimated dose rate at the fence line of 0.625 µSv/h meets the radiological safety Zone 2 dose rate limit of 10 µSv/h.

14.2.3 Environment

Normal operation releases to the environment include airborne emissions, and releases to groundwater/surface water body.

14.2.3.1 Airborne Emissions – Engineered Containment Mound

Landfill gases generated in the ECM are anticipated to have low concentrations of methane and carbon dioxide and will largely dissipate through air flow across the working area, with a small portion of LFGs being retained in the waste beneath the daily cover material [14-23]. The LFGs generated in the ECM may contain small amounts of tritium or C-14.

The vast majority of LFG is anticipated to result from anaerobic decomposition of organic materials disposed in the NSDF. There are several reasons for this anaerobic decomposition of organic materials. Oxygen in air that is trapped in the void spaces within the disposed waste mass is consumed relatively quickly (within days or weeks) by aerobic decomposition of organic materials. Aerobic decomposition generates primarily carbon dioxide (CO_2) gas, which is expelled to atmosphere through the surface of the disposed waste in the ECM. Movement of CO_2 out of the waste mass limits infiltration of oxygen bearing air into the waste mass. As a result, the waste mass deeper than several tens of centimeters from the surface quickly turns anaerobic. Once the decomposition process turns anaerobic, the gaseous byproducts are primarily methane (CH_4) and CO_2.

To account for anaerobic gas generation, the LFG generated within the ECM is assumed to consist of approximately 50% methane (±5%) and 50% carbon dioxide (±5%) by volume, with very small amounts (fractional percent volume) of other gases, similar to LFG generated by decomposition of organic material in other landfills (for example, municipal solid waste) [14-23]. An example reaction that will occur in the closed ECM during the anaerobic phase of the ECM is the reaction involving bacterial decomposition of cellulose. Cellulose in the form of wood comprises the majority of the organic matter disposed in the ECM [14-23]. In the anaerobic phase, oxygen is drawn from the molecular structure of cellulose. Anaerobic bacterial decomposition of cellulose produces approximately equal volumes of methane and carbon dioxide [14-23].

The generation rate of LFG, methane and carbon dioxide are documented in Table 5-4. Landfill gas generation increases as the ECM is filled with waste over the 50 year operations period. After closure of the ECM and construction of the final cover, gas generation decreases since waste placements have stopped and there is reduced availability of moisture and oxygen in the waste [14-23].

The LFG generation rate models in [14-23], clearly show CH_4 generation, which can only occur under anaerobic conditions. Consumption of oxygen and conversion from aerobic to an anaerobic decomposition occurs before the construction of the final cover system. And while the final cover system does limit infiltration of moisture (an essential for LFG generation) into the ECM, the primary reason that LFG generation decreases upon closure of the ECM is the cessation of waste placement. The LFG generation rate begins to decrease exponentially within about 1 year of cessation of waste placement in the ECM [14-23].

The peak generation rates of LFG occurs at the time, 1 year after closure of the ECM (equivalent year 51), and the LFGs and peak generation rates are [14-23]:

- Landfill gases generation rate is 2.517E+05 m^3/year.
- Methane generation rate is 1.258E+05 m^3/year.
- Carbon dioxide generation rate is 1.258E+05 m^3/year.

To address the unlikely event that ECM LFGs generation rates are higher than are currently anticipated in [14-23], the final cover system design includes LFG vents to mitigate against potential future build-up of gas pressures within the ECM after closure.

The gaseous emissions, radon, tritium and Carbon-14, are discussed in Section 14.2.2.2.1.

14.2.3.1.1 Particulate Matter and Dust Emissions

Dust and particulate matter emissions, during the operations phase, are expected to be generated by [14-26] and [14-27]:

- The ECM operation and material handling.
- Temporary storage area and laydown area.
- Vehicle emissions.
- Operating vehicles on unpaved roads.
- Aggregate stockpiles.
- Natural gas combustion for comfort heating of the NSDF buildings.

Vehicle exhaust and fugitive dust from unpaved roads is the largest contributor to Suspended Particulate Matter (SPM) and Particulate Matter $(PM)_{10}$ during the operations phase [14-27].

The primary dust control method during the operations phase is water spraying or misting techniques using water trucks.

The following dust controls methods will be implemented during NSDF operations [14-26]:

- Limit the material/waste fall distance.
- Limit the size of the disposal cell working face.
- Dust suppression of the inactive surfaces of the ECM and surrounding support areas.
- Restrict or shut down operations during high wind conditions. Operations will be restricted or shut down during sustained wind speeds of 40 km/h as registered by the on-site wind gauge, or if visible dust plumes are observed on-site.
- Restrict or limit vehicle access to the ECM and NSDF site.
- Water is applied to roads to minimize dust generation on NSDF haul roads and ECM access roads using a water truck or other method as needed.
- Water (or approved chemical agents), is applied to the stored waste to mitigate dust emissions. A tarp or fabric cover may be used or the material may be stored within a sheltered area to prevent dust generation.

Table 14-15 shows that the estimated concentrations of SPM and PM during the construction and operations phases are below the Ontario Air Quality Guideline/Standard for SPM, PM_{10}, and $PM_{2.5}$ [14-27]. The estimated atmospheric emissions in Table 14-15 are the predicted concentrations for the Application Case at the CRL site boundary [14-27]. The predicted concentrations for the Application Case represent the combined concentrations of the Base Case, plus the maximum predicted incremental concentrations from the NSDF Project [14-27].

The overall residual adverse effect of the NSDF Project during the operations phase on air quality is determined to be not significant [14-27].

Table 14-15
Particulate Matter Concentrations during the Operations Phase [14-27]

Indicator	Averaging Period	Air Quality Guideline / Standard ($\mu g/m^3$)	Operations Phase ($\mu g/m^3$)
SPM	24 hour	120	38.19
SPM	Annual	60	14.98
PM_{10}	24 hour	50	17.83
$PM_{2.5}$	24 hour	27	8.40
$PM_{2.5}$	Annual	8.8	3.66

14.2.3.2 Airborne Emissions – Equalization Tanks

Emissions from the Equalization Tanks occur because of evaporative loss of the liquid in storage and as a result of changes in liquid level. The Equalization Tanks are fixed roof tanks, vented directly to the atmosphere. The tanks are subject to evaporative losses during storage (also known as breathing losses or standing storage losses), which occur due to diurnal variations in ambient temperature, and evaporative losses during filling and emptying operations (known as working losses).

The emissions from a single Equalization Tank were calculated and compared to the CRL site DRL [14-28]. Detailed calculations are in Appendix B.

The total radioactive material losses for organics and water phases were calculated. The organics phase contributes almost twice that of the water phase to the radioactive releases. The comparison of the total radioactive material losses to the DRL for roof vents on the CRL site [14-28] are shown in Table 14-16. The DRLs represent release rates that correspond to critical groups at the public dose limits. If the gross alpha, gross beta and gross gamma values are compared to the most restrictive radionuclide DRL for that main emission type, (i.e. the lowest DRL which for alpha is Ra-226, for beta is Cl-36 and for gamma is Co-60), total radioactive material loss is 0.04% of the DRL. From the individual radionuclide comparison with the DRLs, it is apparent that this entirely from the Co-60 release. There are no appreciable radiological airborne releases from a single Equalization Tank vent.

Table 14-16
Single Equalization Tank Radioactive Releases as Percentage of Roof Vent Derived Release Limits

Radionuclides	Radioactive Material Losses (Bq/wk)	Roof Vent DRL (Bq/wk) [14-28]	Percentage of DRL
Gross alpha	7.18E+01	7.88E+08	0.00%
Gross beta	5.42E+04	3.12E+09	0.00%
Gross gamma	3.77E+06	1.03E+10	0.04%
Ag-108m	5.21E-01	No calculated DRL	NV
Am-241	8.11E+00	1.48E+09	0.00%
Am-243	4.92E-03	No calculated DRL	NV
C-14	8.98E+03	1.35E+13	0.00%
Cl-36	1.71E+02	3.12E+09	0.00%
Co-60	3.77E+06	1.03E+10	0.04%
Cs-135	1.19E-01	No calculated DRL	NV
Cs-137	2.69E+03	1.00E+10	0.00%
H-3	4.06E+08	3.98E+14	0.00%
I-129	2.64E+02	4.32E+09	0.00%
Mo-93	1.19E-03	No calculated DRL	NV
Nb-94	4.35E+01	No calculated DRL	NV
Ni-59	4.92E-01	No calculated DRL	NV
Ni-63	1.27E+02	No calculated DRL	NV
Np-237	1.82E-03	1.40E+09	0.00%
Pu-239	1.27E+01	1.23E+09	0.00%
Pu-241	2.29E+02	6.83E+10	0.00%
Pu-242	9.56E-03	No calculated DRL	NV
Ra-226	1.85E+00	7.88E+08	0.00%
Se-79	6.95E-02	No calculated DRL	NV
Sn-126	2.09E-02	No calculated DRL	NV
Sr-90	2.78E+04	1.01E+10	0.00%
Tc-99	1.65E+04	1.40E+11	0.00%
Th-230	6.37E-01	No calculated DRL	NV
Th-232	2.78E+00	8.97E+08	0.00%
U-233	8.40E-02	1.06E+10	0.00%
U-234	2.26E+01	1.09E+10	0.00%
U-235	9.56E-01	7.99E+09	0.00%
U-238	2.20E+01	9.25E+09	0.00%
Zr-93	1.27E+02	No calculated DRL	NV

14.2.3.3 Airborne Emissions – Waste Water Treatment Plant Tanks

The WWTP process tanks are vented directly to the atmosphere. Emissions from the WWTP process tanks occur because of evaporative loss of the liquid in storage and as a result of changes in liquid level. The WWTP process tanks are fixed roof tanks, vented outside of the building, directly to the atmosphere. The tanks are subject to evaporative losses during storage (also known as breathing losses or standing storage losses), which occur due to diurnal variations in ambient temperature, and evaporative losses during filling and emptying operations (known as working losses).

The emissions from the filter press feed tank were calculated and compared to the CRL site DRLs [14-28]. Detailed calculations are presented in Appendix C. The filter press feed tank emissions were estimated, since this tank has the largest radiological source term of the WWTP process tanks.

The total radioactive material losses for organics and water phases were calculated. The organics phase is the main contributor to the radioactive releases, with the organic phase release being around two orders of magnitude higher than the water phase. The comparison of the total radioactive material losses to the DRLs for roof vents on the CRL site [14-28], are shown in Table 14-17. The DRLs represent release rates that correspond to critical groups at the public dose limits. If the gross alpha, gross beta and gross gamma values are compared to the most restrictive radionuclide DRL for that main emission type, (i.e. the lowest DRL which for alpha is Ra-226, for beta is Cl-36 and for gamma is Co-60), total radioactive material loss is 0.004% of the DRL. From the individual radionuclide comparison with the DRLs, it is apparent that this is entirely from the Co-60 release. There are no appreciable airborne releases from the filter press feed tank vent.

Table 14-17
Filter Press Feed Tank Radioactive Releases as Percentage of Roof Vent Derived Release Limits

Radionuclides	Radioactive Material Losses (Bq/wk)	Roof Vent DRL (Bq/wk) [14-28]	Percentage of DRL
Gross alpha	6.41E+00	7.88E+08	0.0000%
Gross beta	3.91E+03	3.12E+09	0.0001%
Gross gamma	3.82E+05	1.03E+10	0.0037%
Ag-108m	2.10E-02	No calculated DRL	NV
Am-241	3.28E-01	1.48E+09	0.0000%
Am-243	1.98E-04	No calculated DRL	NV
C-14	6.16E+01	1.35E+13	0.0000%
Cl-36	1.17E+00	3.12E+09	0.0000%
Co-60	3.82E+05	1.03E+10	0.0037%
Cs-135	8.16E-04	No calculated DRL	NV
Cs-137	1.85E+01	1.00E+10	0.0000%
H-3	2.79E+06	3.98E+14	0.0000%

I-129	1.81E+00	4.32E+09	0.0000%
Mo-93	8.16E-06	No calculated DRL	NV
Nb-94	1.75E+00	No calculated DRL	NV
Ni-59	6.19E-02	No calculated DRL	NV
Ni-63	1.60E+01	No calculated DRL	NV
Np-237	7.34E-05	1.40E+09	0.0000%
Pu-239	5.13E-01	1.23E+09	0.0000%
Pu-241	9.22E+00	6.83E+10	0.0000%
Pu-242	3.85E-04	No calculated DRL	NV
Ra-226	7.47E-02	7.88E+08	0.0000%
Se-79	2.81E-03	No calculated DRL	NV
Sn-126	8.40E-04	No calculated DRL	NV
Sr-90	3.70E+03	1.01E+10	0.0000%
Tc-99	1.13E+02	1.40E+11	0.0000%
Th-230	2.56E-02	No calculated DRL	NV
Th-232	1.12E-01	8.97E+08	0.0000%
U-233	9.85E-03	1.06E+10	0.0000%
U-234	2.64E+00	1.09E+10	0.0000%
U-235	1.12E-01	7.99E+09	0.0000%
U-238	2.58E+00	9.25E+09	0.0000%
Zr-93	5.13E+00	No calculated DRL	NV

14.2.3.4 Releases to Groundwater/Surface Water Body

Treated effluent generated at the WWTP that meets the NSDF effluent discharge targets [14-29], Table 6-13 and Table 6-14, is discharged to the exfiltration gallery and/or Perch Lake. The discharge to exfiltration gallery is a release to the groundwater. The discharge to Perch Lake is a release to a surface water body.

The NSDF is subject to groundwater monitoring, which is augmented by routine surface water monitoring. The measurement of groundwater quality around the perimeters of the NSDF and the measurement of surface water quality near the NSDF, provides a means of monitoring the conditions and behaviour of the Facility and operations.

Groundwater sampling and analysis occurs twice a year in the spring and the fall. Surface water body sampling and analysis occurs monthly during the operating months of April – October.

14.2.3.5 Radiological Effect on Non-Human Biota

The non-human biota benchmark values, as recommended in Environmental Risk Assessments at Class 1 Nuclear Facilities and Uranium Mines and Mills [14-30] are:

- 2 400 µGy/day for terrestrial animals.
- 9 600 µGy/day for aquatic animals.

Non-human biota are expected to be exposed contaminants from treated effluent discharged from the WWTP, as well as airborne contaminants and direct gamma radiation from the waste.

Aquatic and terrestrial species may be exposed to contaminated surface water and sediment in the East Swamp Stream, Perch Lake, Perch Creek, and Ottawa River.

The radiological effect on ecological receptors from the NSDF wastewater tanks air emissions is expected to be negligible, based on the tanks air emissions being a fraction of the CRL site DRLs [14-27]. The surface water quality modelling confirms that environmental concentrations of contaminants are below the No Effect concentrations for protection of aquatic biota for radiological contaminants with the exception of one parameter, gross beta as Sr-90 [14-27]. By ensuring that releases and subsequent environmental concentrations are below the relevant guidelines, or are below levels that would result in potential adverse effects on aquatic life, there will be no adverse effects to biota during the operations phase of the NSDF Project [14-27]. Residual effects on Ottawa River water quality are determined to be negligible during operations [14-27].

The residual effects of the NSDF Project on aquatic biodiversity and the terrestrial environment (vegetation communities and wildlife species), are not significant [14-27].

14.2.4 Radiological Consequences to Off-Site Receptors during Normal Operations

The nearest off-site receptors are located at the cottages, 3 km away and Chalk River, 5 km away. The radiological consequences to the off-site receptors during normal operations of the NSDF are expected to be negligible and much lower than 0.3 mSv/y.

The primary exposure pathways for the off-site receptor are inhalation of airborne contaminants and ingestion of drinking water. Cloudshine and groundshine of the waste placed in the NSDF will have a negligible effect on the off-site receptors. The estimated radon concentration in air in the disposal cell is 0.5 Bq/m^3, and does not pose a health risk to workers [14-25], and will have a negligible effect on the off-site-receptors.

Airborne and liquid effluents during the operation of the NSDF are monitored and controlled through the CRLs' site DRLs [14-28] and environmental Administrative Levels and Action Levels [14-31]. During the operation of the NSDF, the Facility releases are a fraction of the total CRL off-site releases to the public, since CRL has many operating facilities under one licence. The CRL licence dose limit is "The dose to the critical group due to the sum of all radioactive releases in any period of 12 consecutive months shall not exceed 0.3 mSv" [14-32]. The overall CRL licence dose limit of 0.3 mSv/y to the public (critical group) is managed, monitored and controlled through the CRL DRLs [14-28] and environmental Administrative Levels and Action Levels [14-31], thus, the NSDF releases will be a fraction to the overall DRL.

In addition, the effluent discharge targets [14-29] derived using Health Canada guidance, will ensure that cumulative WWTP radiological effluents are well below the CRL site DRLs [14-28], and doses to the public from CRL site airborne and liquid effluents remain well below the licence requirement of 0.3 mSv/y. Specifically, the potential off-site emissions from the NSDF airborne and liquid effluents will be a small fraction of the CRL site DRLs [14-28], which aligns with CSA N288.1-14 [14-33]. Thus, the approach proposed provides the same level of protection as aligning with CSA N288.1-14 [14-33].

The effluent discharge targets for radionuclides are based on a 0.1 mSv/y maximum drinking water dose consequence [14-29]. During normal operations, only the discharge of treated effluent meeting the effluent discharge targets, [14-29], is expected. Therefore, the off-site receptor ingestion radiological consequence will be much lower than 0.1 mSv/y.

The radiological consequence to the off-site receptor from normal operations of the NSDF is expected to be very low based on:

- The airborne and liquid effluents from the NSDF are a fraction of the CRL site DRLs [14-28].
- The airborne effluents from the WWTP process tanks are a fraction of the CRL site DRLs [14-28].
- During WWTP operations where there is potential for airborne releases, the active ventilation system is implemented to control the spread of contamination, and gaseous effluents are directed through HEPA filters to abate particulate discharges.
- During ECM operations, dust emissions will be controlled following the Dust Management Plan [14-26], mitigating the airborne releases of PM.
- The off-site receptor inhalation breathing rate is lower than that of the ECM worker who is in direct contact with the waste.

14.2.5 Chemical Hazards

Chemical hazards are associated with materials that are required during normal operation and with some wastes being placed in the ECM. Worker exposure to the chemical hazards is a potential hazard during ECM waste handling and WWTP wastewater processing. Chemicals may pose a hazard if inhaled, ingested, absorbed through the skin, or in contact with the skin.

Non-radioactive chemical contaminants may escape from the waste and be transported through the environment in a manner similar to the way that radioactive contaminants are transported. Although non-radioactive contaminants are not subject to radioactive decay, they may chemically react or break down in the environment.

The chemical hazards present during the operations activities include:

- Acidic solutions – 93% sulphuric acid, 38% ferric chloride.
- Caustic solutions – 50% sodium hydroxide, 15% sodium sulphide, 5% - 10% sodium hypochlorite.
- Perlite or Dicalite (diatomaceous earth) used for pre-coating the WWTP filter press.
- Granular activated carbon.
- Ion exchange resins.

- Flammable and combustible liquids including fuel and hydraulic oil for portable equipment and heavy equipment. The refueling station aboveground diesel tank, 4 500 L, is equipped with secondary containment, leak detection and vehicle impact protection.
- Muskol bug spray.
- Herbicide.
- Batteries (lead acid).

Acidic solutions and caustic solutions are used in the WWTP for wastewater treatment processes, and are stored in separate chemical areas in the WWTP. Chemical Room 1 contains acidic chemicals including three 1 200 L totes of Ferric Chloride and four drums (210 L) of Sulphuric Acid. Chemical Room 2 contains caustic chemicals including three 1 200 L totes of Sodium Hydroxide and one 1 200 L tote of Sodium Sulfide. The storage of these incompatible chemicals in separate areas, ensures that the chemicals are not mixed together under uncontrolled conditions. The consequences of mixing incompatible chemicals under uncontrolled conditions may result in the generation of heat or pressure, fire or explosion, violent reaction, toxic fumes or gases or flammable gases or fumes.

The chemical hazards are managed under the Workplace Hazardous Material Information System [14-34] and Safety Data Sheets, are available for the workplace chemicals and products. There are no significant sources of chemicals for operational activities stored within the NSDF.

Additionally, chemical hazards are mitigated by the following safeguards:

- Occupational Safety and Health Program [14-1].
- Fire Protection Screening.
- Worker training.
- Spill kits and clean-up of spills immediately.
- Personal Protective Equipment & Clothing.
- Interlocks associated with the WWTP chemical addition system.
- Segregated chemical storage areas.
- Chemical storage cabinets.

14.2.6 Conventional Non-Radiological Hazards

Conventional non-radiological hazards, were evaluated only to the extent of determining their ability to initiate or contribute to accidents with radiological consequences; otherwise such hazards are adequately covered by the OSH Program [14-1]. Conventional hazards event groupings as AOOs and DBAs, and mitigated risks are shown in Table 14-18. The conventional non-radiological hazards that exist in the Facility for routine work activities include:

- Operation of the filter press in the WWTP.
- Handling of large, heavy containers.

- Exhaust from vehicles including heavy equipment.
- Tripping hazards due to un-level surfaces.
- Pinch points.
- Heat and cold stress.
- Excavation.
- Noise.
- Material movement – lifting and hoisting.
- Use of power tools.
- Operation of heavy equipment.
- Fuel for equipment.
- Wildlife incursions (e.g. bears).
- Confined space.
- Working at heights.
- Impact/collision.
- Chemical exposure.
- Hazardous reaction.
- Spill or leak.
- Dropped load.

Table 14-18
Conventional Health and Safety Event Grouping and Mitigated Risk Ranking

Event Grouping and Description		CAT	Mitigated Risk			Reference
			S	F	RR	
D	**Conventional Health and Safety**					
D.1	**Anticipated Operational Occurrences**					
D.1.1	**ECM**					
D.1.1.1	**Impact/Collision**					
D.1.1.1	Vehicle collision due to human error, resulting in potential worker injury.	Industrial Safety (IS)	S1	F2	R1	[14-3]
D.1.1.2	**Noise**					
	Excessive noise from heavy equipment, resulting in potential worker injury.	IS	S0	F2	R0	[14-3]
D.1.1.3	**Fall**					
	Worker falls into the contact water or non-contact water collection pond at the ECM, resulting in potential worker injury.	IS	S1	F2	R1	[14-4]
D.1.2	**WWTP, Equalization Tanks and Piping Infrastructure**					
D.1.2.1	**Fall**					
	Fall hazard within the confined space (WWTP effluent valve chambers and or utility access points), resulting in potential worker injury due to the worker falling.	IS	S0	F2	R0	[14-4]
	The worker falls out of the boat into Perch Lake during the diffuser inspection, resulting in potential worker injury.	IS	S0	F2	R0	[14-4]
D.1.2.2	**Spill/Leak**					
	Potential damage to the WWTP building structure due to tornado or microburst, resulting in the release of hazardous chemicals.	IS	S0	F2	R0	[14-3]
	Chemical addition tank overflows due to human error, resulting in potential worker injury.	IS	S1	F2	R1	[14-3]
	Human error during the transfer of chemicals in drums/totes into the chemical feed tank results in a spill on the floor, and the worker being splashed.	IS	S1	F2	R1	[14-4]
	Chemical drum/tote is dropped due to human error in the WWTP chemical storage area, resulting in the loss of containment, the spill of chemicals, and the worker being splashed.	IS	S1	F2	R1	[14-4]
	There is an impact to the chemical drum/tote during movement within the WWTP due to human error resulting in the loss of containment and the spill/leak of chemicals.	IS	S1	F2	R1	[14-4]

Event Grouping and Description		CAT	Mitigated Risk			Reference
			S	F	RR	
D.1.2.3	**Hazardous Reaction**					
	Caustic chemical is unloaded into the acidic chemical storage room resulting in the potential for an adverse chemical reaction, if chemicals leak/mix generating H_2S gas.	IS	S0	F2	R0	[14-4]
	Acidic chemical is unloaded into the caustic chemical storage room resulting in the potential for an adverse chemical reaction, if chemicals leak/mix generating H_2S gas.	IS	S0	F2	R0	[14-4]
	The wrong chemical is transferred into the chemical feed tank resulting in the wrong chemical in the chemical feed tank, potential line blockage and off-gassing.	IS	S0	F2	R0	[14-4]
D.1.2.4	**Hazardous atmosphere**					
	Hazardous atmosphere in the confined space resulting in potential worker injury.	IS	S0	F2	R0	[14-4]
D.2	**Design Basis Accidents**					
D.2.1	**ECM**					
D.2.1.1	**Impact/Collision**					
	Seismic activity, DBE, resulting in a vehicle roll over and potential worker injury.	IS	S1	F1	R0	[14-3]
	Collapse or damage of the off-loading ramp structure during waste placement resulting in potential vehicle roll over, and potential worker injury.	IS	S2	F1	R1	[14-3]
	Vehicle collision due to mechanical failure, resulting in potential worker injury.	IS	S1	F1	R0	[14-3]
	Failure of the non-contact water discharge line resulting in potential worker injury due to pipe whip.	IS	S2	F1	R1	[14-4]
D.2.2	**WWTP**					
D.2.2.1	**Spill/Leak**					
	Tornado causes the potential collapse of the WWTP building structures, resulting in the release of hazardous chemicals.	IS	S0	F1	R0	[14-3]
	Failure of the chemical fill lines resulting in a spill/leak of chemicals (acids or caustics) and potential worker injury.	IS	S2	F1	R1	[14-3]
	Chemical feed line failure resulting in a spill of chemicals (acids or caustics) and the worker being splashed.	IS	S1	F1	R0	[14-4]
	A drum/tote containing chemicals (acids or caustics) is dropped due to mechanical failure in the WWTP chemical storage area, resulting in the loss of containment, spill of chemicals and the worker being splashed.	IS	S1	F1	R0	[14-4]

	Event Grouping and Description	CAT	Mitigated Risk			Reference
			S	F	RR	
	There is an impact to the drum/tote containing chemicals (acids or caustics) during movement of equipment within the WWTP due to human error resulting in the loss of containment and spill/leak of chemicals (acids or caustics).	IS	S1	F1	R0	[14-4]
	Failure of the chemical feed tank due to mechanical error resulting in the loss of containment, spill of chemicals (acids or caustics) and the worker being splashed.	IS	S0	F1	R0	[14-4] [14-3]
	Failure of the chemical feed tank due to human error, vehicle impact on tank, resulting in the loss of containment, spill of chemicals (acids or caustics) and the worker being splashed.	IS	S0	F1	R0	[14-4]
	Chemical feed tank overflows due to mechanical failure resulting in spill of chemicals (acids or caustics).	IS	S0	F1	R0	[14-4]
D.2.2.2	**Hazardous Reaction**					
	Hazardous Reaction - Incorrect chemical mixing, wrong chemical addition sequence, or wrong chemical addition resulting in potential worker injury and worker exposure to off gassing.	IS	S2	F1	R1	[14-3]
D.2.2.3	**Dropped Load**					
	Dropped load due to human error and or mechanical resulting in potential worker injury.	IS	S2	F1	R1	[14-3]
D.2.3	**VDF**					
D.2.3.1	**Spill/Leak**					
	Tornado causes the potential collapse of the VDF building structures, resulting in the release of hazardous chemicals.	IS	S0	F1	R0	[14-3]
D.2.3.2	**Impact/Collision**					
	Water hose under pressure fails (pressure washer), resulting in potential worker injury.	IS	S2	F1	R1	[14-3]

14.2.6.1 Safeguards for Conventional Occupational Hazards

The risks of the potential conventional occupational hazards are mitigated by the following administrative safeguards and controls:

- Use of spotters at a safe distance during material movement, hoisting and heavy equipment operation.
- Work/rest cycles based on environmental working conditions.
- Work areas are controlled with barriers and signage.
- Fire Protection Screening.

- Personal Protective Equipment & Clothing including hard hats, safety footwear, hearing protection, respirators, gloves, and safety glasses/face shields/goggles.
- Worker training.
- Procedural adherence.
- Equipment maintenance and inspection - maintenance schedule and monitoring equipment performance.
- Use of spotters and noise makers during wildlife incursions.

The risks of the potential conventional occupational hazards are mitigated by the following design safeguards and controls:

- Interlocks associated with the chemical addition system, chemical precipitation system, polishing system, and final pH adjustment.
- Separate chemical storage areas for acids and caustics.
- Hydrogen sulphide monitors with alarms.
- Double contained chemical piping.
- Leak detection.

14.2.6.2 Site Preparation and Construction

Radiological hazards during the site preparation and construction phases, prior to the operations phase, are very limited or non-existent because the NSDF site footprint is an area that has never been used by operations at CRL that have involved radioactive (or otherwise contaminated) materials [14-35]. The tree sampling program undertaken in 2017 March, found no contamination in the wood samples [14-35]. The NSDF site surface soils, upper 0.15 m of the soil profile, do not contain radionuclide concentrations above natural background [14-35]. The groundwater samples collected from the NSDF site and area, found no radiological anomalies [14-35]. Standard CNL environmental sampling procedures are followed to establish the baseline radiological characteristics of the site before construction begins. The site preparation and initial construction activities are not expected to release any radioactive effluents to air or water.

A 30 m buffer area has been established along all identified wetlands near the NSDF site and no new construction is permitted within this 30 m buffer zone to protect the wetland [14-36].

The NSDF construction activities will follow the CNL construction process as defined in Construction Program Description Document [14-37] and Construction Program Requirements Document [14-38]. The Construction Process establishes the requirements to ensure the successful execution of construction and installation activities [14-38]. An effective Construction Process ensures that activities comply with the design intent, the applicable codes, standards, regulatory requirements, quality standards and applicable environmental and health and safety requirements [14-38].

A Construction Safety Hazards Evaluation [14-39] is required to be developed during the pre-construction phase, to identify and mitigate any known or potential hazards. The construction conventional hazards are controlled and managed by the OSH Program [14-1].

The potential conventional non-radiological hazards that exist during site preparation and construction include:

- Particulate matter and dust generation.
- Leak/spill.
- Vehicle collision.
- Rock blasting including the hazards: detonator malfunction and over blasting.
- Fire (internal).
- Material movement – lifting and hoisting.
- Drilling and excavation.
- Trenching, sloping and shoring.
- Tree clearing and removal.
- Electrical.
- Traffic (vehicle and/or pedestrian).
- Welding, cutting and grinding.
- Work at heights.
- Operation of heavy equipment.
- Exhaust from vehicles including heavy equipment.
- Tripping hazards due to un-level surfaces.
- Fuel for equipment.
- Hazardous materials and chemicals.
- Pinch points.
- Environmental including weather, and heat and cold stress.
- Noise.
- Use of power tools.
- Wildlife incursions (e.g. bears).

The key conventional non-radiological hazards for the site preparation and construction phase, in alignment with the EIS [14-27], assessed in the following subsections are PM and dust generation, leaks/spills, vehicle collision, detonator malfunction, over blasting and fire (internal).

14.2.6.2.1 Particulate Matter and Dust Generation

Approximately 37 hectares will be cleared for the construction of the NSDF. Several thousand cubic metres of material will be excavated from the NSDF site during construction of the ECM, buildings, support facilities and infrastructure. Some areas of the site will remain undisturbed to allow for natural dust attenuation properties of the forested and surrounding areas.

Dust and PM is expected to be generated during the following site preparation and construction activities [14-26]:

- Clearing, grading and excavation to support construction.
- Rock blasting.
- Hauling and loading of excavated materials for construction and transport to spoil or stockpiles areas.
- Stockpiles are created for imported soil materials including clay, granular materials, and material excavated from the ECM area.

Vehicle exhaust and fugitive dust from unpaved roads is the largest contributor to SPM and PM_{10} during the construction phase [14-27]. Vehicle exhaust and fugitive road dust during construction of the ECM, development of the surface water management structures, construction of the WWTP and other support facilities, and on-site road access development would be the largest contributor to PM emissions.

The primary dust control method during the construction phase is water spraying or misting techniques using water trucks. The construction contractor will develop a dust management plan specific to construction activities which will be approved by CNL EnvP Program before use.

Table 14-19 shows that the estimated concentrations of SPM and PM during the construction phase are below the Ontario Air Quality Guideline/Standard for SPM, PM_{10}, and $PM_{2.5}$ [14-27]. The estimated atmospheric emissions in Table 14-19 are the predicted concentrations for the Application Case at the CRL site boundary [14-27]. The predicted concentrations for the Application Case represent the combined concentrations of the Base Case plus the maximum predicted incremental concentrations from the NSDF Project [14-27].

The overall residual adverse effect of the NSDF Project during the construction phase on air quality is determined to be not significant [14-27].

Table 14-19
Particulate Matter Concentrations during the Construction Phase [14-27]

Indicator	Averaging Period	Air Quality Guideline / Standard ($\mu g/m^3$)	Construction Phase ($\mu g/m^3$)
SPM	24 hour	120	85.51
SPM	Annual	60	19.12
PM_{10}	24 hour	50	31.13
$PM_{2.5}$	24 hour	27	10.30
$PM_{2.5}$	Annual	8.8	3.81

14.2.6.2.2 Leaks/Spills

Leaks/spills during the construction phase are a conventional non-radiological hazard due to human error and/or mechanical failure, and the potential hazard consequence is a leak/spill to the environment.

The spill of fuel could occur during the fueling of vehicles and equipment in the construction area. Fueling of vehicles and equipment will occur within an area with secondary containment to contain any spill or leak. Failure of a hydraulic hose on the heavy equipment could result in a leak/spill of hydraulic fluid to the environment. Overheating of a vehicle or heavy equipment could result in a leak/spill of coolant to the environment. The coolant is either ethylene glycol or propylene glycol.

A leak/spill of fuel, hydraulic fluid or coolant, results in a localized effect that is readily remediated, and the potential health effect to the on-site receptor, worker, and environmental effects are negligible.

The mitigation measures to mitigate leaks/spills during the construction phase include:

- Spill kits.
- Secondary containment.
- Vehicle and equipment maintenance and inspections.

14.2.6.2.3 Vehicle Collision

Vehicle collision during the construction phase is a conventional non-radiological hazard due to human error and/or mechanical failure, and the potential hazard consequences are:

- Potential worker injury.
- Damage to the vehicle(s) and or structures.
- Potential leak of oil, fluid and/or fuel from the damaged vehicle(s).
- Potential vehicle fire and release to the environment.

Human errors, including misjudging vehicle speed, distracted driving and or lack of vehicle maintenance may lead to a vehicle collision. Equipment mechanical failure could be the result of lack of maintenance and or manufacture defect. Workers in construction vehicles are required to wear seat belts, which will reduce the severity of the worker injury in the event of vehicle impact. Vehicles travelling in the NSDF construction area are required to operate at the appropriate speed limit, which is anticipated to reduce the severity of the vehicle damage and the worker injury in the event of vehicle impact.

Heavy equipment vehicles and trucks powered by hydrocarbon fuels are potential sources of flammable materials. Generally, diesel and gasoline fuel tanks on heavy equipment vehicles and trucks are located on the side and are shielded with a steel plate. Due to these types of fuel tank configurations, the fuel tanks are not easily accessible to result in a breach of their integrity in a collision with other vehicles or structures within the Facility. Furthermore, the maximum speed attainable by a heavy equipment vehicle is limited by speed limit restrictions, such that an impact is not anticipated to lead to a catastrophic fuel tank failure. A leak of oil and or fuel following a collision will be localized and will be cleaned up using spill kits following emergency procedures.

Snow clearing operations may be performed during the winter months based on construction work activities. Vehicle impact during snow clearing operation could result in damage to equipment, and structures. Vehicles performing snow clearing are required to operate at the appropriate speed limit, which is anticipated to reduce the severity of the vehicle damage and the worker injury in the event of vehicle impact.

Vehicle collision during the construction phase results in a localized effect that is readily remediated, and the potential health effect to the on-site receptor, worker, and environmental effects are negligible.

14.2.6.2.4 Detonator Malfunction

Malfunction of detonators used for rock blasting is a construction conventional non-radiological hazard due to human error and/or mechanical failure, and the potential hazard consequence is potential worker injury. A blasting plan will be developed [14-40], in accordance with Ontario Provincial Standard Specification - General Specification for Use of Explosives [14-41]. Procedures will be developed in the blasting safety plan in accordance with Ontario Regulation 213/91, Construction Projects [14-42], Specification Rock Blasting [14-43], and Ontario Provincial Standard Specification - General Specification for Use of Explosives [14-41]. The blasting plan and associated blasting procedures will ensure the malfunction of detonators for rock blasting is controlled and mitigated.

The construction rock blasting activities could use non-electronic or electronic detonators. The malfunction of a non-electronic detonator could be the result of:

- Manufacture defect.
- Pinch or tear in the shock tube during the placement of blasting mats.

- Improper tie-in hookup or missed detonator during tie-in hookup.
- Damaging the shock tube during the loading operation.

The malfunction of an electronic detonator could be the result of:

- Manufacture defect.
- Pinch or tear in the leg wire or the trunk line during the placement of blasting mats.
- Improper tie-in hookup or missed detonator during tie-in hookup.
- Damaging the leg wire during the loading operation.

The mitigation measures to mitigate the malfunction of detonators, to ensure the safety of workers and protection of the environment, include:

- Blasting Plan.
- Blasting Safety Plan.
- Blasting procedures.
- Designated Blast Area.
- Blasting system notification and detonator redundancies.
- Visual inspection of blasting tie-in sequence and shock tube condition, for non-electronic detonators, prior to placing blasting mats.
- Testing of the electronic detonators and circuit prior to blast initiation.
- Testing of the electronic detonators and circuit prior to, during and after placing blasting mats.
- In the event of a primary detonator malfunction, immediate blasting using the redundant secondary detonator will occur.
- Barriers for access restrictions.
- Minimum setback distance.
- Blasting mats.

Detonator malfunction during the construction phase results in a localized effect, and the potential health effect to the on-site receptor, worker, and environmental effects are negligible.

14.2.6.2.5 Over blasting

Over blasting during the construction phase is a conventional non-radiological hazard due to human error and/or mechanical failure, and the potential hazard consequences are potential worker injury and potential environmental damage. Uncontrolled or unmanaged blasting could result in excess noise and vibration effects or damage from fly rock extending beyond the defined boundaries of the blast area.

A blasting plan will be developed [14-40], in accordance with Ontario Provincial Standard Specification - General Specification for Use of Explosives [14-41]. Procedures will be developed in the blasting safety plan in accordance with Ontario Regulation 213/91, Construction Projects [14-42], Specification Rock Blasting [14-43], and Ontario Provincial Standard Specification - General Specification for Use of Explosives [14-41]. The blasting plan and associated blasting procedures will ensure that the over blasting hazard is controlled and mitigated.

The mitigation measures to mitigate the hazards of over blasting, to ensure the safety of workers and protection of the environment, include:

- Blasting Plan.
- Blasting Safety Plan.
- Blasting procedures.
- Designated Blast Area.
- Barriers for access restrictions.
- Minimum setback distance.
- Blasting mats.
- Defined safety limit around the blast area to isolate the potential effects of flying rock.

Over blasting during the construction phase results in a localized effect, and noise and vibration effects from an uncontrolled explosion would be short in duration. The potential health effects are moderate for on-site receptors, workers, and negligible for the off-site public. The potential environmental effects are negligible.

14.2.6.2.6 Fire (Internal)

Fire (internal) during the construction phase is a conventional non-radiological hazard due to human error and/or mechanical failure, and the potential hazard consequences are potential worker injury and potential airborne release to the environment. An internal fire during the NSDF construction could be initiated by the wildland fire, lightning, hot work activities, rock blasting, vehicle collision, vehicle fire, use of combustible materials or equipment electrical failure resulting in the ignition of combustible materials. The internal fire could be the result of human error or mechanical failure of vehicles/equipment.

A wildland fire could initiate from ignition sources such as tree clearing activities, trees falling over transmission lines and lightning strikes during the forest fire season. Forest fire season is defined as April 1st to October 31st [14-44].

A vehicle fire may result from a vehicle accident due to human error or mechanical failure. The maximum speed attainable by vehicles is limited by speed limit restrictions such that a vehicle impact is not anticipated to lead to a severe accident. Vehicle maintenance will reduce the frequency of mechanical failure.

The construction hot work activities include welding, cutting and grinding. Appropriate fire protection clearances are required for any hot work. Combustible construction materials include diesel fuel, gasoline, paints, resins, adhesives and tar.

The controls and safeguards that are in place to prevent fires, and or to limit the consequences of a fire event during the construction phase include the CRL Fire Department, NSDF Fire Water Pump Station (if constructed and available for use), vehicle/equipment maintenance and engine compartment fire suppression system on heavy equipment, and portable fire extinguishers on the vehicles/equipment.

In the event of a fire at the NSDF construction site, work will be immediately stopped and placed into a safe state, if possible. The NSDF Construction Emergency Procedure will be followed. The Fire Department will be notified as well as others working in the area. If an equipment fire were to occur, the hazard consequences could be worker injury, burns and equipment damage.

14.3 Anticipated Operational Occurrences (Group A)

The AOOs, identified as Group A in Section 14.1.4, for the NSDF are external events, loss of services, containment failure, dropped load, contamination, unintended contents, vehicle collision, intrusion of non-human biota, damage to structure, higher flow than anticipated, ground subsidence, erosion, and radiation.

14.3.1 External Events (A.1)

The external events that are AOOs include extreme wind, severe precipitation and extreme drought.

14.3.1.1 Extreme Wind, Tornado and Microburst (A.1.1)

The potential hazards posed by extreme winds, including tornado and microburst events, are those due to the direct force of the wind and due to tornado-borne missiles. Extreme winds including tornado and microburst events, may impact the ECM, WWTP including the Equalization Tanks and facility building structures.

14.3.1.1.1 Engineered Containment Mound (A.1.1.1)

Extreme winds including tornado and microburst events at the ECM, may result in the *radiological consequences and associated hazards consequences*:

- An increase in dust generation.
- The potential for the spread of contamination, if the waste is exposed or not covered.

- Erosion and/or displacement of the daily cover and/or interim cover, resulting in increased water infiltration into the waste, and increased leachate generation.
- Soil erosion on the ECM final cover system, leading to water infiltration into the waste.

The increase in dust generation and the spread of contamination within the ECM, is mitigated through the use of dust suppression techniques, daily covers, interim covers and sacrificial liners. No uncontained waste is stored in the TSWRPA to mitigate the spread of contamination. All waste is either in its transportation container or disposal container, or covered with daily cover. Potential hazards associated with dust generation are mitigated by the implementation of the mitigation measures documented in the Dust Management Plan [14-26]. Dust control measures include conditioning material with water during waste placement, covering stockpiles and exposed areas prior to high wind or dry conditions, minimizing the size of exposed active working areas using a phased excavation approach, and revegetating impacted areas. The primary dust control method is water spraying or misting techniques (e.g. water trucks).

Extreme winds may cause erosion and/or displacement of the daily cover or the interim cover, which may result in increased leachate generation if the cover damage goes unrepaired. Extreme wind could displace the interim cover's sacrificial liner, if the sacrificial liner is not adequately anchored to prevent uplift by the wind. The increased leachate generation would temporarily increase radionuclide loading to the WWTP, but is expected to have negligible impact on WWTP workers or releases of treated wastewater.

The final cover system will be vegetated to enhance evapotranspiration and reduce the potential for soil erosion from wind and water. The vegetation will be limited to grass species that are maintenance free and drought resistant. Soil erosion of the final cover could lead to water infiltration into the waste layer and may reduce shielding over the buried wastes. Lost soils would be replaced when the cover erosion is detected during routine Facility inspections.

Waste placements using cranes could be affected by extreme winds. The waste handling operations using a crane are cancelled when wind conditions are greater than 40 km/h. The safety standard for mobile cranes, CAN/CSA-Z150-11 [14-45], states that the operation of mobile cranes for hoisting of loads should be minimized during wind conditions greater than 40 km/h.

During high winds, the active working areas will be restricted to assist in the control of dust migration, and ECM waste placement operations may also be suspended during high wind conditions for safety [14-46].

In addition, operations at the ECM may be suspended when visible dust is generated, or when wind speeds exceed 40 km per hour for more than two hours, unless it can be demonstrated that the work site is sufficiently protected and dust will not be generated by the wind [14-46].

The frequency of this event is expected to be Occasional, the radiological consequence is Negligible and the risk ranking is for the event is R0.

14.3.1.1.2 WWTP, Equalization Tanks and Piping Infrastructure (A.1.1.2)

Extreme winds including tornado or microburst events may cause potential minor damage to the WWTP building and may damage the Equalization Tanks' secondary containment resulting in the potential radiological consequence, release to the environment. The secondary containment is concrete and provides containment for a spill or leak from the Equalization Tanks and associated piping. The damage to the concrete secondary containment would be detected during inspections following the event, and actions would be taken to clean up and repair any identified damage.

The WWTP building structure is designed to NBCC 2015 [14-47] and the building is not expected to be impacted by AOO extreme wind events. The Equalization Tanks are designed to API-650 and designed to withstand a DBT.

The frequency of this event is expected to be Occasional, the radiological consequence is Minor and the risk ranking is for the event is R1.

14.3.1.1.3 Building Structures (A.1.1.3)

Extreme winds including tornado or microburst events may cause potential minor damage to the NSDF building structures. The NSDF building structures are designed to NBCC 2015 [14-47], and are not expected to be impacted by AOO extreme wind events.

The frequency of this event is expected to be Occasional, the radiological consequence is Negligible and the risk ranking is for the event is R0.

14.3.1.2 Severe Precipitation (A.1.2)

Severe precipitation could result in the following radiological consequences and associated hazards consequences: erosion, slope destabilization, water ingress and increased sediment or solids in the surface water run-off.

Erosion may impact the base liner system layers under construction, construction material stockpiles, natural or engineered slopes, roadways, waste in the disposal cell, daily covers, interim covers, and final cover. The areas with erosion damage would be detected during inspections following the severe precipitation event, and actions would be taken to clean up and repair any identified erosion or damage.

Severe precipitation may cause potential erosion and or subsidence of the interim covers, final cover system, and waste layers, resulting in increased precipitation infiltration and increased volume of leachate. Each lift of waste is graded at approximately 2% to provide surface water run-off from the waste within the disposal cell. Precipitation that makes contact with the waste, referred to as contact water, is directed to temporary catchment areas within the disposal cell or in an adjacent cell that has the floor system already installed. Precipitation falling into the active cell is managed as contact water and or non-contact water. All precipitation falling into the inactive cells, is treated as non-contact water (i.e. water that does not contact waste), and conveyed to the SWMPs.

Severe precipitation events could lead to soil erosion of the ECM final cover system. As part of the operations and closure phases, the final cover system is installed on the ECM. The final cover system is designed to limit water infiltration, to direct infiltration and surface water run-off away from the ECM waste placement area, to resist degradation by surface geologic processes and biotic activity (e.g. prevent burrowing of animals), and inadvertent intruder attempts to access or excavate into the wastes waste cell. A series of drainage control features are installed in conjunction with placement of the final cover system over the ECM. The finished surface of the ECM is elevated from the surrounding terrain, which limits the quantity of surface water entering the ECM from areas outside the extent of the ECM. The topographical slopes within the ECM footprint are sufficient to promote drainage, and by lining the ECM surface water, collection ditches and stilling basins with rip rap and other erosion control measures, sediment transport and erosion will be minimized.

Erosion of the roadways and or the natural or engineered slopes may contribute sediment into the surface water management ponds. The surface water management ponds are designed to reduce total suspended solids loadings by 60% and 80% (depending on the pond), to reduce the sediment loading from the surface water and the impact to the adjacent wetlands. The surface water management ponds are constructed early in the construction phase to provide solids and sediment control of surface water flow into the adjacent wetlands. The surface water management ponds for non-contact water and surface water, are designed to address erosion and sediment control concerns during construction, by providing interim sediment control and by providing water quality and quantity controls during operations and closure. Non-contact water from active/inactive cells is collected within the ECM in the non-contact water pond and is pumped after the rainfall event, to perimeter ditches which convey the water to the SWMPs. Annual maintenance activities of the SWMP will remove built-up sediment and identify any erosion problems. In addition, an inspection will be completed after severe precipitation events and after the annual spring melt to confirm there are no erosion or sediment loading issues associated with the SWMP.

Within the ECM, severe precipitation could result in:

- Increased water within the contact water storage area.
- Increased water within the non-contact water storage area.
- Increased leachate volume.
- Increase in the volume wastewater for the WWTP.
- Potential overflow of contact water and non-contact water within the disposal cell.

Water ingress due to precipitation at the ECM disposal cells, will result in increased leachate generation. An interim cover is installed over the placed waste within waste disposal areas that will remain inactive for more than 30 days and waste disposal areas that have reached the design waste fill grade, to minimize the water ingress and leachate generation due to precipitation. Erosion of the interim cover may result in increased precipitation infiltration and increased volume of leachate. In addition, sacrificial liners are used as a component of the interim cover and are used cover the ECM floor within the inactive disposal cells, to promote precipitation water run-off and collection as non-contact water. During a severe precipitation event, the LCS mitigates against water build-up and potential erosion within the ECM. There may be an increase in leachate generation, however this is expected to have a negligible impact on WWTP workers or releases of treated effluent.

In the event that the contact water storage area overflows, the contact water will contaminate the non-contact water and non-contact water will be managed as contact water.

Following a severe precipitation event during the operations phase, ECM personnel will inspect drainage structures and ECM cover areas for erosion, and will make repairs as soon as practicable.

For the severe precipitation AOO, the frequency of this event is expected to be Occasional, the radiological consequence is Negligible or Minor, and the risk ranking is for the event is R0 or R1 [14-3].

14.3.1.3 Extreme Drought (A.1.3)

Extreme drought may cause increased dry conditions, resulting in the following radiological consequences and associated hazards consequences: increased dust and increased airborne PM during the construction and operations phases. Additionally, extreme drought may cause the spread of contamination during the operation and closure phases.

Extreme drought may cause the loss of grass or vegetation on the final cover system, resulting in the potential erosion of the final cover system and water infiltration into the waste. In the event of an extreme drought event, the NSDF final cover system would be inspected for erosion damage. If erosion damage occurs to the final cover system, the erosion damage would be repaired.

Dust suppression techniques and monitoring are used in the NSDF areas that have the potential for generating dust. The primary dust control method is water spraying or misting techniques using water trucks. Wetting the areas that have the potential for generating dust will mitigate the release of dust, airborne PM and the spread of contamination.

The approach to managing fugitive dust emissions follows the Dust Management Plan [14-26] and best management practice guidance is provided in Management Approaches for Industrial Fugitive Dust Sources [14-48].

Alternative dust control mitigation methods, other than water spraying that could be implemented during extreme fugitive dust conditions include:

- Use of fixatives (e.g. chemical suppressant) for dust control.
- Covering stockpiles and exposed areas with tarps or fabric covers prior to high wind or dry conditions where standard dust suppressants may be inadequate in preventing dust generation caused by wind erosion.

- Minimizing the size of the exposed working areas containing contaminated materials to the extent practicable using a phased excavation approach. Limit the size of the disposal cell working face.
- Revegetating affected areas or adding mulch to completed cells and excavated areas as soon as practicable.
- Reducing activities to avoid unnecessary dust generation.
- Restrict or limit vehicle access to the ECM and NSDF site.
- Limit the material/waste fall distance.
- Use wind fencing around work areas.
- Restrict or postpone work activities that are likely to cause dust if sustained wind speeds are predicted to exceed 40 km/h, unless the work activity can be shown to be sufficiently protected, such that wind will not generate unacceptable amounts of dust.

For the extreme drought AOO, the frequency of this event is expected to be Occasional, the radiological consequence is Negligible and the risk ranking is for the event is R0 [14-3].

14.3.2 Loss of Services (A.2)

Loss of services in the NSDF that are AOOs, includes loss of the following services; Class IV power, ventilation, and other services. Routine inspection, maintenance and testing will reduce the probability of the service system failures and the loss of services.

14.3.2.1 Loss of Class IV Power (A.2.1)

The loss of Class IV power, due to off-site failures, is an AOO that is expected to occur occasionally during the Facility operation. Table 14-20 indicates the Class IV power failure statistics that affected the CRL site during 2014 to 2018 [14-49].

Upon the loss of Class IV power, the electrical systems in all buildings will lose power including lighting and ventilation systems. In the event of a Class IV power failure, the back-up natural gas generator will start up supplying Class III power for the WWTP, VDF, OSC, Administration Building, North and South Kiosks, PWPS, and FWPS including:

- Class III process loads and mechanical loads in the WWTP.
- 20% of lighting loads in the WWTP including control room.
- WWTP - SCADA system, Building Automation and Control Network system, UPS units and life safety loads.
- 50% load of Equalization Tanks' heaters.
- Security and communication systems.
- Fire alarm control panels.
- Whole body radiation monitors in the WWTP and OSC.

- Hand and foot monitors in the WWTP, VDF and OSC.
- Class III mechanical loads and 20% lighting loads in VDF.
- Class III mechanical loads and 20% lighting loads in OSC.
- Class III mechanical loads and 20% lighting loads in Administration Office.
- Contact Water Pump Station #1 and #2.
- Site vehicle refueling station.

Ventilation systems and air monitoring systems, which are considered important to safety, are not supplied by Class III Power. Area radiation monitors in the WWTP have back-up power supplied by a UPS.

The fire alarm systems in all buildings have back-up power supplied by UPS and batteries. In the buildings, emergency and emergency exit light fixtures have back-up power supplied by batteries.

At the WWTP, a loss of Class IV power would result in suspension of WWTP operations and any maintenance tasks that may be occurring. Class II power is provided for all monitoring, alarms, and shutdown systems. The Class II power system derives its normal power from the Class IV power system, and its back-up power from an integral battery system designed to operate for 1 hour at rated load. This duration is expected to be sufficient for maintaining the functionality of radiation monitoring systems, while workers evacuate the WWTP.

Additionally, during a loss of Class IV power, the Class III power system provides electrical power to the WWTP Compressed Air System (i.e. service air). If all power is lost, all air operated valves and dampers, such as those in the membrane filtration and residuals management systems, are fail-safe.

In summary, with back-up power supplies for process systems, the suspension of operations due to a loss of Class IV power, will occur gradually to protect process systems and components. Any ongoing maintenance activities would be ceased in a manner such that systems are left in a safe state. There will not be any increase in radiological hazards as a result of loss of Class IV power and therefore, the risk is not unreasonable.

Vehicle decontamination services in the VDF will be temporarily unavailable as a result of loss of Class IV power. Unavailability of the VDF may result in operational delays, but temporary inability to decontaminate vehicles is not associated with any significant radiological exposure.

Operations Support Centre services will be temporarily unavailable as a result of Class IV power outage.

In the event that loss of Class IV Power occurs, all operations in the WWTP and VDF involving radioactive material, will stop and the work areas will be left in a safe state. The Operations Supervisor will notify all personnel who are performing radioactive work within the ECM of the power failure. The ECM work is not impacted by the loss of Class IV power. However, the weigh scales will be unavailable during the loss of Class IV power.

The radiological hazards associated with loss of Class IV Power, are the same as those associated with the loss of ventilation.

For the loss of Class IV power AOO, the frequency of this event is expected to be Occasional, the radiological consequence is Negligible and the risk ranking is for the event is R0 [14-3].

Table 14-20
Class IV Power Failures - CRL On-site Failures

Number of Class IV Power Failures	Year				
	2014	2015	2016	2017	2018
Off-site Failures (Hydro One supply)	9	4	2	3	3
On-site Failures (Switchyard)	0	1	1	4	1
Total Failures	9	5	3	7	4

14.3.2.1.1 Unavailability of the Natural Gas Generator (New)

The loss or unavailability of the natural gas generator during the loss of Class IV power is an AOO that results in an operational delay. The natural gas generator provides Class III power on the loss of Class IV power. The generator supplies back-up power to three ATSs; an ATS located in the WWTP for non-life safety essential loads, an ATS located in the WWTP for life safety essential loads, and an ATS located at the power distribution center, Building 1561, for non-life safety loads at the support buildings. The natural gas generator automatically starts upon loss of the Class IV power system detected from any ATS and connects via an ATS to the Class III distribution system. The ATS engages the natural gas generator to start to achieve restoration of power within 15 seconds of the loss of Class IV power. The ATS for the natural gas generator has an electrical safety function as the ATS automatically engages the Class III standby natural gas generator upon loss of Class IV power. The ATS fault signal is monitored and should the ATS fail to transfer from Class IV power to Class III power, an alarm is activated on the WWTP main alarm annunciator panel to initiate worker intervention. The loss or unavailability of the natural gas generator during the loss of Class IV will result in the loss of Class III and the activation of ATS fault signal alarm. The ATS fault signal alarm will inform the workers that the Class III power is not functioning and the alarm will be investigated.

In the event of loss of Class IV power, the natural gas generator will supply Class III power. If the natural gas generator fails while supplying Class III power, the loss of Class III power relay alarms will inform the worker of the loss of Class III power.

The loss or unavailability of the natural gas generator could be the result of:

- Human error damaging the natural gas generator.
- Loss of natural gas supply.
- Mechanical failure of natural gas generator.
- Scheduled maintenance of the natural gas generator.

The loss of both Class IV power and Class III power will result in no electrical power being supplied to the WWTP, VDF, OSC, Administration Building, North and South Kiosks, PWPS, and FWPS. The workers will evacuate the buildings following the NSDF Emergency Procedures.

In the event, that loss of Class IV Power occurs with the loss during or followed by the unavailability of the natural gas generator, all operations in the WWTP and VDF, will stop and the work areas will be left in a safe state, following NSDF Emergency Procedures. Administrative controls require the NSDF personnel to evacuate the WWTP and VDF buildings, if the ventilation systems stop operating.

The loss of both Class IV power and Class III power will result in the loss of ventilation. The spread of contamination due to loss of ventilation in the WWTP, is not significant because of the low level of airborne contamination in the building. In the VDF and OSC, airborne radiological hazards are expected to be negligible due to loss of ventilation.

The Operations Supervisor will notify all personnel who are performing radioactive work within the ECM of the Class IV and Class III power failures. The ECM work is not impacted by the loss of Class IV power. However, radiological work within the Facility will stop, since no radiological work can take place if shower facilities are unavailable. The NSDF shower facilities will be unavailable upon the loss of both Class IV power and Class III power. The work in the ECM will stop and the work areas will be left in a safe state. The NSDF workers could be transported to other CRL shower facilities.

The loss of Class IV power and Class III power will result in the facility losing the operation of the fire water pumps in the FWPS and fire water will be unavailable. The fire water piping system is typically in a drained condition when not in use. In the event of a fire emergency, the fire water service piping is filled and pressurized with water from the storage tanks by way of booster pumps and ultimately provides water for firefighting to each hydrant in the network. In response to the loss of fire water, the CNL Fire Department will be notified, placed on standby, and a fire watch is initiated at the Facility.

During winter months, the loss of Class IV power during or followed by the unavailability of natural gas (gas generator), will result in the loss of Equalization Tank heating, and may lead to the freezing of the Equalization Tank lines. The NSDF Class III power supply design has the option for connecting another generator to supply power in the event that the natural gas generator is unavailable. In addition, the Equalization Tanks are insulated and cladded to minimize the loss of heat, which will provide operations time for responding to the loss of Equalization Tank heating. The heat tracing system monitors and control line temperatures above freezing (4^{o}C), and the system alarms to notify operators of low low temperature in the Equalization Tanks. Freezing of wastewater in the Equalization Tanks and piping would not occur immediately upon loss of heating.

In the event of loss of both Class IV power and Class III power, the Class II UPS provides enough power for connected equipment to shut down properly or remain functional during the power outage. Class II power provides instantaneous backup power capability in the event of loss of

Class III power supply for the communication system, security system, and PA system in the HUB room. Class II battery loads provide 30 minutes of backup power to the emergency lighting, exit lighting, and FACP.

If the Class IV power outage is prolonged, and the natural gas generator is unavailable, diesel or gasoline portable generators can be connected to supply Class III power to the Facility. A large generator could be connected to feed all Class III loads or smaller generators could be connected at various points, where manual transfer switches are installed to provide Class III power to CSCS loads that have been identified in Section 8.1.4.

14.3.2.2 Loss of Ventilation (A.2.2)

The loss of ventilation could occur, either due to mechanical failure or Class IV power failure. In the event of a Class IV Power failure, all ventilation fans will stop operating and administrative controls require the Facility staff to follow the NSDF Emergency Procedures. Administrative controls require the NSDF personnel to evacuate the buildings with the exception of OSC, if the ventilation systems stop operating.

Ventilation failure will impact the WWTP, VDF and OSC. Routine inspection, maintenance and testing will reduce the probability of the service system failures and the loss of services.

A loss of ventilation in the OSC or VDF would result in suspension of operations, but is not associated with significant radiological exposure. In the VDF and OSC, airborne radiological hazards are expected to be negligible.

Loss of ventilation in WWTP could result in potential airborne release in process area and potential radiological consequences to worker. Upon loss of WWTP ventilation, box-up does not occur. Spread of contamination due to loss of ventilation, is not significant because of the low level of airborne contamination in the building.

The following design aspects mitigate the consequences of loss of ventilation:

- On loss of Class IV power, isolation dampers in the exhaust ducts close to minimize exfiltration of indoor air.
- Active ventilation exhaust fans in the WWTP are powered from the Class III power in the event of loss of Class IV power.
- If a supply air handling unit fails in the WWTP or the VDF process areas, interlocked emergency dampers open to allow outdoor air into the active areas Radiological Safety Zones 2 and 3, to replace the lost supply air and an alarm is activated on the OWS. The exhaust air system will continue to operate.
- In active areas Radiological Safety Zones 2 and 3, hard wired control of the ventilation system is provided in case of BAS failure.
- If loss of ventilation air is detected inside the Filter Press enclosure, the local SSC's important to safety control panel will trigger a local visual and audible alarm to ensure staff

do not continue working and exit promptly. The visual and audible alarm will be located inside and outside the room by the entrance door to the room.

For the loss of ventilation AOO, the frequency of this event is expected to be Occasional, the radiological consequence is Negligible and the risk ranking is for the event is R0 [14-3].

14.3.2.3 Loss of Other Services (A.2.3)

The loss of other services that result in delays in operations and operational inconvenience, include the loss of the following services; natural gas, HVAC, air, potable water, service water, and septic system. The loss of water, potable water and service water, will impact the water supply in the OSC change rooms. This may impact radiological work within the Facility, since no radiological work can take place if shower facilities are unavailable. In the event of failure of the service water system, or loss of the septic system, the shower trailer beside Spring B could be used as an alternative area for the workers and worker showers.

The loss of natural gas results in an operational delay and impacts the emergency natural gas generator that supplies Class III power, and the heating of the buildings. Natural gas is used for domestic hot water heaters, building ventilation and air handling systems, including make-up air units and gas-fired unit heaters. The natural gas services is connected to the WWTP, VDF, OSC, Administration Building, and the natural gas generator. The loss of natural gas will also impact the supply of hot water in the NSDF shower facilities.

If an extended loss of natural gas occurs, diesel or gasoline portable generators can be connected to supply Class III power to the Facility. A large generator could be connected to feed all Class III loads or smaller generators could be connected at various points, where manual transfer switches are installed to provide Class III power to CSCS loads that have been identified in Section 8.1.4.

If an extended loss of heating occurs in the winter months, freezing may occur in the Equalization Tanks and piping infrastructure. During normal operations, there is likely to be sufficient headspace in the Equalization Tanks, such that the tanks would not be damaged by freezing. Additionally, 50% of the Equalization Tank heater load is powered by Class III power in the event of loss of Class IV power, therefore, the likelihood of a total loss of Equalization Tank heating is low. Freezing of wastewater within the WWTP tanks and piping would not occur immediately upon loss of heating. In the event that heating in the WWTP was unavailable for an extended period of time, portable heaters could be used.

The loss of air in the WWTP results in operational delay and impacts the operation of the filter press, membrane filtration system, air pumps (filter press feed, pre-coat feed, media change-out/de-watering), media change-out/de-watering system, air actuated valves and the breathing air system located in the Residual Management Area. The air actuated valves associated with the membrane filtration system, filter press system and media change-out/de-watering system are designed to fail in a safe position. The WWTP compressed air system is on Class III power, in the event of loss of Class IV power, the WWTP compressed air system will remain functional.

The loss of Class III power results in the loss of WWTP exhaust ventilation and the potential spread of contamination.

For the loss of other services AOO, the frequency of this event is expected to be Occasional, the radiological consequence is Negligible and the risk ranking for the event is R0 [14-3].

14.3.3 Engineered Containment Mound (A.3)

The AOOs at the ECM include containment failure, dropped load, contamination, unintended contents, vehicle collision, intrusion of non-human biota, damage to structure, higher flow than anticipated, ground subsidence or erosion, and radiation.

14.3.3.1 Containment Failure (A.3.1)

Containment failure of waste packages at the ECM is an AOO. Containment failure of waste packages may be the result of degradation, deterioration, corrosion, and or damage.

For the ECM containment failure AOO, the frequency of this event is expected to be Occasional, the radiological consequence is Negligible and the risk ranking is for the event is R0 [14-3].

14.3.3.1.1 Damaged Package and Package Degradation

A damaged waste package is an AOO and a waste package may be damaged due to mechanical stress (e.g. impact, puncture), degradation (e.g. corrosion) or human error (e.g. Impact). The damaged or degraded waste package could result in the following radiological consequences and associated hazards consequences: the spill/leak of waste material, spread of contamination, and or radiological consequences to the worker. Potential radiological consequences include potential radiological consequences to worker, and potential release of contaminants into the disposal cell, and or TSWRPA.

Heavy equipment impact with the waste package(s) due to human error could causes containment failure, resulting in the spread of contamination and the potential radiological consequences to on-site and off-site receptors. The maximum speed attainable by a heavy equipment vehicle is limited by the speed limit restrictions, which will limit the damage to the package. However, the forks of a forklift may damage the waste package at a speed less than the Facility speed limit. In the event of containment failure or failing integrity of the waste package, the waste package may be repacked into the appropriate metal container (e.g. metal bin, metal overpack drum). Damaged waste packages within the TSWRPA will require repackaging if the waste does not meet the bulk waste radionuclide activity characteristics, defined in .

Package degradation may occur following waste placement and gradual degradation for waste packages (i.e. drums, boxes, etc.) is accounted for in leachate projections. Waste compaction is assumed to result in the immediate failure of 5% of the waste packages [14-50]. In addition, waste containers are assumed to fail at a rate of 1% per year due to corrosion [14-50]. Due to the requirement to minimize void space, package degradation caused by mechanical forces (i.e. crushing) is mitigated by limiting the package void space. Failed packages will no longer effectively isolate their contents from infiltrating water and will contribute to the leachate quality, an increase in radionuclide activity concentration.

For the waste package containment failure AOO, the frequency of this event is expected to be Occasional, the radiological consequence is Negligible and the risk ranking is for the event is R0 [14-3].

14.3.3.2 Dropped Load (A.3.2)

A dropped load is an AOO that may occur at the ECM during waste package placement or handling. Waste placement and handling activities are completed either manually by hand or by mechanical means such as using a mobile crane. A crane is used for hoisting activities of the waste packages. The potential causes of a dropped load event include mechanical failure of hoisting equipment and human error.

A dropped waste package could result in the following potential radiological consequences and associated hazards consequences: damage to the dropped waste package, damage to other waste packages, spread of contamination and radiological consequences to the workers. In the event of a dropped load, a safe back-out will be performed, and the damaged package(s) and spilled waste would be remediated and repackaged.

Safeguards in place to mitigate the consequences of a dropped load include preventative maintenance and routine inspections of hoisting equipment, RP requirements, barriers during hoisting activities, worker distance, and worker PPE&C.

The radiological consequence to the worker for a dropped load in the TSWRPA was analyzed and the detailed analysis is presented in Appendix D.

The dropped load event results in a waste package being dropped onto another waste package, resulting in two waste packages being damaged, the loss of containment and the spread of contamination. The waste packages are B-25 containers containing Waste Type 5, and meet the external dose rate criteria of ≤ 2 mSv for mechanical means handled wastes. Waste packages exceeding these criteria, will be subject to the Infrequently Performed Operations process [14-51].

The external radiation and inhalation radiological consequences to the on-site receptor located at the TSWRPA, and 1 m from the dropped load accident, are 3.3E-02 mSv and 7.3E-03 mSv, respectively. The radiological consequence to the on-site receptor is 4.0E-02 mSv. The primary radionuclides contributing to the inhalation radiological consequences are Am-241, Co-60 and Pu-239.

The radiological consequence to the on-site receptor for the dropped load AOO meets the DBA dose acceptance criteria as defined in Table 3-4. The AOO dose acceptance criteria in Table 3-4 is < 5 mSv for the on-site receptor, and < 0.5 mSv for the off-site public.

For the TSWRPA dropped load AOO involving a waste package with a near contact dose rate ≤2 mSv/h, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.3.2.1 Dropped Load Packaged Waste Exceeding Dose Rate Limit

For the TSWRPA dropped load AOO involving a waste package with a dose rate >2 mSv/h near contact or > 0.1 mSv/h at 1 m, exceeding the dose rate limits, the frequency is expected to be Occasional, the severity of the radiological consequence is Moderate, and the risk ranking for the event is R2 [14-3]. The estimated risk ranking for this dropped load event is considered an unreasonable risk; engineered solutions must be put in place to protect against the hazard. To mitigate this hazard, waste packages with near contact dose rate >2 mSv/h or >0.1 mSv/h at 1 m, are managed as non-compliant waste, assessed following the Infrequently Performed Operations process [14-51], and will be authorized on a case by case basis by the FA. The safety goals and design targets for normal operations or design targets for accidents as presented in Section 3 will be met.

14.3.3.3 Contamination (A.3.3)

The contamination AOO includes failure to monitor due to human error, radon and contamination on waste packages, vehicles, waste transportation containers, or waste handling equipment. The primary release mechanisms for contamination include:

- External contamination on the waste package or waste handling equipment caused by human error, such as inadequate contamination survey at source.
- Waste package potential off-gassing.
- New loose contamination on the waste handling equipment generated during waste placement or waste handling.
- Environmental conditions - wind.
- Failure to monitor vehicles and/or waste transportation containers exiting the NSDF.
- Failure to monitor the worker on exiting the WWTP or OSC.
- Failure to monitor the worker when crossing contamination zone boundaries.
- Radon in the waste.

For the contamination AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.3.3.1 Failure to Monitor (A.3.3.1)

Failure to monitor incoming waste packages and bulk waste transportation containers for surface contamination as required by procedures, could lead to contamination events with the potential for worker radiological consequences, and the spread of contamination.

Contamination events could potentially occur during waste placement, waste handling and waste receiving activities.

Failure to monitor outgoing vehicles and bulk waste transportation containers for surface contamination as required by procedures, could lead to contamination events with the potential for on-site receptor radiological consequences and the spread of contamination to the environment. The VDF is used to decontaminate any vehicle, equipment or waste transportation container that is found to be contaminated, and require decontamination.

Vehicles transporting waste packages and bulk waste may become contaminated as a result of loose contamination on the waste packages or bulk waste and during off-loading activities. The contamination on the waste package or bulk waste may be transferred to the vehicle and/or the waste transportation container as a result of environmental factors including precipitation and wind, and mechanical stress including vibration.

Routine contamination surveys of the vehicles and the waste transportation containers exiting the NSDF are conducted by the RP personnel. The vehicle and the waste transportation container surface contamination limits for unrestricted use are averaged over 300 cm^2 and must meet the surface contamination levels defined in Table 14-21 [14-52]. If any contamination above the limits in Table 14-21 is detected, then the contaminated area is decontaminated or the area may be replaced and managed as radioactive waste, e.g. the contaminated area is wood. The transport float may be used for transporting waste packages and the float has a wooden floor.

Mitigation measures to control contamination and the radiological consequences to the worker, includes work control, preliminary contamination surveys and radiation monitoring. Waste Acceptance Criteria for loose contamination will ensure that there is no increase in surface and extremity dose due to handling and storage of the waste package. During activities with a potential contamination risk, the workers will wear appropriate PPE&C for the contamination hazard, in order to minimize worker radiological consequences.

Routine contamination surveys of the NSDF are conducted by the RP personnel. Mandatory personnel contamination monitoring is conducted when there is a contamination zoning change. There is an RP Program requirement for individuals to pass through contamination monitors upon leaving a CA.

Table 14-21
Surface Contamination Release Levels [14-52]

Radionuclide	Release Level (Bq/cm^2)	
	Removable*	**Total†**
Strontium-90, all radioiodines	0.05	4.0
Low Toxicity Alpha Emitters	0.2	4.0
Alpha emitters that are not Low Toxicity Alpha Emitters	0.01	0.4
Low Toxicity Beta Emitters	2.0	40
All other radionuclides	0.2	4.0

Removable is determined by dividing the amount of radioactive material measured residing on swipe by the area over which the swipe was taken.

† Total is the sum of the loose and fixed as measured by direct monitoring of the surface.

14.3.3.3.2 Waste Packages (A.3.3.2)

Minimizing the contamination on the exterior surfaces of the waste packages or the transportation container, is effective to minimizing the potential for contamination spread during waste placements and or waste handling. The maximum surface contamination on the outer surface of the waste package or transportation container, averaged over 300 cm^2, must be less than 3.7 Bq/cm^2 for beta/gamma emitters and less than 0.37 Bq/cm^2 for alpha emitters.

Incoming waste shipments are inspected by NSDF staff and surveyed by RP personnel upon receipt at the NSDF. This waste receiving activity mitigates the potential for worker exposure resulting from contamination on waste packages or transportation containers.

Contamination on the waste package, transportation container, or waste handling equipment, can result in the spread of contamination during waste placement or waste handling. The spread of contamination may result in the following potential consequences: worker contamination, skin contamination, release of contamination to the environment, soil contamination, and the spread of contamination to the TSWRPA.

After waste placements, the workers are assessed for contamination before undressing from PPE&C and leaving the ECM. If any contamination above background is detected, further monitoring is performed in a lower background area, followed by additional undressing if required. Additionally, there is a potential for skin contamination for workers found with contaminated PPE&C due to environmental conditions, wind, or human error during the undress process. Loose contamination can be released into the environment generally downwind and any surface/soil contamination detected will be remediated.

Contamination control measures consist of contamination monitoring, PPE&C, and waste placement restrictions (of potentially contaminated waste packages), during adverse weather conditions. During operations with the potential for contamination hazards, the workers will wear appropriate PPE&C in order to minimize the radiological consequence to the worker. The requirement for respiratory protective equipment use in environments with airborne contamination is defined by the RP Program [14-52].

14.3.3.3.3 Radon (A.3.3.3)

Radon is a transient hazard within the ECM and the WWTP. Radon is a radioactive gas that naturally occurs in the environment and is a chemically and biologically inert noble gas. When radon gas migrates through the atmosphere, the solid radon progeny are deposited onto soil and water. The decay products of radon gas (radon-222) are radon progeny, which include four short-lived radioisotopes, Po-218, Pb-214, Bi-214, and Po-214, with half-lives of fewer than 30 minutes. An increase in detected worker contamination, due to radon, has been observed in the CRL WMAs during operation activities when there is precipitation or moisture present in the environment and this contamination hazard is assumed to exist within the NSDF. Worker contamination associated with radon is expected to decay by half to negligible values within less than 30 minutes. Higher radon levels (e.g. during precipitation events) may impact the functionality of the stand-in RP monitors in the WWTP.

In the event that a worker is suspected to be contaminated due to radon, the worker will re-monitor after approximately 30 minutes and the radon contamination will generally no longer be present. When contaminated clothing is wet, the clothing is either allowed to dry or removed. If the worker is required to remove the contaminated clothing in order to leave the Facility, CNL RP issued loaner clothing is available for use. Approximately after 30 minutes or the next day, the radon contaminated clothing will be checked. If there is no detectable radon contamination remaining, the clothing will be returned to the owner.

14.3.3.4 Unintended Contents (A.3.4)

Unintended or unanticipated contents in the waste package and bulk waste shipments are an AOO due to:

- Human errors during waste loading and waste characterization.
- Incomplete or deficient records.
- The WAC [14-53] is based on the external radiation field of the waste package and the transportation container, rather than the actual activity of the waste in the package or transportation container.

The waste is characterized to a degree that provides all information to ensure compliance with the NSDF WAC [14-53]. Characterization includes assessing the physical, mechanical, chemical, biological, thermal, and/or radiological properties of the waste material, as applicable [14-54]. Waste is characterized based on the waste properties that are necessary and sufficient to demonstrate compliance with the most stringent applicable regulations and requirements throughout the lifecycle of the waste [14-54].

The CNL Waste Certification Program is the basis for ensuring that the wastes are managed in a manner that meets all applicable rules, regulations, license conditions, and requirements CNL must follow [14-55]. The CNL Waste Certification Program [14-55] and waste characterization [14-54], should reduce the event frequency of unintended or unanticipated contents in the waste package and bulk waste shipments.

All shipments of waste received shall be accompanied by a completed Waste Package Data Form and supporting documentation as required. The Waste Package Data Form lists, or references a document that lists, the origin of the waste and a description of the waste form, volume, radionuclide content, and content of any other hazardous materials, as identified by the waste generator. The supporting documentation may include a Waste Management Plan, waste identification checklist, and characterization documentation.

Upon receipt in the NSDF, the waste is inspected and RP staff measure the near contact dose rate and the dose rate at 1 m. If the unintended contents is a gamma emitting radionuclide, the RP staff may measure unanticipated dose rates that do not align with the Waste Package Data Form and supporting documentation. In this scenario, the waste shipment should be further investigated and the Facility Supervisor notified.

The workers are protected by work controls, PPE&C and radiation monitoring during the waste receiving / inspection and waste placement and compaction. The workers are required to wear a PAD and the PPE&C as documented on the Radiological WP or WP. The PPE&C may include respiratory protection. The PAD records the overall dose, dose rates and provides audible notification if the permitted dose rate is being exceeded. Radiation Protection provides oversight and surveillance for the waste receiving and inspection activity.

Packaged waste that requires gas venting must be assessed following the Infrequently Performed Operations process [14-51].

For the unintended contents AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.3.5 Vehicle Collision (A.3.5)

Vehicle collision or impact is an AOO due to human error resulting in the following radiological consequences and associated hazards consequences:

- The potential spread of contamination.
- The potential vehicle fire with the potential for a waste fire and a release to the environment.

Vehicles travelling in the NSDF are required to operate at the appropriate speed limit, which is anticipated to reduce the severity of the damage consequence in the event of vehicle collision or impact. The damage as result of vehicle collision/impact will be negligible. Human errors including misjudging vehicle speed, distracted driving, and or lack of vehicle maintenance may lead to a vehicle collision.

Heavy equipment vehicles and trucks powered by hydrocarbon fuels are potential sources of flammable materials. Generally, diesel and gasoline fuel tanks on heavy equipment vehicles and trucks are located on the side and are shielded with a steel plate. Due to these types of fuel tank configurations, the fuel tanks are not easily accessible to result in a breach of their integrity in a collision with other vehicles or structures within the Facility. Furthermore, the maximum speed attainable by a heavy equipment vehicle is limited by speed limit restrictions such that an impact is not anticipated to lead to a catastrophic fuel tank failure.

In addition, the refueling station fuel storage tank is designed for use in a heavy equipment environment and is provided with an integral vehicle impact barrier to prevent damage from vehicle impacts. A vehicle fire adjacent the aboveground diesel fuel tank will not cause the tank to explode or subject the internal liner to temperatures above its design rating, as the tank is designed and provided with the safety features required by NFPA 30 and ULC-S601 [14-56].

To mitigate the risk of an engine compartment fire, waste delivery vehicles and ECM heavy equipment used for waste placement and compaction shall be provided with on board fire suppression systems [14-56]. To control the spread and severity of fire and minimize operator injury, the on board extinguishing systems shall be certified to FM Global FM 5970 standards [14-56]. Systems meeting FM Global standards are deemed to be adequate control measures [14-56].

The controls and safeguards that are in place to prevent fires and or to limit the consequences of an ECM fire event, include CRL Fire Department, NSDF FWPS, vehicle/equipment maintenance, engine compartment fire suppression system on heavy equipment, and portable fire extinguishers on the vehicles. Fire water is stored in the FWPS.

A vehicle collision resulting in a fire at the ECM is bounded by the TSWRPA fire event analyzed in Section 14.4.2.6.

Snow clearing operations may be performed during the winter months based on operational needs. Vehicle impact during snow clearing operation could result in damage to equipment, and structures.

For the vehicle collision AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.3.6 Intrusion of Non-Human Biota (A.3.6)

At the NSDF, only transient wildlife use of the area is plausible. Animal intrusion could result in the transfer of contamination by non-human biota and radiological consequences to the non-human biota. The NSDF is fenced and cleared of vegetation in order to limit access and discourage terrestrial non-human biota from inhabiting the area.

Intrusion of non-human biota burrowing into the ECM may cause minor damage to the daily cover, interim cover and or final cover system. In addition, the final cover system has an intrusion barrier layer to prevent the intrusion of non-human biota. Routine Facility inspections will identify the damage to the covers and the damage will be repaired as required. The perimeter fence reduces the potential for the intrusion of burrowing non-human biota into the vicinity of the ECM.

Birds such as geese may inhabit the surface water management ponds if the ponds retain water, however the surface water management ponds should be dry except during precipitation events.

For the non-human biota intrusion AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.3.7 Damage to Structures (A.3.7)

Damage to the ECM structure is an AOO. Damage to ECM structures and components could occur as a result of heavy equipment operations during construction or waste placement activities due to human error or mechanical failure resulting in potential radiological consequences to the worker. The ECM structures and components that could be affected and damaged include: the side slope of the liners, base liner system, LCS, LDS, sacrificial liner, interim cover, and final cover system.

The contact water and non-contact water ponds could also be damaged. Damage to the contact water and non-contact water ponds could result in a spill or leak of contact water or non-contact water, which will result in the increase in leachate generation. The spilled or leak water will be contained and collected by the LCS.

Damage to the side slope of the liners and the base liner system could result in the loss of containment and the potential release of contaminated leachate to the environment. Damage to the LCS may result in leachate being collected in the LDS. The LDS provides defence-in-depth for the leachate collection within the ECM. Damage to the sacrificial liners that are a component of the interim cover or are applied to the floor of inactive cells, may result in increased leachate generation and non-contact water becoming contaminated and managed as contact water. Damage to the interim covers and the final cover system may result in increased precipitation infiltration and increased leachate generation.

Any damage to ECM structures and components would be repaired, therefore, consequences are expected to be negligible.

For the damage to the ECM structures AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.3.8 Higher Flow than Anticipated (A.3.8)

Higher flow than anticipated of contact water, due to human error leading to the overflow of CWPS #1 and resulting in a release to the environment is an AOO. The CWPS #1 is located on the perimeter berm and any overflow results in a release to the environment.

Contact water pump station #1 receives leachate and contact water from the gravity system and pumps the water into the force mains to the Equalization Tanks. Contact Water Pumping Stations #1 is equipped with stand-alone control panels and the pumps are operated automatically by the local PLC. A radar level transmitter in the wet well is used by the PLC to start and stop the pumps based on selected level set points. Three submersible pumps are housed at CWPS #1 and typical duty pumping is provided by up to two pumps at a time, with the third serving as standby. The design operating capacity for each of the pumps is 23.3 L/s at 28.6 m head. The minimum pump rate is approximately 17 L/s when one pump is operating and when only one of the pressure mains used. The maximum pump rate is about 44 L/s when two pumps are operating and both pressure mains are used. The flow of leachate into CWPS #1 is via gravity and the leachate flow rate cannot be manipulated. The flow and flow rate of contact water into CWPS #1 can be controlled by throttling the contact water pump within the ECM.

Under normal operating conditions, when all the equipment is in SCADA-AUTO mode, it is not expected that all three pumps will operate simultaneously. However, because it is critical that the pump stations do not overflow, starting the standby pump when level continues to rise, minimizes potential flooding. The pump stations' pumps have been sized and selected such that the stations' peak flow requirement can be conveyed when one pump is out of service.

The pump station wet well has a high level alarm, LIT-100, that provides notification of the alarm to the Operator Interface Terminal and the WWTP monitoring and control system.

The following aspects could lead to CWPS #1 overflowing into the environment:

- Failure of the high level alarm located in the pump station wet well.
- If the contact water pumping rate into pump station #1 exceeds the pump station output flow.
- If the contact water and leachate flow rate into pump station #1 exceed the pump station output flow.

The overflow results in a release to the environment, which would be an uncontrolled release of untreated wastewater, leachate and contact water. To prevent overflow of CWPS #1, during the transfer of contact water from the ECM, the level within CWPS #1 must be monitored visibly by the worker or using the Operator Interface Terminal. Upon notification of high level alarm in CWPS #1, the worker could activate the stand-by pump or shutdown the contact water pump. The design includes hard wire controls and interlocks to prevent the overflow of CWPS #1.

For the higher flow than anticipated AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-4].

14.3.3.9 Ground Subsidence or Erosion (A.3.9)

Ground subsidence or erosion is an AOO for the ECM disposal cells. Ground subsidence or erosion of the waste layers, daily covers, interim covers, or final cover system may be the result of a natural external event or human error.

Ground subsidence is the downward movement within the ground. Shifting or settling of wastes, and deterioration/degradation of packages, containers and structures, can result in ground subsidence. Erosion, due to ground subsidence, can reduce cover soil shielding thickness and/or expose waste, resulting in potential increased direct exposures to radiation and contamination. Erosion of the waste layers and or covers may cause some position shifting of the placed waste. Lost soils could be replaced when erosion is detected during routine inspections. If the waste layer is shifted, an assessment may be needed to determine whether the waste layer is fit for continued use. Damage to the daily cover, interim cover, or final cover system may increase the water infiltration into the waste and the leachate generation rate.

The operation of vehicles and equipment in the proximity of the placed wastes in the waste layer, could initiate subsidence due to the extra load on the buried waste. The compaction of the placed waste and daily/interim cover soils is compacted to a minimum of 92% of the Standard Proctor Density (SPD) [14-57]. The minimum 92% SPD compaction limits settlement, minimizes void spaces and subsidence, and is readily achievable over a wide range of soil conditions [14-57]. Compaction procedures are developed and adjusted as required in the field based on waste characteristics, moisture levels, and the type and size of compaction equipment used. Compaction of the waste is performed using a combination of a landfill compactor or a wheel tractor soil compactor.

Risks associated with subsidence and erosion are mitigated by administrative controls including erection of barriers around the subsidence or erosion area to prevent entry, Facility inspections, and RP monitoring the subsidence or erosion area.

For the subsidence and erosion AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.3.10 Radiation (A.3.10)

Higher than anticipated dose rate on the waste package or the transportation container is an AOO due to human error, resulting in potential radiological consequences to the worker. Upon receipt at the NSDF, the waste packages and transportation containers are inspected, and RP staff monitor the dose rates. Waste packages and transportation containers must meet the external radiation fields as defined in the WAC [14-53], and in Section 9.3.1.2 and Section 11.2.1.1, limiting the radiological consequence to the workers.

In the event that a waste package or transportation container is found to have a higher than the anticipated dose rate, in exceedance of 2 mSv/h near contact and/or 0.1 mSv/h at 1 m, the waste package or transportation container will be segregated and the Facility Supervisor notified. The non-compliant waste package or transportation container will be either returned to the generator or will be stored within the TSWRPA awaiting assessment and authorization of the FA.

The handling and transferring of waste packages or transportation containers with dose rates exceeding 2 mSv/h near contact and/or 0.1 mSv/h at 1 m, is subject to RP Program controls, Infrequently Performed Operations [14-51] and assessment approval by the NSDF FA. The non-compliant waste shall be authorized on a case by case basis by the FA, and shall not in any circumstances result in contravening the safety goals and design targets for normal operations or design targets for accidents as presented in Section 3.

The primary safeguards in place to mitigate the radiation hazard of the waste include:

- RP oversight/surveillance.
- Workers wear a PAD that provides audible notification if the permitted dose rate is being exceeded.
- Work controls.
- PPE&C.

For the higher than anticipated dose rate AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Minor, and the risk ranking for the event is R1 [14-3].

14.3.4 Waste Water Treatment Plant (A.4)

The WWTP AOOs include containment failure, contamination, dropped load, and impact/collision.

14.3.4.1 Containment Failure (A.4.1)

Containment failure within the WWTP is an AOO due to human error and includes the following potential events:

- Overflow of the Equalization Tank resulting in the spill of wastewater.
- Valve left open during sampling or drain valve left open during the tank or line draining activity resulting in spill/leak.
- Loss of the seal between the filter press plates, resulting in the spread of contamination and the potential radiological consequence to the worker.

The primary safeguards in place to mitigate a valve being left open include secondary containment, leak detection in the secondary containment, tank level monitors, WWTP active drain, and tank low level alarms.

The primary safeguards in place to mitigate the overflow of the Equalization Tank are tank level monitors, high level alarms and the Equalization Tanks' secondary containment. In the event of an overflow of the Equalization Tank, the tank high level alarm will alarm, the spilled wastewater will be contained within the secondary containment and the secondary containment sump alarm will alarm. In the event of a valve being left open at an Equalization

Tank, the leaked wastewater will be contained within the secondary containment and the secondary containment sump alarm will alarm. The worker will investigate the alarms at the Equalization Tanks and the spilled wastewater will be pumped back into an available Equalization Tank.

In the event of a valve being left open at a WWTP process tank, the leaked wastewater will be contained within the secondary containment and drain into the active drain system. The WWTP secondary containment has leak detection that will alarm to provide notification of the leak.

The WWTP process system has a bypass line to bypass treatment processes and to bypass the entire process system to direct discharge. To mitigate human error in the use of the bypass line, valves V-019, V-020, V-057, and V-058 on the bypass line are normally closed and shall be locked closed. The valves can be unlocked with Facility Manager or FA approval.

The primary safeguards in place to mitigate the loss of seal between the filter press plates include: active ventilation, filter press enclosure, radiation monitoring CAM and trench drain that drains to the active drain system. If the worker is present during the failure, the worker is protected by PPE&C and wearing a PAD that provides audible notification if the permitted dose rate is being exceeded.

In addition to the human errors, freezing of the air valve on the effluent force main to Perch Lake (located at the high point of Perch Lake discharge line), is an AOO. This event may lead to the potential for water hammering effect, resulting in damage to the force main and release to the environment. The air valve on the effluent force main is located below grade and has internal freeze protection, insulated to prevent freezing. The air valve allows air into the effluent force main to prevent an air lock within the effluent force main. Maintenance and inspection of the air valve will mitigate the potential for freezing and valve failure.

For the WWTP containment failure AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

For the effluent force main containment failure AOO, the frequency is expected to be Occasional, the severity of the environmental consequence is Minor, and the risk ranking for the event is R0 [14-3].

14.3.4.2 Contamination (A.4.2)

Contamination within the WWTP is controlled through radiological safety zoning, barriers, surface contamination monitoring, work controls, and RP oversight. Contamination on equipment and a worker being splashed could result in potential radiological consequence to the worker. Personal surface contamination monitoring equipment will provide notification to the worker of contamination. Radioactive contamination of skin and clothing is to be immediately reported to a Group 1 qualified Radiation Surveyor.

For the WWTP contamination AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.4.2.1 Worker Splashed

The worker could become contaminated during sampling of the tanks, resulting in the potential radiological consequence to the worker. The WWTP worker could be splashed during the sampling of the process tanks. A radiological consequence, skin dose, may occur from accidental splashes or spillage either onto exposed (bare) skin or clothing of the worker.

The skin dose to the worker being splashed during sampling was analyzed and the detailed analysis is presented in Appendix E. Two sampling locations are assessed for the skin dose to the splashed worker; the chemical precipitation tanks and the membrane filter residuals. The chemical precipitation tank radiological source term is equivalent to that of the Equalization Tanks. The membrane filter residuals in the Filter Press Feed Tank and the Residuals Storage Tanks has the highest radiological source term of the WWTP tanks.

For the splash event involving the chemical precipitation tank water, the calculated dose rates for both the droplet and the uniform deposit are less than 2E-05 mGy/h (2E-05 mSv/h), so even with an 8 or 10 hour exposure time the radiological consequence, skin dose, would be insignificant, being orders of magnitude below the equivalent dose limit of 500 mSv for skin.

For the splash event involving the membrane filter residuals in the filter press feed tank, the calculated dose rates for both the droplet and the uniform deposit are less than 3E-04 mGy/h (equivalent to 3E-04 mSv/h), even with an 8 or 10 hour exposure time the radiological consequence, skin dose, would be insignificant, being orders of magnitude below the equivalent dose limit of 500 mSv.

For both splash events, the radiological consequence, skin dose, to the splashed worker meets the AOO dose acceptance criteria of < 5 mSv for the on-site receptor as defined in Table 3-4.

For the WWTP worker splashed AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.4.3 Dropped Load (A.4.3)

A dropped load in the WWTP is an AOO due to human error, resulting in the radiological consequences: the spread of contamination and potential radiological consequence to the worker. A dropped load involving the filter press dewatered residuals bin was analyzed and the detailed analysis is presented in Appendix F.

Exposure to dewatered residuals may occur as a result of small leaks during filter press operation, failure of the filter press during operation, exposure during cleaning, or if the dewatered residuals box is spilled or dropped during transfer. Exposure during operations is mitigated by a ventilated physical enclosure surrounding the filter press.

A bounding scenario is assessed in which a WWTP worker is exposed to dewatered residuals following a spill or dropped load during transfer. This scenario is considered to be bounding because the radiological source term for dewatered filter press cake is assumed to be bounding. A conservative Airborne Release Fraction (ARF) is utilized to ensure that the spill scenario is bounding of other filter press events.

The total volume of filter press cake inside the dewatered residuals bin is approximately 2.72 m^3, based on the inner volume of the dewatered residuals bin, and that when spilled, the height of the filter press cake on the floor is 0.5 m. The affected volume (resuspension) is half the volume of the filter press enclosure (i.e. 91 m^3). The WWTP worker is assumed to be located 30 cm away from the spilled residuals, and remains for ten minutes. Given the uncertainty of the exposure duration, the analysis includes a sensitivity calculation for an exposure of 1 hour. A small portion of the spilled residuals is assumed to become suspended in air and inhaled by the worker.

The radiological consequence to a worker is calculated based on external exposure and inhalation of a small portion of re-suspended residuals. The calculated radiological consequences are summarized in Table 14-22, including for the exposure durations of 10 minutes and 1 hour. The radiological consequence to the worker is 7.4E-03 mSv for a 10 minute exposure and 4.4E-02 mSv for a 60 minute exposure. The radiological consequence to the worker meet the AOO dose acceptance criteria of < 5 mSv for the on-site receptor as defined in Table 3-4.

For the WWTP dropped load AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

Table 14-22
Radiological Consequence to the Worker from Spilled Filter Press Cake

Type	**Radiological Consequence**	
	Dose for 10 min exposure (mSv)	**Dose for 1 hour exposure (mSv)**
External (at 30 cm)	4.6E-03	2.8E-02
Inhalation of re-suspended radionuclides	2.7E-03	1.6E-02
TOTAL	7.4E-03	4.4E-02

14.3.4.4 Vehicle Collision (A.4.4)

Vehicle collision or impact is an AOO due to human error resulting in damage to structures, including the Equalization Tank secondary containment and the leachate extraction box.

Vehicles travelling in the NSDF are required to operate at the appropriate speed limit, which is anticipated to reduce the severity of the damage consequences in the event of vehicle collision/impact. The damage as result of vehicle collision/impact will be negligible. Human errors, including misjudging vehicle speed, distracted driving, and or lack of vehicle maintenance may lead to a vehicle collision.

In the event of damage to the structures, the damage will be assessed, mitigation measures will be put in place as required and the damage repaired.

For the WWTP vehicle collision AOO, the frequency is expected to be Occasional, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.3.5 Vehicle Decontamination Facility (A.5)

The VDF AOOs are greater than anticipated contamination and/or radiation on the vehicle, transportation container or waste handling equipment, resulting in the potential radiological consequence to the worker. This AOO may occur due to human error, resulting in gross contamination not being removed from the vehicle, transportation container or waste handling equipment prior to leaving the ECM and entering the VDF.

The radiological consequence to the VDF worker as a result of an upper-range exposure event, representing exposure to a higher than anticipated quantity of radioactive material entering the VDF as surface contamination on a VDF vehicle, was analyzed and the detailed analysis is presented in Appendix G.

The scenario assumes that a vehicle enters the VDF with a thick layer of bulk LLW surface contamination. During decontamination operations, the VDF worker is exposed to external gamma radiation from surface contamination on the vehicle being decontaminated, and inhales radionuclides that may be suspended in the air from decontamination activities.

The estimated dose rate from the vehicle being decontaminated is 1.02E-03 mSv/h. The estimated radiological inhalation consequence to the worker from the vehicle decontamination activities is 3.53E-02 mSv. Therefore, assuming the VDF worker is exposed to the higher than anticipated levels of contamination for one hour, the radiological consequence to the VDF worker is 3.63E-02 mSv. The radiological inhalation consequence to the VDF worker meets the AOO dose acceptance criteria of < 5 mSv for the on-site receptor as defined in Table 3-4.

For the VDF AOO, greater than anticipated contamination and/or radiation, the frequency is expected to be Occasional, the severity of the radiological consequence is Minor, and the risk ranking for the event is R1 [14-3].

14.4 Design Basis Accidents (Group B)

This section analyzes the DBAs, identified as Group B in Section 14.1.4, for the NSDF including external events, containment failure, dropped load, unintended contents, impact/collision, damage to structure, misguided flow, and internal fire.

14.4.1 External Events (B.1)

The DBA external events include seismic activity, wildland fire, lightning, and extreme wind and tornado.

14.4.1.1 Seismic Activity (B.1.1)

Seismic activity, DBA, may impact the ECM, WWTP, Equalization Tanks and piping infrastructure, and building structures.

14.4.1.1.1 Engineered Containment Mound (B.1.1.1)

Seismic activity involving a DBE, will have a negligible impact on the ECM and the placed wastes within the ECM. Seismic activity, DBE, may result in the potential displacement of the placed waste in ECM disposal cell and/or waste in the TSWRPA, and the spread of contamination and the potential release to the environment. If a seismic event were to occur during waste placement operations of packaged waste, the waste package being handled could drop and become damaged with similar consequences to the dropped load events assessed in Section 14.3.3.2.

The ECM is designed to withstand a DBE seismic event that has a frequency of occurrence of 1 in 10 000 years. The seismic evaluation of the ECM included liquefaction triggering, slope stability, and seismic deformation analyses [14-58]. Based on the seismic analysis, ground improvements are included in the design to mitigate against liquefaction of the silty sand foundational soils that underlie certain areas of the ECM.

Based on the Seismic Analysis [14-58], assuming that liquefaction prone soils are improved, the maximum shear displacements along the base and cover liner systems as a result of the DBE are 2 cm and 5 cm, respectively. The ECM structure is expected to remain functional when exposed to ground motions of magnitude equal to or less than the design 1 in 10 000 year earthquake. While the ECM will remain intact, seismic activity may result in dust generation and associated airborne release of small quantities of bulk LLW from uncovered areas of the ECM.

Following a seismic event, the ECM would be inspected for structural damage and waste displacement. If structural damage or waste displacement is identified, the damage or waste displacement will be assessed, mitigation measures will be put in place as required, and the damage or waste displacement repaired.

For the ECM seismic activity DBA, the frequency is expected to be Rare, the severity of the radiological is Negligible, the severity of the environmental is Minor, and the risk ranking for the event is R0 [14-3].

14.4.1.1.2 WWTP, Equalization Tank and Piping Infrastructure (B.1.1.2)

Seismic activity involving a DBE has the potential to damage the piping infrastructure. The piping may break, which may result in a spill or leak and a potential release to the environment. The radiological consequences of damage to the piping infrastructure are expected to be minor.

The WWTP is designed to withstand applicable live loads as required for the design basis seismic event of the frequency 1 in 2 500 years, in accordance with the NBCC 2015 [14-47].

Following a seismic event, the Equalization Tanks and piping infrastructure would be inspected for structural damage and leaks. If structural damage is identified, the damage will be assessed, mitigation measures will be put in place as required and the damage repaired. If a leak/spill is identified, the leak/spill will be cleaned up, and mitigation measures will be put in place as required.

For the WWTP, Equalization Tanks and piping infrastructure seismic activity DBA, the frequency is expected to be Rare, the severity of the radiological is Negligible, the severity of the environmental is Minor, and the risk ranking for the event is R0 [14-3].

14.4.1.1.3 Building Structures (B.1.1.3)

The NSDF buildings are designed and built in accordance with the NBCC 2015 [14-47] applicable at the time of design/construction. The buildings are designed to withstand applicable live loads as required for the design basis seismic event of the frequency 1 in 2 500 years. The buildings would withstand minor earthquakes without significant damage. The impact of seismic activity is expected to have minimal effect on the NSDF buildings.

Following a seismic event, the building structure would be inspected for structural damage. If structural damage occurs, the structure would be repaired.

For the NSDF building structures seismic activity DBA, the frequency is expected to be Rare, the severity of the radiological is Negligible, and the risk ranking for the event is R0 [14-3].

14.4.1.2 Wildland Fire (B.1.2)

Wildland and forest fires could initiate from ignition sources such as ground maintenance activities, trees falling over transmission lines and lightning strikes during the forest fire season. Forest fire season is defined as April 1st to October 31st [14-44].

Early detection of a wildland/forest fire will limit the consequences of the fire. During daylight hours, a wildland fire in proximity to the NSDF would be rapidly detected by CRL personnel at the NSDF or people travelling on Plant Road. During off-hours, Security personnel would likely detect any significant wildland fires during security patrols of the site. The CRL Fire Department has a procedure for responding to an emergency incident involving wildland/forest fire fighting in areas having potential radiological contamination [14-59]. The CRL Fire Department possesses the equipment to fight wildland fires and may also request support from adjoining municipal fire departments and the Ontario Ministry of Natural Resources. Access to the site of the fire would be provided by a number of roads and fire trails extending throughout the Supervised Area. Additionally, the CRL Fire Department can meet the CSA N393 [14-60], which dictates the fire response team shall be capable of performing effective and sustained intervention through implementation of fire attack plan within 15 minutes of being notified of fire incident.

Five firebreaks have been established on the south, west and north property boundaries of the CRL site. A firebreak is an existing barrier or a wide strip of land on which the native vegetation has been modified or cleared, to act as a buffer to the spread of fire so that forest fires burning into them can be more readily controlled. In the event of a fire, a firebreak also acts as a vehicular access point to obtain water for fire control measures. Usually the break in vegetation is 6 m to 9 m wide. This allows enough space for a tanker to enter the area and for two vehicles to pass if necessary.

A fire involving combustible waste at the NSDF may occur due to a wildland or forest fire. The closet point to the top of ECM perimeter berm is approximately 45 m from the NSDF perimeter fence and the forest edge is 4 m beyond the NSDF fence line, meeting NFPA 1144 requirements [14-56]. The NSDF has a 5 m tree line buffer area from the NSDF perimeter fence inside the NSDF boundary [14-36]. In addition, buildings or structures will not be situated within 5 m of the 5 m tree line buffer area, 10 m from the NSDF perimeter fence [14-36].

Vegetation is maintained, approximately 4 m from the NSDF perimeter fence. The quarterly inspections are made to detect excess vegetation growth and ongoing maintenance includes grass cutting and vegetation control.

Wildland/forest fires are not expected to affect:

- Waste within the ECM since the ECM perimeter berm is approximately 45 m from the NSDF perimeter fence and the forest edge is 4 m beyond the NSDF fence line.
- Waste placed in disposal cells - the use of a daily soil cover and interim cover over the placed waste in the disposal cell, minimizes the risk of the waste catching on fire.
- Buildings because they are constructed of non-combustible materials and are equipped with fire detection systems.

A forest fire spreading to the NSDF site may affect waste within the TSWRPA or the open disposal cell. The internal fire at the TSWRPA is discussed in Section 14.4.2.6.

For the wildland/forest fire event, the frequency is expected to be Rare, the severity of the radiological consequence is Minor, the severity of the environmental consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.4.1.3 Lightning (B.1.3)

A lightning strike may cause a fire in the electrical system (e.g. ignition of wire insulation) in the NSDF buildings with electrical systems. The electrical system fire could ignite nearby combustible material. All of the NSDF buildings have lightning protection systems. Lightning could strike the metal construction buildings (WWTP, VDF), but their all-metal construction would likely conduct the electrical charge into the ground without any significant consequences. In addition, the WWTP Equalization Tanks are equipped with lightning protection and are grounded.

A lightning strike may cause a fire at the site vehicle refueling station and the aboveground diesel fuel tank. There are not expected to be any radioactive materials in the vicinity of the vehicle refueling station, therefore the radiological consequences resulting from this event are considered to be negligible. In addition, the aboveground diesel fuel tank is equipped with a grounding cable and the system is electrically grounded for static electricity build-up.

A lightning strike on the ECM perimeter berm could result in damage to the perimeter berm and could cause small missiles (e.g. fragments of rock). Although damage to the ECM perimeter berm produced by a lightning strike is unlikely to cause significant damage, explosive forces could be generated within the rock by an electric arc and large pieces of rock could become dislodged.

A lightning strike may start a fire with the waste in the TSWRPA or uncovered/exposed placed waste in the disposal cell. Placed waste in the disposal cell could be exposed if the waste is not covered by the daily cover or interim cover. The consequences of a TSWRPA fire is analyzed in detail in Section 14.4.2.6.

Following a lightning strike event, the building or structure would be inspected for structural damage. If structural damage is identified, the damage will be assessed, mitigation measures will be put in place as required and the damage repaired.

For the lightning DBA event, the frequency is expected to be Rare, the severity of the radiological consequence is Minor, the severity of the environmental consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.4.1.4 Extreme Wind and Tornado (B.1.4)

The potential hazards posed by a tornado and extreme winds are those due to the direct force of the wind and to tornado-borne missiles. Tornadoes and extreme winds will have a negligible impact on the ECM, WWTP and Equalization Tanks, and building structures.

The design considers a minimum wind load of 220 km/h, corresponding to the CRL DBT which is an upper Enhanced Fujita (EF2) Tornado with maximum wind speed 220 km/h, which has a frequency of 10^{-5}/year [14-61].

The fence surrounding the NSDF could be damaged by tornado winds, extreme winds or tornado generated missiles and would be detected during Facility inspections. Human monitoring presence and temporary barriers would be immediately installed and the damaged fence would be repaired, restoring the required functionality.

14.4.1.4.1 Engineered Containment Mound (B.1.4.1)

A tornado or extreme wind event could cause damage within the ECM to the covers, and displacement of wastes resulting in the radiological consequences: spread of contamination and potential radiological consequences to the on-site and off-site receptors.

No significant damage is expected from tornado or extreme windblown missiles such as poles or vehicles for the perimeter berm and the base liner since the structures are constructed of natural materials and designed for the CRL site DBT [14-61].

The damage to the open disposal cell would be limited to damage to covers, erosion, water infiltration and some spread of surface contamination. The damage to the interim, daily and or final cover system could result in the spread of contamination and increased precipitation infiltration. The damage would be detected during inspections following the event, and actions could be taken to limit the spread of contamination and to clean up and repair any damage.

In a tornado or extreme wind event, high winds event, operations at the ECM would be suspended [14-46], therefore, the radiological consequences to on-site receptors are considered to be negligible.

Following a tornado or excessive wind event, the ECM would be inspected for damage and the spread of contamination. Actions could be taken to limit the spread of contamination and to clean up. If damage is identified, the damage will be assessed, mitigation measures will be put in place as required and the damage repaired.

For the ECM tornado and extreme wind DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequences is Negligible, and the risk ranking is R0 [14-3].

14.4.1.4.2 WWTP, Equalization Tanks and Piping Infrastructure (B.1.4.2)

A tornado or extreme wind has the potential to damage the Equalization Tanks, secondary containment and the above ground piping infrastructure. The Equalization Tanks and or the piping may become damaged due to wind generated missiles, which may result in the radiological consequences: spill or leak and potential release to the environment. The Equalization Tanks are designed to the CRL DBT (wind speed and maximum atmospheric drop) as per Table 3-1 of [14-61] and tornado generated projectiles A to E [14-61].

Following a tornado or extreme wind, the Equalization Tanks and piping infrastructure would be inspected for structural damage and leaks. If structural damage is identified, the damage will be assessed, mitigation measures will be put in place as required and the damage repaired. If a leak/spill is identified, the leak/spill will be cleaned up, and mitigation measures will be put in place as required.

In the event of an Equalization Tank failure, the wastewater released would be contained within the secondary containment, which is sized to accommodate 110% of one tank.

For the WWTP, Equalization Tanks and piping infrastructure DBA tornado or extreme wind event, the frequency is expected to be Rare, the severity of the radiological consequence is Minor, the severity of the environmental consequence is Minor, and the risk ranking for the event is R0 [14-3].

14.4.1.4.3 Building Structures (B.1.4.3)

The NSDF buildings are designed and built in accordance with the NBCC 2015 [14-47] applicable at the time of design/construction. The buildings are designed to withstand applicable live loads as required for wind loadings for the area. A tornado/extreme wind event could cause potential damage of the building structures. However, the impact of a tornado/excessive wind event is expected to have minimal effect on the buildings.
Following a tornado/excessive wind, the building structure would be inspected for structural damage. If structural damage occurs, the structure would be repaired.
For the building structures DBA tornado or extreme wind event, the frequency is expected to be Rare, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.4.2 Engineered Containment Mound (B.2)

The ECM DBAs include containment failure, dropped load, unintended contents, impact/collision, damage to structure, misguided flow and internal fire.

14.4.2.1 Dropped Load (B.2.1)

A dropped load is a DBA that could occur at the ECM during packaged waste placement or handling. Waste placement and waste handling activities are completed using either manual means, or by mechanical means, such as a mobile crane. A crane is used for hoisting activities of the waste packages. A dropped waste package due to equipment mechanical failure could result in the following potential radiological and associated hazards consequences: damage to the dropped waste package, damage to other waste packages, spread of contamination and radiological consequences to the workers. In the event of a dropped load, a safe back out will be performed, and the damaged package(s) and the spilled waste would be remediated and repackaged, as required.

Safeguards in place to mitigate the consequences of a dropped load include preventative maintenance and routine inspections of hoisting equipment, RP requirements, barriers during hoisting activities, worker distance, and worker PPE&C.

The radiological consequence to the on-site receptors, workers, for a dropped load in the TSWRPA was analyzed and the detailed analysis is presented in Appendix D. The dropped load event results in a waste package being dropped onto another waste package, resulting in two waste packages being damaged, the loss of containment and the spread of contamination. The waste packages are B-25 containers containing Type 5 packaged waste, and meet the external dose rate criteria for handling the waste by mechanical means only. The dose rates for handling the waste by mechanical means only are >0.5 mSv/h to ≤2 mSv/h near contact with any external surfaces of the package, and >0.001 mSv/h to ≤0.1 mSv/h at a distance of 1 m from the package. Waste packages exceeding this criteria, will be subject to the process, Infrequently Performed Operations [14-51].

The radiological consequences to the on-site receptor, worker, located at the TSWRPA and 1 m from the dropped load accident are 3.3E-02 mSv for the external radiation exposure pathway and 7.3E-03 mSv for the inhalation exposure pathway. The overall radiological consequence to the worker is 4.0E-02 mSv. The primary radionuclides contributing to the radiological inhalation consequence are Am-241, Co-60 and Pu-239. The radiological consequence to the worker meets the DBA dose acceptance criteria of 5 mSv to 50 mSv for on-site receptor, worker, as defined in Table 3-4.

Equipment mechanical failure could lead to a dropped load involving a high dose rate waste package, up to 2 mSv/h near contact, and potential damage to the waste package resulting in the loss of shielding and radiological consequences to the worker. Waste packages or transportation containers with a higher dose rate >2 mSv/h, are not compliant with the WAC [14-53], and are subject to the Infrequently Performed Operations process [14-51]. Acceptance of waste that is non-compliant with the requirements of the NSDF WAC [14-53], are authorized on a case by case basis by the FA, and shall not in any circumstances result in contravening the safety goals and design targets for normal operations or design targets for accidents as presented in Section 3. Prior to acceptance of packaged waste that is non-compliant with the NSDF WAC [14-53], a dropped load assessment shall be completed and the radiological consequence to the on-site receptor shall meet the dose acceptance criteria for a DBA dropped load, 5 mSv to 50 mSv for the on-site receptor.

For the ECM dropped load DBA event, the frequency is expected to be Rare, the severity of the radiological consequence is Negligible, and the risk ranking for the event is R0 [14-3].
For the ECM dropped load DBA event involving a high dose rate waste package (>2 mSv/hour near contact or >0.1 mSv/h at 1 m), the frequency is expected to be Rare, the severity of the radiological consequence is Moderate, and the risk ranking for the event is R1 [14-3].

14.4.2.2 Unintended Contents (B.2.2)

Unintended or unanticipated contents in the waste placed in the ECM could result in a potential increase in radioactivity in the leachate and potential radiological consequence to the worker. The radionuclide activity concentration in the leachate could increase. An increase in the tritium activity concentration in the leachate may impact the WWTP operation since tritium cannot be removed from the treated wastewater.
The estimated tritium activity concentration in the wastewater from the Equalization Tanks is 1.40E+05 Bq/L [14-17] and the tritium effluent discharge target is 2.3E+05 Bq/L [14-29]. Operations staff monitor and report the tritium activity concentration of the leachate at the CWPS, and the wastewater in the Equalization Tanks and the WWTP process tanks. The tritium activity concentrations are reviewed daily by the Facility Supervisor and WWTP operations staff. The tritium activity concentration in the wastewater entering the WWTP shall meet the tritium effluent discharge target of 2.3E+05 Bq/L.
The workers are protected by work controls, PPE&C and radiation monitoring during the waste receiving / inspection and waste placement and waste compaction. The workers are required

to wear a PAD and the PPE&C as documented on the Radiological WP or WP. The PPE&C may include respiratory protection. The PAD records the overall dose, dose rates and provides audible notification if the permitted dose rate is being exceeded. Radiation Protection provides oversight and surveillance for the waste receiving and inspection activity.
For the ECM unintended contents DBA event, the frequency is expected to be Rare, the severity of the radiological consequence is Minor, and the risk ranking for the event is R0 [14-3].

14.4.2.3 Impact/Collision (B.2.3)

Vehicle impact/collision is a DBA that may occur due to mechanical failure of the vehicle and could result in the following radiological and associated hazards consequences:

- Potential spread of contamination.
- Damage to vehicles and the potential for a vehicle falling into the disposal cell.
- Damage to ECM structures and covers.
- Potential vehicle fire with waste in the vehicle catching on fire and release to the environment.

Vehicles travelling in the NSDF are required to operate at the appropriate speed limit, which is anticipated to reduce the severity of the damage consequence in the event of vehicle impact. The damage as result of vehicle impact will be negligible. Human errors including misjudging vehicle speed, distracted driving, and or lack of vehicle maintenance may lead to a vehicle collision. Vehicle maintenance will reduce the frequency of mechanical failure.

Wheel chocks will be used under the tires of vehicles that are loaded with waste and the driver is not in the vehicle (i.e. driver is removing the tarp covering the waste at the off-loading ramp). The wheel chocks will prevent the vehicle from rolling, and this will prevent an unattended vehicle from rolling/falling into the disposal cell.

Heavy equipment vehicles and trucks powered by hydrocarbon fuels are potential sources of flammable materials. Generally, diesel and gasoline fuel tanks on heavy equipment vehicles and trucks are located on the side and are shielded with a steel plate. Due to these types of fuel tank configurations, the fuel tanks are not easily accessible to result in a breach of their integrity in a collision with other vehicles or structures within the Facility. Furthermore, the maximum speed attainable by a heavy equipment vehicle is limited by speed limit restrictions such that an impact is not anticipated to lead to a catastrophic fuel tank failure.

To mitigate the risk of an engine compartment fire, waste delivery vehicles and ECM heavy equipment used for waste placement and compaction, shall be provided with on-board fire suppression systems [14-56]. To control the spread and severity of fire and minimize operator injury, the on board extinguishing systems shall be certified to FM Global FM 5970 standards [14-56]. Systems meeting FM Global standards are deemed to be adequate control measures [14-56].

The controls and safeguards that are in place to prevent fires and or to limit the consequences of an ECM fire event, include CRL Fire Department, NSDF Fire Water Pump Station, vehicle/equipment maintenance, engine compartment fire suppression system on heavy equipment and portable fire extinguishers on the vehicles. Fire water is stored in the FWPS.

A vehicle collision resulting in a fire at the ECM is bounded by the TSWRPA fire event analyzed in Section 14.4.2.6.

For the ECM impact/collision DBA event, the frequency is expected to be Rare, the severity of the radiological consequence is Minor, the severity of the environmental consequence is Negligible, and the risk ranking for the event is R0 [14-3].

14.4.2.4 Damage to Structure (B.2.4)

The collapse or damage of the ECM waste structure due to settlement and displacement of placed wastes, could result in the loss of mound stability and potential damage to the final cover system. Damage to the final cover system may result in increased water infiltration and increased leachate generation.

The placed waste is compacted following procedures to meet the compaction requirements [14-57] to ensure stability of the mound. The waste is placed to maximize the wastes' in-place density and reduce the void space to minimize the potential for future waste settlement and to ensure seismic stability of the ECM [14-57]. Settlement of the waste is anticipated to occur primarily due to consolidation of the waste/cover soil and waste degradation [14-57]. The collapse or damage of the ECM waste structure will be identified during routine inspections. The damage will be assessed and actions would be taken to clean up and repair any identified damage.

Damage to ECM structures and components could occur during heavy equipment operations during construction or waste placement activities, due to mechanical failure of the heavy equipment resulting in the potential radiological consequences to the worker. The ECM structures and components that could be affected and damaged include: the side slope of the liners, base liner system, LCS, LDS, sacrificial liner, daily cover, interim cover, and final cover system. Damage to the side slope of the liners and the base liner system could result in the loss of containment and the potential release of contaminated leachate to the environment. Damage to the LCS may result in leachate being collected in the LDS. The LDS provides containment of the leachate in event of failure of the LCS, preventing leachate from being released to the environment. The LDS provides defence-in-depth for the leachate collection within the ECM. Damage to the sacrificial liner that are a component of the interim cover or are applied to the floor of inactive cells, may result in increased leachate generation and non-contact water becoming contaminated and managed as contact water. Damage to the interim covers and the final cover system may result in increased water infiltration into the waste and increased leachate generation. Any damage to the ECM structures and components would be repaired, therefore, consequences are expected to be negligible.

The collapse or damage of the off-loading ramp could lead to a potential vehicle roll over, resulting in the potential spread of contamination. The off-loading ramps are constructed with compacted gravel and are routinely inspected. The collapse or damage of the off-loading ramp will be identified during routine inspections. The damage will be assessed and actions would be taken to clean up and repair any identified damage. The off-loading ramp with identified damage will not be used until the damage is repaired.

For the ECM damage to structure DBA event, the frequency is expected to be Rare, the severity of the radiological consequence is Minor, and the risk ranking for the event is R0 [14-3].

14.4.2.5 Misdirected Flow (B.2.5)

Misdirected flow of contact water to the surface water management system, is a DBA that could occur due to human error resulting in a release to the environment.

The contact water is transferred from the ECM to the Equalization Tanks via the CWPS #1. The contact water source term is assumed to have no radiological contamination [14-50], however at a minimum, the contact water will be contaminated with tritium, likely less than the tritium effluent target value, 2.3E+05 Bq/L.

Separate lines and pumps are used to transfer the contact water and the non-contact water. The non-contact water from active/inactive cells is collected within the ECM in the non-contact water pond and is pumped after the rainfall event, to the perimeter surface water ditches, which convey the water to the SWMPs.

Human error could result in the contact water being pumped to the perimeter surface water ditches and into the SWMPs, resulting in a release to the environment. To mitigate human error associated with transferring contact water and non-contact water from the ECM, the workers will use a contact/non-contact water transfer checklist, and supervisory approval is required prior to any water transfer to the perimeter surface water ditches.

For the misdirected flow of contact water DBA, the frequency of this event is expected to be Rare, the severity of the environmental consequence is Moderate, and the risk ranking is R1 [14-4].

14.4.2.6 Internal Fire (B.2.6)

An internal fire at the ECM is a DBA resulting in radiological consequences to on-site and off-site receptors, and release to the environment. An internal fire within the ECM could be initiated by the wildland fire, lightning, vehicle fire or equipment electrical failure resulting in the ignition of combustible materials.

A vehicle fire may result from a vehicle accident or mechanical failure of the vehicle. The maximum speed attainable by vehicles at the NSDF is limited by speed limit restrictions such that a vehicle impact is not anticipated to lead to a severe accident. Vehicle maintenance will reduce the frequency of mechanical failure.

Combustible bulk waste (wood) makes up approximately 11% of the overall volume, in addition to the regular mixed stream of wood and bulk waste. A purely wood stream cannot be placed in the mound as one monolith and must be mixed with other bulk waste prior to placing and grouting within the disposal cell [14-56].

The controls and safeguards that are in place to prevent fires and or to limit the consequences of an ECM fire event include CRL Fire Department, NSDF FWPS, vehicle/equipment maintenance, engine compartment fire suppression system on waste delivery vehicles and ECM heavy equipment used for waste placement and compaction, and portable fire extinguishers on the vehicles. Fire water is stored in the FWPS.

To mitigate the risk of an engine compartment fire, waste delivery vehicles and ECM construction vehicles shall be provided with on-board fire suppression systems [14-56]. To control the spread and severity of fire and minimize operator injury, the on board extinguishing systems shall be certified to FM Global FM 5970 standards [14-56]. Systems meeting FM Global standards are deemed to be adequate control measures [14-56].

In the event of a fire, work will be immediately stopped and placed into a safe state, if possible. The NSDF Emergency Procedure will be followed. The Fire Department will be notified as well as others working in the area. If an equipment fire were to occur, the potential consequences could be worker injury, burns and equipment damage.

The radiological consequences to the on-site and off-site receptors for a TSWRPA fire involving bulk and packaged waste was analyzed and the detailed analysis is presented in Appendix G.

A fire occurring at the ECM TSWRPA, affects 800 m^3 of contaminated bulk waste and packaged waste. No uncontained waste is stored in the TSWRPA. This limits the amount of waste, which is readily available as fuel for a fire. All waste is either in its transportation container or disposal container, or covered with daily cover. The affected waste volume represents approximately 0.08% of the total inventory of bulk and packaged waste to be placed in the ECM. This fire results in the atmospheric dispersion of radioactive contaminants from the waste burning.

The radiological consequences of a fire in the TSWRPA are limited to the radiological source term stored in the TSWRPA. The radiological consequences to the on-site receptors located at the NSDF and Building 700 are 2.4 mSv and 5.2E-02 mSv, respectively.

The radiological consequence to the off-site receptors located at the cottage location, 3 km away are 2.1E-02 mSv for the adult receptor and 1.4E-02 mSv for the infant, 1 year old child. The primary radionuclide contributing to the inhalation radiological consequence is Co-60.

For the TSWRPA fire scenario, the radiological consequences to the on-site and the off-site receptors meets the DBA dose acceptance criteria as defined in Table 3-4. The DBA dose acceptance criteria in Table 3-4 is 5 mSv to 50 mSv for the on-site receptor, and 0.5 mSv to 20 mSv for the off-site public.

For the ECM internal fire DBA, the frequency of this event is expected to be Rare, the severity of the environmental consequence is Negligible, the severity of the radiological consequence is

Minor, and the risk ranking is R0 [14-3].

14.4.3 Waste Water Treatment Plant (B.3)

The WWTP DBA include containment failure, dropped load, unintended contents, vehicle collision, internal fire and radiation.

14.4.3.1 Containment Failure (B.3.1)

Containment failure at the WWTP includes the following events pressure boundary failure, and IX resin spill. These DBA are discussed in Section 14.4.3.1.1 – Section 14.4.3.1.2.

Loss of the fumehood due to mechanical failure resulting in the potential radiological consequences to the worker is also containment failure. Upon loss of the fumehood flow, the fumehood low flow alarm will provide notification to the workers using the fumehood, and the workers will leave the area.

14.4.3.1.1 Pressure Boundary Failure

Mechanical failure of the WWTP tanks, piping and/or valves could result in a spill of wastewater in the WWTP. The membrane filter system has an operating pressure of 100 psig and a design pressure of 125 psig. The radiological consequence to the on-site receptor, WWTP worker, for a WWTP pressure boundary failure was analyzed and the detailed analysis is presented in Appendix H.

The pressure boundary DBA is assumed to affect the membrane filter feed tanks, membrane filter process tanks and as associated piping resulting in a spill of 96 000 L of wastewater with a small amount of water becoming suspended in air following the free-fall spill. The spilled wastewater is confined to the main treatment area of the WWTP and the wastewater does not drain into the active drain system. The WWTP worker remains in the area for 10 minutes during an attempt to mitigate the situation.

The radiological consequence to the worker in the WWTP was calculated based on external exposure to radiation from the spilled wastewater, calculated using MicroShield, and inhalation exposure to airborne contaminants. The radiological consequence to the on-site receptor, WWTP worker, is calculated to be 7.6E-05 mSv, which meets the DBA dose acceptance criteria of 5 mSv to 50 mSv for the on-site receptor, as defined in Table 3-4.

For the WWTP pressure boundary containment failure DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequence is Negligible, and the risk ranking is R0 [14-3].

14.4.3.1.2 Ion Exchange Resin Spill

An IX resin spill may occur during the replacement or the transfer of spent resins. A bounding scenario is analyzed for a potential spill of contaminated IX resins and subsequent worker exposure. The radiological consequence to the on-site receptor, WWTP worker, for an IX resin spill was analyzed and the detailed analysis is presented in Appendix I.

The event involves a pressure buildup in the IX vessel containing the SAC resin, with a simultaneous failure of pressure relief components. The feed pump continues to operate without "deadhead". Consequently a pipe fitting fails, leading to the spill of free water and spent SAC resin to the WWTP floor. The spilled SAC resin has reached exhaustion; this equates to 712 bed volumes to exhaustion (approximately 59 days of wastewater treatment) [14-17]. The worker is assumed to remain in the area at a distance of 30 cm away from the spill for 10 minutes during an attempt to mitigate the situation. Given the uncertainty of the exposure duration, the analysis also includes a sensitivity calculation for an exposure duration of 1 hour.

Table 14-23 shows the radiological consequence to the WWTP worker for the spill of spent SAC resin is 5.2E-03 mSv for a 10 minute exposure and 3.1E-02 mSv for a 60 minute exposure. The radiological consequence to WWTP worker meets the DBA dose acceptance criteria of 5 mSv to 50 mSv for the on-site receptor, as defined in Table 3-4.

For the WWTP IX resin spill DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequence is Negligible, and the risk ranking is R0 [14-3].

Table 14-23
Radiological Consequence to the Worker from Failure of the Ion Exchange System

Exposure Pathway	Radiological Consequence (mSv)	
	10 min exposure	1 hour exposure
External (at 30 cm)	5.2E-03	3.1E-02
Inhalation of re-suspended radionuclides	3.8E-05	2.3E-04
Inhalation of water droplets	1.2E-07	7.2E-07
Inhalation of evaporated tritium	8.6E-07	3.1E-05
TOTAL	5.2E-03	3.1E-02

14.4.3.2 Dropped Load (B.3.2)

Mechanical failure of the waste handling equipment (i.e. crane or forklift), could lead to a dropped load, resulting in the radiological consequences: the spread of contamination, and the potential radiological consequence to the on-site receptor, worker. Equipment maintenance can mitigate the mechanical failure of the waste handling equipment.

The dropped load of the filter cake dewatered residuals bin was analyzed as an AOO in Section 14.3.4.3 and Appendix J. The estimated radiological consequence to the WWTP worker due to the dropped load of the filter cake dewatered residuals bin, as a result of mechanical failure, is the same as the radiological consequence to the WWTP worker as a result of human error.

The radiological consequence to the WWTP worker is calculated based on the exposure pathways: external radiation and inhalation of a small portion of re-suspended residuals. The calculated radiological consequences, are summarized in Table 14-22, including the exposure durations of 10 minutes and 1 hour. The radiological consequence to the WWTP worker is 7.4E-03 mSv for a 10 minute exposure and 4.4E-02 mSv for a 60 minute exposure. The radiological consequence to the WWTP worker meets the DBA dose acceptance criteria of 5 mSv – 50 mSv for the on-site receptor, as defined in Table 3-4.

For the WWTP dropped load DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequence is Negligible, and the risk ranking is R0 [14-3].

14.4.3.3 Unintended Contents (B.3.3)

Unintended or unanticipated contents in the waste placed in the ECM could result in a potential increase in radioactivity in the leachate and wastewater. The radionuclide activity concentration in the leachate and wastewater could increase. An increase in the tritium activity concentration in the leachate may impact the WWTP operation since tritium cannot be removed from the treated wastewater.

The estimated tritium activity concentration in the wastewater from the Equalization Tanks is 1.40E+05 Bq/L [14-17] and the tritium effluent discharge target is 2.3E+05 Bq/L [14-29]. Operations staff monitor and report the tritium activity concentration of the leachate at the CWPS, and the wastewater in the Equalization Tanks and the WWTP process tanks. The tritium activity concentrations are reviewed daily by the Facility Supervisor and WWTP operations staff. The tritium activity concentration in the wastewater entering the WWTP shall meet the tritium effluent discharge target of 2.3E+05 Bq/L.

For the WWTP unintended contents DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequence is Negligible, and the risk ranking is R0 [14-3].

14.4.3.4 Impact/Collision (B.3.4)

A vehicle impact/collision DBA due to mechanical failure of the vehicle could damage structures, resulting in damage to the Equalization Tanks’ secondary containment or leachate extraction box. Bollards will provide impact protection to these structures.

Vehicles travelling in the NSDF are required to operate at the appropriate speed limit, which is anticipated to reduce the severity of the damage consequence in the event of vehicle impact. The damage as result of vehicle impact will be negligible. Vehicle maintenance can mitigate the vehicle mechanical failure.

For the WWTP impact/collision DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequence is Negligible, and the risk ranking is R0 [14-3].

14.4.3.5 Internal Fire (B.3.5)

A fire in the WWTP processing area could be initiated due to flammable gas release, activated carbon dust release, mechanical failure of natural gas piping, spontaneous combustion from chemical reaction, vehicle fire or electrical fire resulting in release to the environment, and potential radiological consequences to the on-site and off-site receptors.

During the transfer of GAC from the storage container into an empty IX vessel (via vacuum pump), a transfer hose could rupture resulting in GAC and GAC dust being released into the WWTP. For the GAC to be a fire hazard, at the Lower Explosive Limit of 55 g/m^3 for carbon dust in air, over 30% of the mass required to fill the IX vessel would have to be released as an airborne dust into the Residue Management Area [14-56]. In addition, the building ventilation air exchange rate will also mitigate the carbon dust fire. The WWTP workers shall confirm ventilation systems are functioning before commencing the transfer of GAC into the IX vessel [14-56].

An internal natural gas pipe could rupture due to mechanical failure leaking natural gas into the building. The natural gas system at the WWTP has an automatic “slam shut” valve downstream of the WWTP natural gas regulator, which mitigates an explosion hazard due to leaking natural gas. In addition to mitigate failure of the natural gas system, all natural gas piping is installed, tested and maintained in accordance with NBCC, NFCC and CSA B149 Natural Gas and Propane Code.

The controls and safeguards that are in place to prevent fires and or to limit the consequences of a WWTP fire event include WWTP fire detection system, CRL Fire Department, NSDF FWPS, vehicle/equipment maintenance and portable fire extinguishers on the vehicles. The installed fire detection systems shall be operational. To minimize the spread of fire and the consequences that arise from an uncontrolled fire, the WWTP has been separated into fire compartments. Penetrations through fire rated compartment walls and floors are compliant with NBCC [14-47] through the use of CAN/ULC-S115 listed fire stop assemblies and fire dampers. Fire water for fighting fires is stored in the FWPS.

In the event of a fire, work will be immediately stopped and placed into a safe state, if possible. The NSDF Emergency Procedure will be followed. The Fire Department will be notified as well as others working in the area. If an equipment fire were to occur, the consequences could be worker injury, burns and equipment damage.

The radiological consequence to the on-site and off-site receptors for an internal fire in the Residuals Management Area was analyzed and the detailed analysis is presented in Appendix K. The internal fire event in the Residuals Management Area involves the IX resins, GAC and filter press residuals. The fire is sustained long enough to dry out all contaminated solids (i.e. resins and filter press cake), resulting in airborne contamination and release to the environment. The WWTP workers are assumed to have evacuated the Facility and the on-site receptor is located near CRL Building 700, approximately 1 km away. The off-site receptor is a cottager located approximately 3 km away. The primary exposure pathway to the receptors is inhalation. The estimated radiological consequence to the on-site receptor is 5.6E-07 mSv. The estimated radiological consequences to the adult and the 1 year old child off-site receptors are 2.4E-07 mSv and 1.5E-07 mSv, respectively. The estimated radiological consequences to the on-site and off-site receptors meet the DBA dose acceptance criteria of 5 mSv - 50 mSv for on-site receptors and 0.5 mSv – 20 mSv for off-site receptors, as defined in Table 3-4.

For the WWTP internal fire DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequence is Negligible, the severity of the environmental consequence is Minor, and the risk ranking is R0 [14-3].

14.4.3.6 Radiation (B.3.6)

Higher than anticipated radiation fields in the WWTP could occur due to higher than anticipated radioactivity in the influent wastewater from the Equalization Tanks, and in the residuals in the residuals management area.

The radionuclide activity concentration in the wastewater could increase due to a higher failure rate for waste packages. The estimated wastewater and leachate activity concentrations documented in [14-17] were derived based on the assumption that the waste package failure rate is 5% immediate failure during waste compaction and 1% failure per year due to corrosion [14-50]. Unintended or unanticipated contents in the waste placed in the ECM could result in a potential increase in radioactivity in the leachate and wastewater. The primary gamma emitting radionuclide contributing to the wastewater radiation field is Co-60. An increase in the Co-60 activity concentration in wastewater, higher than the estimated influent Co-60 activity concentration of 1.3E+03 Bq/L [14-17], will be treated by the WWTP processes. The estimated Co-60 efficiency removal by the membrane filter and the SAC resin are 70.8% and 95%, respectively [14-17]. An increase in the Co-60 activity concentration in wastewater will result in increased radiation fields associated with the SAC resin vessel, Residuals Storage Tank, Filter Press Feed Tank and the filter press dewatered residuals bin.

The primary safeguards in place to mitigate the radiation hazard are barriers and RP oversight/surveillance. The WWTP workers are protected by work controls, PPE&C and radiation monitoring of the WWTP processes during the operation. The WWTP workers are required to wear a PAD and the PPE&C as documented on the WP. The PPE&C may include respiratory protection. The PAD records the overall dose, dose rates and provides audible notification if the permitted dose rate is being exceeded.

For the WWTP radiation DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequence is Minor, and the risk ranking is R0 [14-3].

14.4.4 Vehicle Decontamination Facility (B.4)

The DBA in the VDF is an internal fire.

14.4.4.1 Internal Fire (B.4.1)

An internal fire at the VDF could be initiated due to a vehicle or electrical fire, resulting in a release to the environment and potential radiological consequence to the on-site and off-site receptors.

The controls and safeguards that are in place to prevent fires and or to limit the consequences of a VDF fire event include the VDF fire detection system, CRL Fire Department, NSDF Fire Water Pump Station, vehicle/equipment maintenance and portable fire extinguishers in the VDF and on the vehicles. Fire water is stored in the Fire Water Pump Station.

In the event of a fire, work will be immediately stopped and placed into a safe state, if possible. The NSDF Emergency Procedure will be followed. The Fire Department will be notified as well as others working in the area. If an equipment fire were to occur, the potential consequences could be worker injury, burns and equipment damage.

The estimated radiological consequence to the on-site and off-site receptors due to an internal fire in the VDF, are bounded by the radiological consequence from the WWTP Residual Management Area fire presented in Section 14.4.3.5.

For the VDF internal fire DBA, the frequency of this event is expected to be Rare, the severity of the radiological consequence is Negligible, and the risk ranking is R0 [14-3].

14.5 Beyond Design Basis Accidents (Group C)

A selected BDBA is very unlikely to occur over the lifetime of the Facility, and is an accident less frequent and potentially more severe than a DBA. The frequency range for the selected BDBAs is 10^{-6} to 10^{-5}, and the selected BDBAs assessed include:

- External events: seismic activity, flooding, and tornado; and
- Human-induced external events: aircraft crash.

The BDBAs generally involves a large scale external event that results in the Facility being affected, extended loss of Class IV Power and impeded access to the Facility. Beyond design basis accidents have a further subset of events known as DECs, which is defined in REGDOC-2.5.2, Design of Reactor Facilities: Nuclear Power Plants [14-6], included in IAEA SSR 2/1 [14-62], and is incorporated in the CSA standards, N290.16 Requirements for Beyond Design Basis Accidents [14-63], and N292.0 General Principles for the Management of Radioactive Waste and Irradiated Fuel [14-64]. The term reflects that the subset of BDBAs are considered by a design, but do not form part of the Design Basis. The term, DEC, is frequently applied to Reactor Facilities and considers events that may or may not result in significant fuel failure. The NSDF Project has used a graded approach in the application of DECs, and has qualitatively assessed the impact of DEC events. Design extension conditions are considered credible abnormal events in the CSA N290.0-19, General Principles for the Management of Radioactive Waste and Irradiated Fuel [14-64].

The NSDF hazard identification identified the following BDBAs events identified as Group C in Section 14.1.4: seismic activity, flooding, tornado, and aircraft crash. The following sections will assess these events and determine if the BDBA fall within the definition of DEC, and if determined to be a DEC, a qualitative analysis will be performed.

14.5.1 Seismic Activity (C.1)

Seismic activity BDBA may result in structural damage to the buildings, engineered structures and displacement of wastes. In addition, seismic activity BDBA may result in damage to the natural gas system. Natural gas is used as a fuel for heating the building and powering the generator supplying Class III Power.

The ECM perimeter berm is designed to withstand a 1 in 10 000 year earthquake. Seismic activity BDBA may result in structural damage to the ECM engineered structures, liquefaction below the perimeter berm, and displacement of wastes.

The base liner system including the LCS and LDS, could be damaged, resulting in loss of containment and a potential release to the environment. The interim cover and final cover system could be damaged resulting in the spread of contamination and radiological consequences to on-site and off-site receptors. Liquefaction below the perimeter berm could occur resulting in damage to the perimeter berm, damage to the primary and secondary liners, strain on the geomembranes and potential strain on the geomembrane and the GCL near the top slope of the perimeter berm. The placed waste within the disposal cells could be displaced and the structural stability of the mound compromised, resulting in the spread of contamination and radiological consequences to on-site and off-site receptors.

Damage to the WWTP could cause the collapse of the building, the loss of containment of wastewater, fire within the building, resulting in release to the environment and radiological consequences to on-site and off-site receptors.

Seismic activity BDBA, may result in damage to the Equalization Tanks and associated piping, and damage to the Equalization Tanks' secondary containment, resulting in a release to the environment.

The BDBA may result in containment failure, spread of contamination and release to the environment, which will produce radiological hazards for on-site workers. After a seismic BDBA, access controls would be used to mitigate on-site worker exposure and an assessment will be completed to determine the remediation methodology for managing the damaged buildings, damaged ECM engineered structures and displaced wastes. The exposure rate for a worker carrying out these activities is expected to be comparable to those from normal waste handling activities.

14.5.2 Flooding (C.2)

A flooding BDBA could occur in the event of catastrophic dam(s) failure upstream of the Ottawa River and precipitation events.

The Design Basis Flood level at CRL for both precipitation events and for complex events involving random (or seismically related) failure of both the upstream dams (and of the control works at the exit from Lake Temiskaming), is 122 mASL including a 2 m safety margin [14-61]. The post 1945 highest and lowest recorded levels of the Ottawa River at the CRL site are 113.6 mASL in 1979 April and 110.6 mASL in 1971 August, respectively [14-61].

If a historically abnormal flood occurred and the Ottawa River rose above 115 mASL, the CRL site would begin to be surrounded by water on all sides and become more cut off from Chalk River and the surrounding communities if the river continued to rise past 115 mASL to 117 mASL and beyond [14-61].

The lowest elevation of the ECM is 163 mASL, which is 41 m above the BDBA maximum flood elevation of 122 mASL. The ECM and the NSDF will not be affected by a BDBA flood event due to dam failure and precipitation but access to the Facility may be impeded.

The ECM and Equalization Tanks storage capacity are designed for the DBA precipitation event of two 100-year storm events occurring back-to-back. Precipitation events exceeding this DBA precipitation event are unlikely during the operations period. During the closure period, a severe BDBA precipitation event may result in erosion of the ECM final cover, water infiltration into the closed disposal cells, and water ingress into the buildings awaiting decommissioning.

14.5.3 Tornado (C.3)

A tornado BDBA could result in displacement of wastes and extensive damage to the NSDF Buildings, Equalization Tanks, and ECM engineered structures.

Tornados are always associated with thunderstorms, so structural damage due to high winds and missiles will be associated with the potential of rain water ingress to the buildings or structures. There is a high risk for the spread of contamination, and the release to the environment due to damaged ECM engineered structures, damaged WWTP, damaged Equalization Tanks, and the displacement of wastes.

After a tornado BDBA, access controls will be used to mitigate on-site receptor, worker, exposure and an assessment will be completed to determine the extent of contamination and the remediation methodology for managing the damaged buildings, damaged ECM engineered structures and displaced wastes. The exposure rate for the on-site receptor, worker, carrying out these activities is expected to be comparable to those from normal waste handling activities.

14.5.4 Aircraft Crash (C.4)

An aircraft crash BDBA could result in displacement of wastes and extensive damage to the NSDF Buildings, Equalization Tanks, and ECM engineered structures. There is a high risk for the spread of contamination and the release to the environment due to damaged ECM engineered structures, damaged WWTP, damaged Equalization Tanks and the displacement of wastes. After an aircraft crash BDBA, access controls will be used to mitigate on-site worker exposure and an assessment will be completed to determine the extent of contamination and the remediation methodology for managing the impact.

A general description of the aircraft crash hazard at CRL is provided in the CRL Site Characteristics report [14-61].

The total footprint of the ECM is approximately 317 m x 347 m, or 110 000 m^2 area and the height is approximately 15 m. The estimated frequency of aircraft crashes at the ECM is calculated based on this area and the methodology in Accident Analysis for Aircraft Crash into Hazardous Facilities [14-65]. The estimated frequency of an aircraft crash into the ECM is 1.35E-07 per year. The frequency for an aircraft to crash into the ECM has been assessed in Appendix L.

An aircraft crash at the ECM is considered to be not a credible event, based on the estimated frequency being less than 10^{-6}, which aligns with the credible event terminology in REGDOC-2.4.1 [14-66]. This low frequency reflects the low level of air traffic near the site and the location of the ECM away from the immediate vicinity of airfields and helicopter pads.

14.5.5 Design Extension Conditions

The BDBAs that are considered to be DECs are:

- Seismic activity (C.1).
- Flooding (C.2).
- Tornado (C.3).

The assessed selected BDBAs, external events, align with the IAEA's [14-67] DECs terminology, and can be considered to meet the intent of DECs. The IAEA [14-67] defines DECs as: postulated accident conditions that are not considered for DBA, but that are considered in the design process of the Facility in accordance with best estimate methodology, and for which releases of radioactive material are kept within acceptable limits.

In addition, the selected BDBAs assessed: seismic activity, flooding, and tornado, are considered to be not practically eliminated conditions and therefore, can be considered as design extension. The selected BDBAs generally involve a large scale external event that results in the Facility being affected, extended loss of Class IV Power and impeded access to the Facility. After a BDBA, access controls would be used to mitigate on-site worker exposure and an assessment will be completed to determine the remediation methodology for managing the damaged buildings, damaged ECM engineered structures and displaced wastes. The mitigation measures for the assessed selected BDBAs (design extension conditions), is the initiation of emergency response procedures and processes. The assessed selected BDBAs are to be used for emergency response planning.

The qualitative analysis presented for the DECs, seismic activity, flooding and tornado, demonstrates that implementing emergency response protocols and access controls following the DEC event would:

- Provide protection to the public and the environment
- Be sufficient to manage any on-site receptor (worker) radiological consequences and that any remediation activities will result in operational radiological consequences similar to those experienced during normal operations.

This graded approach is used, since unlike nuclear power plants where a DEC has the potential to result in fuel failure and significant off-site releases, the DEC events for the NSDF do not present such a significant release due to the nature of the waste material within NSDF being LLW.

14.6 Conclusions

The safety analysis demonstrates that the estimated radiological consequences to the on-site and off-site receptors from the NSDF under normal operations and accident conditions, meet the effective and equivalent dose limits in Table 3-1, the CNL RP action levels in Table 3-2, and the dose acceptance criteria for accidents documented in Table 3-4, and that the NSDF does not pose an unreasonable risk for the public, workers and the environment.

The estimated radiological consequences to the on-site receptor, worker, during normal operations meet the effective dose limits documented in Table 3-1 and the CNL RP action levels in Table 3-2. The highest estimated radiological consequences to the on-site receptor, worker, is 1.3 mSv/4 week period and 10.4 mSv/y, which meets the CNL effective dose action levels of 6 mSv/4 weeks, and 20 mSv/y, presented in Table 3-2.

Table 14-24 presents the summary of the estimated radiological consequences to the on-site receptors, workers, and the off-site receptors, public, as a result of AOOs and DBAs.

The estimated radiological consequences to on-site receptors and off-site receptors from AOOs meet the dose acceptance criteria for accidents presented in Table 3-4. The AOO dose acceptance criteria for the on-site and off-site receptors are < 5 mSv per event and < 0.5 mSv per event, respectively.

The estimated radiological consequences to on-site receptors and off-site receptors from DBAs meet the dose acceptance criteria for accidents presented in Table 3-4. The DBA dose acceptance criteria for the on-site and off-site receptors are 5 mSv – 50 mSv per event and 0.5 mSv – 20 mSv per event, respectively.

The safety analysis of the NSDF was performed to assess the hazards and initiating events during normal operation and accident conditions. Scenarios of the potential credible initiating events and accidents occurring at the NSDF have been postulated and the consequences evaluated. The potential hazards and initiating events associated with the activities conducted in the NSDF have been systematically identified in [14-2], [14-3], [14-4], and [14-5]. The safety analysis addressed the risks to workers, the public and the environment.

Hazards during normal operation, AOOs, DBAs, and BDBAs including DECs, were evaluated and meet the dose acceptance criteria. The AOO, DBA and BDBA including DEC scenarios were analyzed using either qualitative or quantitative analysis. The consequences of the AOO, DBA, and BDBA including DEC analyzed, meet the safety targets and goals identified in Section 3. Additionally, all of the safety objectives and regulatory requirements identified in Section 3 have been satisfied.

The following controls and processes provide layers of protection and defence-in-depth that reduce the risk at the NSDF to the workers and reduce the risk/impact to the environment and the public:

- Containment of waste.
- Administrative controls – operating procedures, training, work control, and assessments.
- Facility inspections.
- Radiation Protection Program.
- Ground Water Monitoring Program.
- Environmental monitoring – air and surface water.

Overall, routine safety considerations and the layers of protection available for managing the identified hazards, initiating events and accidents provide confidence that the NSDF can be operated safely without exposing Facility Staff, associated staff, CRL on-site personnel, the public and the environment to unreasonable risk. The safety analysis demonstrates that waste containment is maintained for the duration of the Facility operation under normal operating conditions.

The overall safety objective for the NSDF is to protect individuals, society and the environment by establishing and maintaining an effective defence against radiological and non-radiological (chemical, conventional) hazards. This safety analysis demonstrates that the overall safety objective for the NSDF has been satisfied, and demonstrates that the design, controls and processes are adequate for the radiological protection of workers, the public and the environment.

Radioactive waste management system performance under normal operating conditions shall be assessed to maintain waste containment for the duration of the Facility operation [14-68]. The NSDF design and operation will provide containment during the operations phase through preventing and controlling the release of nuclear and/or hazardous substances. The NSDF Project has considered measures to contain and isolate waste during waste placement specifically to minimize/prevent contact water and radionuclide migration. The principles of isolation and containment are satisfied in the inventory management, design features and planned operational practices.

Table 14-24
Summary of Accident Estimated Radiological Consequences to the Receptors

Event Grouping and Description		Estimated Radiological Consequences		Section
Grouping	**Event Description**	**On-site Receptor**	**Off-site Receptor**	
Anticipated Operational Occurrences				
A.3.2	Dropped load at the ECM during waste package placement or handling.	4.0E-02 mSv - NSDF worker	NA	14.3.3.2
A.4.2	Contamination - WWTP worker could be splashed during the sampling of the process tanks.	3.0E-04 mGy/h (3.0E-04 mSv/h) - NSDF worker	NA	14.3.4.2.1
A.4.3	Dropped load at the WWTP involving the filter press dewatered residuals bin.	7.4E-03 mSv for a 10 minute exposure, and 4.4E-02 mSv for a 60 minute exposure - NSDF worker	NA	14.3.4.3
Design Basis Accidents				
B.2.1	Dropped load at the ECM during waste package placement or handling.	4.0E-02 mSv – NSDF worker	NA	14.4.2.1
B.2.6	An internal fire at the ECM TSWRPA.	2.4 mSv – NSDF worker 5.2E-02 mSv – at Building 700	2.1E-02 mSv – adult 1.4E-02 mSv - 1 year old child	14.4.2.6
B.3.1	Mechanical failure of the WWTP tanks, piping and/or valves could result in a spill of wastewater.	7.6E-05 mSv – WWTP worker	NA	14.4.3.1.1
B.3.1	An IX resin spill may occur during replacement or transfer of spent resins.	5.2E-03 mSv for a 10 minute exposure and 3.1E-02 mSv for a 60 minute exposure - NSDF worker.	NA	14.4.3.1.2
B.3.2	Dropped load at the WWTP involving the filter press dewatered residuals bin.	7.4E-03 mSv for a 10 minute exposure, and 4.4E-02 mSv for a 60 minute exposure - NSDF worker.	NA	14.4.3.2
B.3.5	An internal fire in the WWTP Residuals Management Area.	5.6E-07 mSv	2.4E-07 mSv – adult 1.5E-07 mSv – 1 year old child	14.4.3.5

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[14-68] CSA Group, *General Principles for the Management of Radioactive Waste and Irradiated Fuel*, CSA N292.0-14, 2014 May.

15. NEAR SURFACE DISPOSAL FACILITY OPERATIONAL LIMITS AND CONDITIONS

The OLCs have been derived following Preparation of Operational Limits and Conditions [15-1]. An OLC provides the linkage between safety-significant parameters and associated operational parameters that must be adhered to, and adherence to OLCs ensures that the Safe Operating Envelope is maintained [15-1]. In addition, adherence to the OLCs will ensure that the Facility, Facility staff, other on-site personnel, members of the public (off-site), and the environment are not exposed to unreasonable levels of risk.

15.1 Safety Limits

The following safety limit for the safe operation of the NSDF is:

1. The ECM radiological inventory at closure shall not exceed the specific radionuclide activity (Bq) limits in the Licensed Inventory at closure, Table 15-1. (The Limiting Condition of Operations (LCO) basis is documented in Section 6.9.8).

Table 15-1
Near Surface Disposal Facility ECM Licensed Inventory at Closure

Radionuclide	Maximum Activity (Bq) at Closure
Ag-108m	2.62E+10
Am-241	9.74E+10
Am-243	5.24E+07
C-14	1.70E+12
Cl-36	3.97E+09
Co-60	1.47E+16
Cs-135	5.19E+08
Cs-137	3.17E+12
H-3	2.79E+14
I-129	1.75E+10
Mo-93	1.47E+05
Nb-94	2.34E+10
Ni-59	1.21E+09
Ni-63	2.59E+11
Np-237	1.74E+07
Pu-239/240	5.06E+10
Pu-241	5.84E+11
Pu-242	6.32E+07
Ra-226	3.61E+10
Se-79	9.26E+07
Sn-126	1.24E+08
Sr-90	3.35E+12
Tc-99	3.16E+11
Th-230	5.30E+09

Th-232	2.70E+10
U-233	2.74E+08
U-234	6.88E+10
U-235	2.96E+09
U-238	7.57E+10
Zr-93	4.92E+11

15.1.1 Criticality

Quantities of SFM exist in residual, unrecoverable amounts, predominately as contaminants on waste equipment, demolished structures and in soil as a result of nuclear fuel cycle activities (e.g. operation of National Research Experimental, National Research Universal (NRU and other research and development activities) and must be limited in the NSDF to ensure nuclear criticality safety [15-2]. The following OLCs are criticality limiting conditions for the safe operation of the NSDF:

1. Operations with Fissionable Materials shall be carried out such that the following Upper Subcritical Limits are not exceeded, under both normal and credible abnormal conditions.
    - 80% of the minimum critical mass, or
    - $k_{eff} + 2\sigma \leq k_c - |\Delta k_c| - |\Delta k_m|$
      Where:
      k_C is the mean k_{eff}, which results from the calculation of benchmark criticality experiments. The difference between the experimentally measured value of k_{eff} and k_c is defined as bias.
      Δk_c is a margin for k_c bias and bias uncertainty.
      The bias (or k_c) and the Δk_c are the results of the validation process.
      Δk_m is the 50 mk administrative margin.
2. All operations involving Fissionable Materials shall comply with the limits and restrictions defined in the Summary of Fissionable Materials, Limits and Restrictions Section of the NSDF CSD [15-2].

15.2 Safety System Settings

1. Safety system setting, is the set-point for a parameter for which a safety system is automatically actuated in the event of AOOs or accident conditions, in order to prevent one or more safety limits from being exceeded [15-1].
2. There are no identified safety system settings.

15.3 Limiting Conditions for Safe Operation

The following LCOs are general limiting conditions for the safe operation of the NSDF Facilities:

1. The NSDF perimeter fence and posted warning signs shall be maintained with the gates locked when unattended, to resist intrusion by unauthorized personnel. (The LCO basis is documented in Section 9.1.)
2. The disposal of waste and waste operations shall be such that the dose rate at the NSDF perimeter fence shall not exceed 10 µSv/h, and the dose at Plant Road shall not exceed 0.5 µSv/h. (The LCO basis is documented in Section 4.3.1.1.)
3. The Facility is operated primarily on Class IV Power. Should a loss of Class IV Power occur, all waste handling activities that require electrically-operated systems important to safety shall be halted until Class IV Power has been restored. (The LCO basis is documented in Section 8.1.3, Section 8.1.4, and Section 14.3.2.1.)
4. Actuation of fixed radiation alarms, H_2S and CO alarms shall be investigated and actions taken as per established procedures, prior to allowing related operations to proceed. Operations shall be allowed to proceed only when the cause(s) are known and appropriate corrective actions have been taken. If causes cannot be determined or corrective actions cannot be completed promptly, normal operations shall not resume without remedial actions in place and authorization of the Facility Authority, after having determined that the resumption of normal operations will have no adverse effect on safety, radiological risk, the environment, or security. The authorization of the Facility Authority shall be documented. (The LCO basis is documented in Section 8.2.2.3, Section 8.2.5, and Section 11.2.)
5. The dose rate limits and the means of handling and transferring that shall be applied to the bulk and packaged waste at the NSDF are presented in Table 15-2. (The LCO basis is documented in Section 9.3.1.2 and Section 11.2.1.1)

Table 15-2
Dose Rate Limits and Means of Handling and Transferring

Radiation Type	Dose Rates	Means of Handling and Transferring
Total gamma and neutron	≤0.5 mSv/h near contact **and** ≤0.01 mSv/h at a distance of 1 metre.	Manual or mechanical means.
Total gamma and neutron	>0.5 mSv/h to ≤2 mSv/h near contact **and** >0.01 mSv/h to ≤0.1 mSv/h at a distance of 1 metre.	Mechanical means.
Total gamma and neutron	>2 mSv/h near contact **or** >0.1 mSv/h at a distance of 1 metre.	Handling and transferring is subject to RP Program controls, Infrequently Performed Operations [15-3] and assessment approval by the NSDF Facility Authority.
Beta	<10 mSv/h near contact	Based on total gamma and neutron dose rates.

15.3.1 Engineered Containment Mound

1. Except as authorized by the FA on a case-by-case basis, only wastes meeting the current WAC as defined in NSDF WAC [15-2] may be placed in the ECM. (The LCO basis is documented in Section 9.3.1 and Section 9.3.1.2.)
2. Acceptance of waste that is non-compliant with the requirements and limits of the current WAC as defined in the NSDF WAC [15-2], shall be authorized on a case by case basis by the FA, and shall not in any circumstances result in contravening the safety goals and design targets for normal operations or design targets for accidents as presented in Section 3. The FA authorization of the acceptance of non-compliant waste and the analysis to support that authorization shall be documented. The acceptance of non-compliant waste shall be documented in the Annual Compliance Report. (The LCO basis is documented in Section 9.3.1.5 and Section 14.3.3.2.1.)
3. All shipments of waste received shall be accompanied by a completed Waste Package Data Form and supporting documentation as required. (The LCO basis is documented in Section 9.3.1).
4. All waste packages received shall have a Waste or Package Identification label/sticker attached to the package. (The LCO basis is documented in Section 9.3.1.)
5. All waste shipping/transportation containers and waste packages received shall have a total maximum surface contamination on the outer surface, averaged over 300 cm^2, and must be less than 3.7 Bq/cm^2 beta/gamma emitters and less than 0.37 Bq/cm^2 alpha emitters. (The LCO basis is documented in Section 9.3.1.3, and Section 11.2.1.2.)
6. Only one cell shall be open for the placement and disposal of waste. An adjacent cell may be open for supporting activities: TSWRPA and contact water management. (The LCO basis is documented in Section 6.3 and Section 6.6)
7. Maximum open cell area is 15 000 m^2 plus 6 000 m^2 (area of TSWRPA). (The LCO basis is documented in Section 5.1.8 and Section 6.3)
8. The maximum volume of bulk and packaged waste stored in the TSWRPA shall be 800 m^3 and the maximum storage duration shall be one year. No uncontained waste is stored in the TSWRPA. All waste is either in its transportation container or disposal container, or covered with daily cover. The only processing that is performed is staging of waste or container preparation for grouting in the ECM. (The LCO basis is documented in Section 5.1.6, Section 6.3, Section 14.4.2.6 and Appendix G).
9. Waste packages identified with greater than 10% void space shall be grouted. (The LCO basis is documented in Section 6.6.2, Section 9.3.2 and Appendix A).
10. De-watered residuals generated by the WWTP shall be disposed of in the ECM. (The LCO basis is documented in Section 9.6.)
11. The location of wastes placed in the disposal cell and characteristic information about the waste, shall be recorded. (The LCO basis is documented in Section 9.3.2.)

12. Conditions to prevent and minimize contact water and leachate (for both placed waste and waste in temporary storage) include, but are not limited to:
    1) Daily cover is applied at the end of each work day over the active disposal area or the placed waste working face. (The LCO basis is documented in Section 9.3.2.)
    2) Interim cover is applied to: 1) waste disposal areas that will remain inactive for more than 30 days; and 2) waste disposal areas that have reached the design waste fill grade. The interim cover is used to promote non-contact surface water run-off. (The LCO basis is documented in Section 9.3.2.)
    3) The surface of each waste lift is graded at a minimum 2% slope to promote run-off and minimize infiltration of surface water into the waste. (The LCO basis is documented in Section 9.3.2.)
13. All Type 6 wastes shall be accepted through the Infrequently Performed Operations [15-3] process. (The LCO basis is documented in Section 6.11.3 and Section 9.3.1.5.)
14. All disused sources being considered for disposal at NSDF shall be evaluated through the Infrequently Performed Operations [15-3] process. (The LCO basis is documented in Section 9.3.1.5.)

15.3.2 Waste Water Treatment Plant

The following LCOs are specific limiting conditions for the safe operation of the WWTP:

1. The Building 1551 active ventilation and exhaust ventilation systems shall be operational when the associated room is occupied. Upon loss of the active ventilation and or exhaust ventilation systems, normal operations in the associated rooms shall be suspended until the active ventilation and exhaust ventilation systems are returned to service and operating within design parameters. (The LCO basis is documented in Section 8.2.3 and Section 8.2.3.1.)
2. Tank volume in the Equalization Tanks of 4 710 m^3 shall be available for the DBA, back-to-back 100 year storm event or AOO precipitation events. If this tank capacity cannot be maintained, the Facility shall develop a plan to restore capacity as soon as possible. (The LCO basis is documented in Section 5.2.1 and Section 6.1.3.1.)
3. The effluent released shall meet the NSDF Effluent Discharge Targets [15-5]. (The LCO basis is documented in Section 5.2.8.)
4. Filter press enclosure ventilation shall be 20 air changes per hour when occupied. (The LCO basis is documented in Section 8.2.3.1.)
5. Valves V-019, V-020, V-057, and V-058 on the bypass line are normally closed and shall be locked closed. The valves can be unlocked with Facility Manager or Facility Authority approval. (The LCO basis is documented in Section 14.3.4.1).
6. The WWTP shall only process wastewater generated by the NSDF. (The LCO basis is documented in Section 5.2.1.)

7. The Hydrogen Sulphide (H_2S) monitors and alarms shall be functional when the sulphuric acid lockable valve is unlocked and sodium sulphide is valved in. (The LCO basis is documented in Section 5.2.10, Section 8.2.2.3 and Section 14.2.6.)
8. In the event the WWTP was to experience a prolonged outage of greater than 30 days, placements of waste in the ECM would be halted and an interim cover would be installed over the open waste surfaces. (The LCO basis is documented in Section 6.3.)
9. The WWTP workers shall confirm active ventilation and exhaust ventilation systems are functioning before commencing the transfer of GAC into the IX vessel. (The LCO basis is documented in Section 14.4.3.5)
10. The tritium activity concentration in the wastewater entering the WWTP for processing shall meet the tritium effluent discharge target of 2.3E+05 Bq/L. (The LCO basis is documented in Section 14.4.2.2 and Section 14.4.3.3)

15.3.3 Vehicle Decontamination Facility

The specific limiting condition for the safe operation of the VDF is:

1. The Carbon Monoxide (CO) monitor and alarm shall be functional when vehicles are present in the VDF. (The LCO basis is documented in Section 8.2.5.)

15.3.4 Fire Prevention and Detection

The specific limiting conditions for the fire preventation and detection are:

1. The installed fire detection systems shall be operational. (The LCO basis is documented in Section 8.2.1.1, and Section 14.4.3.5)
2. If any of the installed fire detection systems are unavailable, compensatory measures as proposed by the Fire Protection Program and approved by the Facility Manager shall be put in place. Compensatory measures could include routine patrols of the area, use of a fire watch or provision of an alternate water supply depending on the nature of the unavailability. (The LCO basis is documented in Section 8.2.1.1.)
3. Actuation of smoke/heat detectors shall be investigated promptly. Normal operations shall be allowed to proceed only when the cause(s) are known and corrective actions have been taken. If causes cannot be determined or corrective actions cannot be completed immediately, normal operations shall not resume without a formal risk review and authorization by the FA and Fire Protection Program Authority or Designate. The authorization of the FA and Fire Protection Program Authority or Designate shall be documented. (The LCO basis is documented in Section 8.2.1.1.)
4. Waste delivery vehicles and ECM heavy equipment used for waste placement and compaction shall be provided with on-board fire suppression systems [15-6]. To control the spread and severity of fire and minimize operator injury, the on board extinguishing systems shall be certified to FM Global FM 5970 standards [15-6]. (The LCO basis is documented in Section 9.8 and Section 14.4.2.6)

15.4 Surveillance Requirements

1. Monitoring and inspections shall be conducted as described in Section 9 and in conformance with approved procedures. (The LCO basis is documented in Section 9.)
2. Records from Inspection and Maintenance activities shall be maintained and findings/actions from these activities shall be formally tracked. (The LCO basis is documented in Section 9.7 and Section 10.2.)

15.5 Administrative Requirements

The minimum staffing requirements during operating periods (e.g. scheduled working hours) in the NSDF are:

1. For licensed activities governed by approved procedures, work plans, etc. the staffing requirements are as given in the appropriate procedure. (The LCO basis is documented in Section 10.5.)

15.6 REFERENCES

[15-1] *Preparation of Operational Limits and Conditions*, 900-508770-FID-003, Revision 0, 2018 October.

[15-2] *Criticality Safety Document*, 232-203230-CSD-001, Revision 7, 2020 August.

[15-3] *Infrequently Performed Operations,* 900-508200-MCP-008, Revision 1, 2019 November.

[15-4] *Near Surface Disposal Facility Waste Acceptance Criteria,*-232-508600-WAC-003, Revision 2, 2020 September.

[15-5] *Near Surface Disposal Facility Effluent Discharge Targets*, 232-106499-REPT-002, Revision 0, 2019 October.

[15-6] *Fire Hazard Analysis*, 232-503230-FHA-001, Revision 2, 2019 March.

16. DECOMMISSIONING

The decommissioning strategy for the NSDF is documented in the Preliminary Decommissioning Plan (PDP) [16-1]. Class I Nuclear Facilities Regulations [16-2] requires that a licence application contain the proposed plan for decommissioning of the nuclear Facility or of the site. Regulatory guidance for the preparation of decommissioning planning for licensed activities is documented in Decommissioning Planning for Licenced Activities [16-3]. As per Canadian Standards Association (CSA), Decommissioning of Facilities Containing Nuclear Substances [16-4], decommissioning process starts at the design stage of a Facility or site and applies throughout the lifecycle of the Facility until the Facility or site is permanently retired from service and prepared for reuse or rendered to a predetermined end-state condition.

The purpose of the PDP [16-1] is to meet the CNSC requirements that a PDP for a licenced activity be filed with the Commission and maintained during the life cycle of the activity [16-2], [16-3] and [16-4].

The PDP [16-1] is reviewed periodically and revised as required during the operations phase to reflect changes to the Facility's configuration and/or operation, changes in relevant regulations, or changes in cost estimates. The PDP [16-1] addresses the decommissioning activities during the 30-year closure period.

The principle decommissioning hazard is the industrial hazard associated with building demolition. Industrial hazards will be minimized by following best industrial safety practices at the time of decommissioning. The demolition work will be conducted in accordance with an approved plan that includes provisions for protection of public safety and the environment. Any contaminated items that cannot be decontaminated to clearance release levels, will be classified as appropriate as radioactive waste, mixed waste, or hazardous waste with disposition through an approved route.

16.1 Facility Elements Identified for Decommissioning

The NSDF infrastructure elements to be decommissioned include [16-1]:

1. **ECM:** The ECM final cover construction and landscaping will occur at closure of the ECM (cease in operations). The ECM is a permanent Facility, with a design life of 550 years. The LCS is the only ECM component system to be decommissioned during the closure activities.
2. **WWTP and Equalization Tanks:** Decommissioning of the WWTP and Equalization Tanks will be performed after the leachate quantity no longer requires this Facility for treatment or the leachate is sent for treatment at an alternate Facility. The decision regarding when the WWTP is no longer required, will be based on leachate generation performance trend data following closure of the ECM, availability of other leachate management/treatment systems, capital costs, and life-cycle operation costs and maintenance costs associated with the alternatives. Decommissioning of the WWTP and Equalization Tanks will be performed after the ECM LCS is decommissioned.

3. **Support facilities and site infrastructure:** Support facilities and site infrastructure to be decommissioned include the VDF, weigh scale, Administration Office, OSC, entrance Kiosks, PWPS, FWPS, exfiltration gallery, CWPSs, power distribution building, fueling station, tie-ins to CNL site infrastructure, and septic systems including sewage lift station and leaching beds. Decommissioning of support facilities may be performed in a phased approach, based on structures no longer being required to support the closure activities.

16.2 Radiological, Chemical and Physical Conditions

The PDP [16-1], documents the predicted radiological, chemical, and physical conditions at time of decommissioning.

Conformance to operating procedures and operating within the bounds of the approved safety analysis over the operating life of the NSDF, provides a high level of confidence that the NSDF site will have minimal radiological and chemical hazards outside of the ECM and the WWTP. The effectiveness of the operational controls will be confirmed by pre-decommissioning surveys of the structures following removal of waste inventories.

16.2.1 Radiological

Residual contamination in the VDF is anticipated based on conformance to operating procedures and operating within the bounds of the approved safety analysis. Any radiation fields and/or contamination that are found during the pre-decommissioning survey are expected to be low level and localized. Localized radiological contamination is expected in the WWTP process equipment and Equalization Tanks, which will be managed as LLRW or mixed waste based on characterization or process knowledge and dispositioned through an approved route.

16.2.2 Chemical

Chemical hazardous wastes are collected and managed under CRL Waste Operations. Chemical hazardous wastes are sent to off-site hazardous waste disposal facilities or placed in on-site storage awaiting off-site disposition. Chemicals and chemical contaminated equipment used in the WWTP will be dispositioned as hazardous waste.

16.2.3 Physical

The facilities can be expected to be in good physical condition at decommissioning based on:

- The site will be operated as a Class I Nuclear Facility regulated by the CNSC.
- The facilities will be of robust construction and will be well maintained during operations.
- The site will have sufficient stormwater facilities, designed to handle substantial storm and rain events without flooding, and the site will be graded to ensure snow melt and stormwater is collected and directed away from the NSDF structures.

16.3 Preliminary Decommissioning Planning Envelopes

The decommissioning planning envelopes for the two decommissioning phases are shown in Table 16-1 [16-1]. The first phase involves decommissioning facilities that are not required after operations. The second phase involves decommissioning facilities that are not required for the post-closure period.

Wastes associated with NSDF decommissioning will require off-site disposition. The majority of NSDF decommissioning wastes will be construction materials, including steel and concrete that are expected to meet the criteria for clearance. Certain equipment associated primarily with the WWTP and construction materials impacted by radioactive contamination, will require disposition through an approved route.

Table 16-1
Decommissioning Work Packages

Phase	Planning Envelopes	Work Packages
1	VDF	Remove materials inventory. Decontaminate and/or remove contaminated structures for disposition through an approved route if contamination present. Demolish remaining structures. Remediate contaminated soils if present. Grade and revegetate immediate area.
1	Weigh Scales	Dismantle structure. Grade and revegetate immediate area.
1	Administration Office	Dismantle structure. Grade and revegetate immediate area.
2	ECM LCS	Remove remaining leachate water for disposition through an approved route. Remove and demolish surface structures and components for disposition through an approved route. Underground leachate systems located within the ECM will remain in place. See notes 1 and 2 below. Demolish remaining structures. Remediate contaminated soils if present. Grade and revegetate immediate area.
2	WWTP	Remove remaining influents, effluents, and chemicals in storage. Remove unnecessary treatment plant, piping, and other structures. See notes 1 and 2 below. Demolish remaining structures. Remediate contaminated areas/structures if present. Grade and revegetate immediate area.

2	Equalization Tanks	Remove remaining influents. Decontaminate and remove for disposition through an approved route. Demolish remaining structures. Remediate contaminated areas if present. Grade and revegetate immediate area.
2	Operations Support Centre	Remove materials inventory. Remove structures for disposal. Demolish remaining structures. Grade and revegetate immediate area.
2	Entrance kiosks	Dismantle structure. Grade and revegetate immediate area.
2	Fire Water Pump Station	Dismantle structure. Grade and revegetate immediate area.
2	Potable Water Pump Station	Dismantle structure. Grade and revegetate immediate area.
2	Exfiltration Gallery	Dismantle structure. Grade and revegetate immediate area.
2	Contact water pump stations	Dismantle structure. Grade and revegetate immediate area.
2	Buried septic systems	Dismantle structure. Grade and revegetate immediate area.
2	Power Distribution Building	Dismantle structure. Grade and revegetate immediate area.
2	Sewage Lift System: North Facility Sanitary Pumping Station	Dismantle structure. Grade and revegetate immediate area.
2	Leaching beds (north and south)	Dismantle structure. Grade and revegetate immediate area.
2	Site Vehicle Refueling Station	Dismantle structure. Grade and revegetate immediate area.

NOTE 1: All subsurface piping or structures in the NSDF that are external to the ECM will be decontaminated, remediated, removed, and dispositioned. All subsurface piping or structures in the NSDF that are internal to the ECM will be left in-situ.

NOTE 2: Decommissioning of the WWTP and all associated structures will be performed after the leachate quantity no longer requires this Facility for treatment, or the leachate is either able to be treated using a different technique, or it becomes more cost- effective to send leachate to an alternate off-site Facility for disposal.

16.3.1 Documentation and Planning

Prior to the commencement of decommissioning, the work will be planned and documented in the Detailed Decommissioning Plan(s) and associated documents including work plans, decommissioning waste management plan, and licence applications. The NSDF will follow the licensing process to obtain a licence to decommission.

The planning documents will include:

- The results of the detailed survey for radiological and other hazards.
- Actions to remove hazards prior to commencement of decommissioning work.
- Provisions for monitoring and mitigating hazards, personnel dosimetry, controlling emissions and effluents during the decommissioning work.
- The clearance process for materials, land, and structures (if any), that are to be removed from regulatory control.

16.3.2 Prepare for Demolition

All building equipment and fixtures will be removed, together with any components that have re-use/recycle value. Subsurface piping and structures will be removed during decommissioning activities. The subsurface piping and structures in the NSDF that are external to the ECM will be decontaminated, remediated, removed, and dispositioned. The subsurface piping and structures that are internal to the ECM will be left in-situ.

16.3.3 Demolition and Site Restoration

The NSDF support buildings and WWTP will be demolished one-by-one. The demolition debris will be reduced to manageable size and subjected to monitoring to meet the clearance release criteria in force at the time of decommissioning. The waste will be removed from the demolition area for disposal or recycling.

The perimeter fence will be retained for access control to the area.

Environmental surveying will be performed following removal of each building and remediation activities undertaken, as required, for any residual contamination that may be found.

Following confirmation that the site is clean, the site will be restored to the desired grade level and restored to meet surrounding environmental conditions (e.g. gravel or topsoil and seeding).

16.4 Planned End State

At the completion of decommissioning, final surveys of residual radioactive and hazardous materials shall be performed and documented to demonstrate that the final end state for remaining equipment, structures, and the site has been achieved in accordance with the criteria specified in the final decommissioning plan.

The ultimate end use(s) of the NSDF Project site will be determined by the Crown, based on the Facility's hazard level at the end of the ICP and supported by CNL documentation.

As the enduring Federal entity, and owner of the assets and liabilities of CNL, AECL is committed to controlling and restricting the land use of the NSDF footprint for as long as necessary. While other areas of the CRL site may be re-used, the NSDF footprint will be restricted as a waste disposal Facility.

16.5 References

[16-1] AECOM, *Preliminary Decommissioning Plan*, 232-508300-PLA-001, Revision 1, 2018 September.

[16-2] *Class 1 Nuclear Facilities Regulations*, SOR/2000-204.

[16-3] CNSC, *Decommissioning Planning of Licensed Activities*, G-219, 2000 June.

[16-4] CSA Group, *Decommissioning of Facilities Containing Nuclear Substances*, N294-09 (reaffirmed 2014), 2014 August.

17. CONCLUSION

The NSDF SAR describes the NSDF design including SSC, safety features and systems important to safety, safety functions and safety principles, design and safety requirements, waste characteristics, processes, O&M, RP, commissioning, OPEX, safety analysis, OLCs and decommissioning.

The NDSF meets the current standards for design and construction and has been engineered for a design life of 550 years including 50 years of operations.

Potential hazards and initiating events have been identified for the construction, operations and closure periods. The waste placement and compaction operations and the WWTP operations will present some minor radiological risks to the operating staff, but negligible risks to other on-site staff and members of the public.

No hazard has been identified that would indicate that the proposed construction and operation of the NSDF is unsafe, and all risks and estimated doses associated with the hazards meet the acceptance criteria.

The safety analysis presented in this report demonstrates that the following safety objectives have been met:

- The safety objective for the NSDF is to protect individuals, society, and the environment by establishing and maintaining an effective defence against radiological and non-radiological (chemical, conventional) hazards.
- Long-term waste management safety objectives for the construction, operations and closure phases: radiological protection of persons, protection of persons from hazardous substances, radiological protection of the environment, and protection of the environment from hazardous substances. Note: Long-term safety in the post-closure phase is assessed in the NSDF Post-closure Safety Assessment [17-1].

The safety analysis presented in this report, demonstrates that the following requirements under normal operations, AOOs, DBA and BDBA including DECs in the NSDF Facility have been met:

- The safety of the off-site public, on-site personnel and on-site workers is protected.
- Demonstrate that the dose acceptance criteria are met for radiological consequences to the on-site and off-site receptors.
- There are no significant adverse impacts on the environment.
- Demonstrate the adequacy of the NSDF design.
- Demonstrate that the proposed design of the NSDF conforms to regulatory requirements and guidance provided by the CNSC and the IAEA.
- Waste containment is maintained for the duration of the facility operation under normal operating conditions.

17.1 References

[17-1] Arcadis, *Post-Closure Safety Assessment 3rd Iterations to the NSDF Project,* 232-509240-ASD-004, Revision 1, 2020 October.

Appendix A

Normal Operations

This Appendix A assesses the normal operations radiological consequences to workers. Radiological exposure rates and durations are estimated for NSDF workers supporting operations at the WWTP and the ECM. Work tasks involve multiple workers (e.g. RP staff, technicians, and heavy equipment operators); however, only the radiological consequence to the most exposed worker is assessed.

Work is controlled and monitored by the RP Program. Dose control points are set for the estimated annual limit of external radiation exposure for an individual set by a Health Physicist and the Facility Manager to control worker dose during normal operations. All DCPs for NSDF staff, are set conservatively low and adjusted as experience is gained with the operations at the NSDF.

The methodology to estimate the normal operations radiological consequence, multiplies the estimated task durations by the anticipated radiation fields to calculate the radiological consequence to the worker. Task durations are based on operations and subject matter expert reviews. Radiation field estimates are based on radiological consequence dose calculations, MircroShield Version 9.07 calculations [A-1] and/or RESRAD-OFFSITE Version 3.2 [A-2] calculations.

A.1 General Assumptions and Inputs

MicroShield [A-1] is used to estimate dose rates near equipment for normal operations. The following general assumptions and inputs are used in the MicroShield models:

- The NSDF operates four days/week for eight months/year working eight hours in a 10 hour work day. For an eight months/year working period, this corresponds to approximately 35 weeks/y or 140 days/y. Work in the ECM does not occur during winter months.
- When a source is larger than the receptor, the dose point height of 1 m is used to represent the centre of the receptor.
- When the source height is smaller than a receptor, the center point of the source is used.
- Liquid source terms are assumed to have a density of 1 g/cm^3 and are modelled as water in MicroShield.
- Solid and sediment source terms are assumed to have a density of 1.5 g/cm^3 and are modelled as soil in MicroShield.
- The source term is uniformly distributed in the source.
- Y-90 is assumed to be in equilibrium with Sr-90.
- Ba-137m is assumed to be in equilibrium with Cs-137.

- For the WWTP, maintenance is conservatively assumed to occur on full tanks. This is considered conservative since the volume assessed is greater than the working volume.
- Maintenance activities are assumed to occur on full tanks. This is considered conservative since maintenance operations would likely occur on empty tanks in the non-operating train of the WWTP system.
- For the WWTP, a distance of 30 cm is used as the average working distance for tasks. The worker may be closer for portions of a task, however, most of the time should be greater than 30 cm from the source. Radiation Protection staff support/oversight will assist in ensuring appropriate worker distance from radiological hazards during tasks.

A.2 Normal Operations Radiological Consequence to Waste Water Treatment Plant Worker

The radiological consequences to the WWTP worker are estimated based on:

- Expected exposure durations for WWTP operations tasks, and
- Estimated dose rates near the sources to perform the task.

Exposure durations are estimated based on consultation with WWTP designers and operations regarding required O&M tasks. Dose rates are calculated using MicroShield. A detailed discussion of WWTP operations is documented in Section 9 and Section 10. A summary of the radiological consequences to the on-site receptor, WWTP worker, during normal operations is provided in Table A-1.

The total estimated radiological consequence to the WWTP worker is 5.65 mSv/y. The work tasks contributing the most significant radiological consequences to the WWTP workers are sampling the SAC resin and transfer of the dewatered residuals bin.

Table A-1
WWTP Worker Normal Operations Radiological Consequences Analysis

Section	WWTP Process tank/component (number of tanks)	Operations or Maintenance Activity	Hours per year	Dose Rate (mSv/h)	Radiological Consequence (mSv/y)
A.2.1	Equalization Tanks (3)	Equalization Tank maintenance	36	6.72E-04	2.42E-02
		Equalization Tank cleaning	36	6.72E-04	2.42E-02
A.2.2	Chemical Precipitation Tank (4)	Sampling and visual inspection of chemical precipitation	46.67	4.03E-04	1.88E-02
		Maintenance of motor and level instrumentation	96	4.03E-04	3.87E-02
A.2.3	Membrane Filter Feed Tank (2)	Maintenance of motor and level instrumentation	48	5.45E-04	2.62E-02
A.2.4	Membrane Filter Process Tank(2)	Maintenance of level instrumentation	24	4.14E-04	9.94E-03

A.2.5	Membrane Filter Skid (2)	Clean-in-place operation	11.67	4.14E-04	4.83E-03
C.2.6	pH adjust Tank (2)	Sampling of pH adjust tank at outlet of membrane filter	46.67	1.18E-04	5.05E-03
		Maintenance of motor and level instrumentation	48	1.18E-04	5.66E-03
C.2.7	Polishing System Feed Tank (2)	Maintenance of level instrumentation	24	1.59E-04	3.82E-03
C.2.8	IX and GAC Tanks (6)	Sampling at outlet of each IX or GAC tank	46.67 (GAC) 46.67 (Zeolite) 46.67 (SAC)	2.54E-05 (GAC) 1.05E-04 (Zeolite) 5.69E-02 (SAC)*	1.19E-03 (GAC) 4.90E-03 (Zeolite) 2.66E+00 (SAC)
		Replacement of GAC or IX resins	9 (GAC) 7 (Zeolite) 6 (SAC)	2.54E-05 (GAC) 1.05E-04 (Zeolite) 5.69E-02 (SAC)	2.29E-04 (GAC) 7.35E-04 (Zeolite) 3.41E-01 (SAC)
C.2.9	Final pH adjust Tank (2)	Maintenance of motor and level instrumentation	48	5.90E-06	2.83E-04
C.2.10	Final Effluent Release Tank (2)	Maintenance of level instrumentation	24	7.96E-06	1.91E-04
C.2.11	Residuals Storage Tank (2)	Maintenance of level instrumentation	48	7.88E-03	3.78E-01
		Removal of supernatant from tank	29	7.88E-03	2.29E-01
C.2.12	Filter Press Feed Tank (1)	Maintenance of motor and level instrumentation	24	1.27E-02	3.05E-01
C.2.13	Filter Press (1)	Operation of filter press	14.35	7.52E-03**	1.08E-01
		Filter press cleaning	58 operations	7.52E-03	4.36E-01
		Transfer of dewatered residuals bin	15	6.77E-02	1.02E+00
				Radiological Consequence Total Dose	**5.65 mSv/y**

*IX tank dose rate during sampling is half of the maximum dose rate, which exists during replacement.

The GAC dose rate is primarily the result of radionuclides in wastewater (rather than accumulated in the GAC), therefore, it is unchanged during GAC exhaustion.

** The filter press dose rate is estimated to be 1/9th the dose from the residuals bin.

A.2.1 Equalization Tanks

The Equalization Tanks require periodic maintenance and annual cleaning. Periodic maintenance of the Equalization Tanks is assumed to occur on a monthly basis, 12 months/year and the Equalization Tanks are cleaned out, removing any built-up sediment and solids, on an annual basis. The duration for Equalization Tanks maintenance, where the worker is near (~30 cm) the Equalization Tanks, is estimated at 1 hour/tank. Therefore, this activity is estimated to result in 36 hours/year of worker exposure.

Cleaning inside each Equalization Tank is estimated to require three workers for 12 hours over two days. Therefore, cleaning the three Equalization Tanks is estimated to result in 36 hours/year of worker exposure.

The dose rate outside of a full Equalization Tank is calculated, to support the estimated normal operations WWTP worker radiological consequences presented in Section 14.2. The following inputs and assumptions are used in the calculation:

- The Equalization Tank height is 807 cm with a radius of 945 cm [A-3], and is conservatively assumed to be full.
- The source term is from WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).
- The dose rate for cleaning the Equalization Tanks is conservatively assumed to be the same as the dose rate from a full Equalization Tank.

The MicroShield dose rate results for a full Equalization Tank are shown in Table A-2. Equalization Tank maintenance and cleaning will likely occur on the Equalization Tanks when empty, removing much of the radiological source term; however, tank maintenance is conservatively assessed using full Equalization Tanks. Based on the dose rate of 6.72E-04 mSv/h at 30 cm from the tank, the estimated radiological consequences for Equalization Tank maintenance and cleaning activities during normal operations are:

- Equalization Tank maintenance radiological consequence is 2.42E-02 mSv/y.
- Equalization Tank cleaning radiological consequence is 2.42E-02 mSv/y.

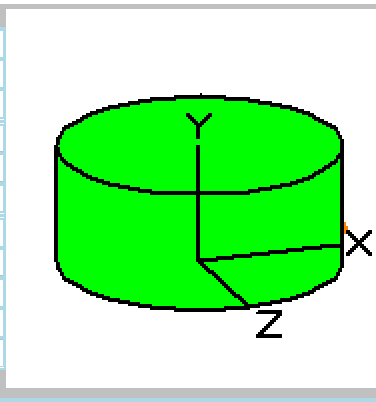
Table A-2
MicroShield Output – Dose Rate Equalization Tanks

MicroShield 9.07 CNL (9.07-0000)			
Filename	Run Date	Run Time	Duration
1-EQ activity in water.msd	May 21, 2019	8:13:33 PM	00:00:01
Project Info			
Case Title	1-EQ		
Description	Dose outside EQ tanks filled with water		
Geometry	7 - Cylinder Volume - Side Shields		

Source Dimensions	
Height	807.0 cm (26 ft 5.7 in)
Radius	945.0 cm (31 ft 0.0 in)

Dose Points			
A	X	Y	Z
#1	975.0 cm (31 ft 11.9 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	2.26e+09 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	1.1014e-008	4.0753e+002	4.8649e-012	1.8000e-007
Am-241	1.7133e-007	6.3394e+003	7.5676e-011	2.8000e-006
Am-243	1.0402e-010	3.8489e+000	4.5946e-014	1.7000e-009
Ba-137m	5.3848e-005	1.9924e+006	2.3784e-008	8.8000e-004
C-14	1.8969e-004	7.0185e+006	8.3783e-008	3.1000e-003
Cl-36	3.6103e-006	1.3358e+005	1.5946e-009	5.9000e-005
Co-60	7.9548e-002	2.9433e+009	3.5135e-005	1.3000e+000
Cs-135	2.5088e-009	9.2826e+001	1.1081e-012	4.1000e-008
Cs-137	5.6907e-005	2.1056e+006	2.5135e-008	9.3000e-004
H-3	8.5667e+000	3.1697e+011	3.7838e-003	1.4000e+002
I-129	5.5684e-006	2.0603e+005	2.4595e-009	9.1000e-005
Mo-93	2.5088e-011	9.2826e-001	1.1081e-014	4.1000e-010
Nb-94	9.1786e-007	3.3961e+004	4.0541e-010	1.5000e-005
Ni-59	1.0402e-008	3.8489e+002	4.5946e-012	1.7000e-007
Ni-63	2.6924e-006	9.9619e+004	1.1892e-009	4.4000e-005
Np-237	3.8550e-011	1.4264e+000	1.7027e-014	6.3000e-010
Pu-239	2.6924e-007	9.9619e+003	1.1892e-010	4.4000e-006
Pu-241	4.8341e-006	1.7886e+005	2.1351e-009	7.9000e-005
Pu-242	2.0193e-010	7.4714e+000	8.9190e-014	3.3000e-009
Ra-226	3.9162e-008	1.4490e+003	1.7297e-011	6.4000e-007
Se-79	1.4686e-009	5.4338e+001	6.4866e-013	2.4000e-008
Sn-126	4.4057e-010	1.6301e+001	1.9459e-013	7.2000e-009
Sr-90	5.8743e-004	2.1735e+007	2.5946e-007	9.6000e-003
Tc-99	3.4879e-004	1.2905e+007	1.5405e-007	5.7000e-003
Th-230	1.3462e-008	4.9809e+002	5.9460e-012	2.2000e-007
Th-232	5.8743e-008	2.1735e+003	2.5946e-011	9.6000e-007
U-233	1.7745e-009	6.5657e+001	7.8377e-013	2.9000e-008
U-234	4.7729e-007	1.7660e+004	2.1081e-010	7.8000e-006
U-235	2.0193e-008	7.4714e+002	8.9190e-012	3.3000e-007
U-238	4.6505e-007	1.7207e+004	2.0541e-010	7.6000e-006
Y-90	5.8743e-004	2.1735e+007	2.5946e-007	9.6000e-003
Zr-93	2.6924e-006	9.9619e+004	1.1892e-009	4.4000e-005

Buildup: The material reference is Source
Integration Parameters

Radial	20

Circumferential									20
Y Direction (axial)									40
Results									
Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0287	3.503e+05	3.023e-06	8.724e-06	3.430e-08	9.896e-08	2.994e-08	8.639e-08	2.994e-10	8.639e-10
0.0619	2.504e+03	1.225e-07	9.439e-07	2.341e-10	1.804e-09	2.044e-10	1.575e-09	2.044e-12	1.575e-11
0.1367	1.053e+02	1.530e-08	9.948e-08	2.461e-11	1.600e-10	2.149e-11	1.397e-10	2.149e-13	1.397e-12
0.1859	5.433e+02	1.199e-07	6.494e-07	2.082e-10	1.127e-09	1.818e-10	9.842e-10	1.818e-12	9.842e-12
0.2214	7.471e-01	2.098e-10	1.014e-09	3.783e-13	1.829e-12	3.302e-13	1.596e-12	3.302e-15	1.596e-14
0.3097	9.665e-02	4.336e-11	1.671e-10	8.257e-14	3.182e-13	7.208e-14	2.778e-13	7.208e-16	2.778e-15
0.4339	3.663e+02	2.658e-07	8.552e-07	5.201e-10	1.673e-09	4.541e-10	1.461e-09	4.541e-12	1.461e-11
0.6144	3.684e+02	4.421e-07	1.208e-06	8.617e-10	2.355e-09	7.523e-10	2.056e-09	7.523e-12	2.056e-11
0.6616	1.793e+06	2.398e-03	6.345e-03	4.648e-06	1.230e-05	4.058e-06	1.074e-05	4.058e-08	1.074e-07
0.6944	5.144e+05	7.385e-04	1.915e-03	1.426e-06	3.696e-06	1.245e-06	3.227e-06	1.245e-08	3.227e-08
0.8711	3.396e+04	6.811e-05	1.617e-04	1.282e-07	3.042e-07	1.119e-07	2.656e-07	1.119e-09	2.656e-09
1.1732	2.943e+09	9.213e+00	1.978e+01	1.646e-02	3.535e-02	1.437e-02	3.086e-02	1.437e-04	3.086e-04
1.3325	2.943e+09	1.116e+01	2.303e+01	1.937e-02	3.995e-02	1.691e-02	3.488e-02	1.691e-04	3.488e-04
Totals	5.889e+09	2.038e+01	4.282e+01	3.584e-02	7.531e-02	3.129e-02	6.575e-02	3.129e-04	6.575e-04

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	3.199e-004	6.723e-004

A.2.2 Chemical Precipitation

Normal operations activities for the chemical precipitation tank are routine inspections and maintenance activities.

Effluent at the chemical precipitation tank is inspected/sampled during each WWTP process run to verify that precipitation is occurring. The task duration is estimated to be 20 minutes/day at 30 cm from the chemical precipitation tanks, while the WWTP process is operating. The WWTP operates up to 140 days/year. Therefore, the annual time spent sampling the chemical precipitation tank is estimated to be 46.67 hours.

Maintenance of the chemical precipitation tank motor and level instrumentation is expected to occur on a monthly basis for 12 months/year for four tanks. This task is expected to have a duration of two hours near the chemical precipitation tank, for a total of 96 hours/year for all four tanks.

The dose rate outside of a full chemical precipitation tank is calculated, to support the estimate of WWTP worker radiological consequence presented in Section 14.2. The following inputs and assumptions are used:

- The chemical precipitation tank has a height of 220 cm with a radius of 84 cm [A-3], and is conservatively assumed to be full.
- The source term is from WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the chemical precipitation tank normal operations are shown in Table A-3. Based on the dose rate of 4.03E-04 mSv/h at 30 cm from the tank, the estimated radiological consequences to the WWTP worker for the Chemical Precipitation Tank sampling and maintenance activities during normal operations are:

- Sampling activities radiological consequence is 1.88E-02 mSv/y.
- Maintenance activities radiological consequence is 3.87E-02 mSv/y.

Table A-3
MicroShield Output - Dose Rate Chemical Precipitation Tank

MicroShield 9.07 CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
2-Chem Prec activity in water.msd	May 21, 2019	8:18:27 PM	00:00:01

Project Info	
Case Title	2-Chem Precip
Description	Dose rate outside Chem Prec tanks filled with water
Geometry	7 - Cylinder Volume - Side Shields

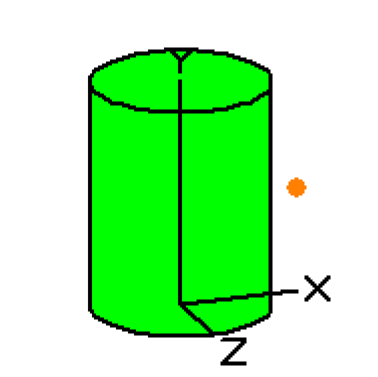
Source Dimensions	
Height	220.0 cm (7 ft 2.6 in)
Radius	84.0 cm (2 ft 9.1 in)

Dose Points

A	X	Y	Z
#1	114.0 cm (3 ft 8.9 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	4.88e+06 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ag-108m	2.3725e-011	8.7783e-001	4.8649e-012	1.8000e-007
Am-241	3.6905e-010	1.3655e+001	7.5675e-011	2.8000e-006
Am-243	2.2407e-013	8.2906e-003	4.5947e-014	1.7000e-009
Ba-137m	1.1596e-007	4.2905e+003	2.3778e-008	8.7979e-004
C-14	4.0859e-007	1.5118e+004	8.3783e-008	3.1000e-003
Cl-36	7.7765e-009	2.8773e+002	1.5946e-009	5.9000e-005
Co-60	1.7135e-004	6.3400e+006	3.5136e-005	1.3000e+000
Cs-135	5.4040e-012	1.9995e-001	1.1081e-012	4.1000e-008
Cs-137	1.2258e-007	4.5354e+003	2.5135e-008	9.3000e-004
H-3	1.8453e-002	6.8276e+008	3.7839e-003	1.4000e+002
I-129	1.1994e-008	4.4378e+002	2.4595e-009	9.1000e-005
Mo-93	5.4040e-014	1.9995e-003	1.1081e-014	4.1000e-010
Nb-94	1.9771e-009	7.3153e+001	4.0541e-010	1.5000e-005
Ni-59	2.2407e-011	8.2906e-001	4.5947e-012	1.7000e-007
Ni-63	5.7994e-009	2.1458e+002	1.1892e-009	4.4000e-005
Np-237	8.3037e-014	3.0724e-003	1.7027e-014	6.3000e-010
Pu-239	5.7994e-010	2.1458e+001	1.1892e-010	4.4000e-006
Pu-241	1.0413e-008	3.8526e+002	2.1351e-009	7.9000e-005
Pu-242	4.3495e-013	1.6093e-002	8.9188e-014	3.3000e-009
Ra-226	8.4355e-011	3.1211e+000	1.7297e-011	6.4000e-007

Se-79	3.1633e-012	1.1704e-001	6.4865e-013	2.4000e-008
Sn-126	9.4899e-013	3.5113e-002	1.9459e-013	7.2000e-009
Sr-90	1.2653e-006	4.6817e+004	2.5946e-007	9.6000e-003
Tc-99	7.5128e-007	2.7797e+004	1.5405e-007	5.7000e-003
Th-230	2.8997e-011	1.0729e+000	5.9460e-012	2.2000e-007
Th-232	1.2653e-010	4.6817e+000	2.5946e-011	9.6000e-007
U-233	3.8223e-012	1.4143e-001	7.8378e-013	2.9000e-008
U-234	1.0281e-009	3.8039e+001	2.1081e-010	7.8000e-006
U-235	4.3495e-011	1.6093e+000	8.9188e-012	3.3000e-007
U-238	1.0017e-009	3.7063e+001	2.0541e-010	7.6000e-006
Y-90	1.2653e-006	4.6816e+004	2.5946e-007	9.5998e-003
Zr-93	5.7994e-009	2.1458e+002	1.1892e-009	4.4000e-005

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0287	7.545e+02	2.905e-06	6.070e-06	3.295e-08	6.886e-08	2.877e-08	6.012e-08	2.877e-10	6.012e-10
0.0619	5.394e+00	8.562e-08	5.419e-07	1.637e-10	1.036e-09	1.429e-10	9.043e-10	1.429e-12	9.043e-12
0.1367	2.269e-01	1.012e-08	5.873e-08	1.627e-11	9.447e-11	1.421e-11	8.247e-11	1.421e-13	8.247e-13
0.1859	1.170e+00	7.801e-08	3.861e-07	1.354e-10	6.703e-10	1.182e-10	5.852e-10	1.182e-12	5.852e-12
0.2214	1.609e-03	1.353e-10	6.043e-10	2.439e-13	1.090e-12	2.129e-13	9.512e-13	2.129e-15	9.512e-15
0.3097	2.082e-04	2.754e-11	1.002e-10	5.244e-14	1.908e-13	4.578e-14	1.666e-13	4.578e-16	1.666e-15
0.4339	7.890e-01	1.666e-07	5.147e-07	3.261e-10	1.007e-09	2.847e-10	8.792e-10	2.847e-12	8.792e-12
0.6144	7.935e-01	2.742e-07	7.279e-07	5.344e-10	1.419e-09	4.666e-10	1.239e-09	4.666e-12	1.239e-11
0.6616	3.861e+03	1.484e-03	3.823e-03	2.876e-06	7.411e-06	2.511e-06	6.469e-06	2.511e-08	6.469e-08
0.6944	1.108e+03	4.566e-04	1.154e-03	8.815e-07	2.228e-06	7.695e-07	1.945e-06	7.695e-09	1.945e-08
0.8711	7.315e+01	4.189e-05	9.737e-05	7.884e-08	1.832e-07	6.883e-08	1.600e-07	6.883e-10	1.600e-09
1.1732	6.340e+06	5.633e+00	1.188e+01	1.007e-02	2.123e-02	8.788e-03	1.853e-02	8.788e-05	1.853e-04
1.3325	6.340e+06	6.811e+00	1.381e+01	1.182e-02	2.395e-02	1.032e-02	2.091e-02	1.032e-04	2.091e-04
Totals	1.269e+07	1.245e+01	2.569e+01	2.189e-02	4.519e-02	1.911e-02	3.945e-02	1.911e-04	3.945e-04

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	1.954e-004	4.034e-004

A.2.3 Membrane Filter Feed Tank

Maintenance of the membrane filter feed tanks motor and level instrumentation is expected to occur once per month. This task is expected to have a duration of two hours per tank (two tanks), for a total of 48 hours/year.

The dose rate at 30 cm from the full membrane filter feed tank is calculated, to support the estimate of WWTP worker radiological consequence presented in Section 14.2. The following inputs and assumptions are used in this calculation:

- The membrane filter feed tank has a height of 715.6 cm (rounded up to 716 cm), radius of 213.5 cm (rounded up to 214 cm) [A-3], and is conservatively assumed to be full.
- The source term is from WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90, and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the membrane filter feed tank normal operations are shown in Table A-4. The estimated normal operation annual radiological consequence to the WWTP worker is 2.62E-02 mSv/y based on the dose rate of 5.45E-04 mSv/h at 30 cm from the tank, and tank maintenance being 48 hours/year.

Table A-4
MicroShield Output – Membrane Filter Feed Tank

MicroShield 9.07 CNL (9.07-0000)

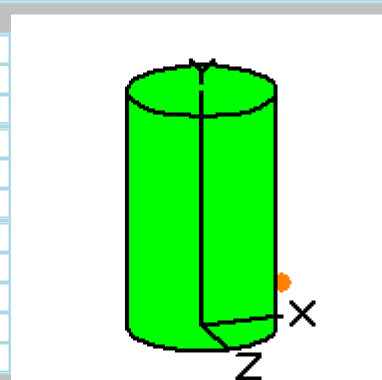
Filename	Run Date	Run Time	Duration
3-Mem Feed activity in water.msd	May 21, 2019	8:22:02 PM	00:00:01

Project Info	
Case Title	3-Mem Feed
Description	Dose rate outside Membrane Feed tank filled with water
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	716.0 cm (23 ft 5.9 in)
Radius	214.0 cm (7 ft 0.3 in)

Dose Points			
A	X	Y	Z
#1	244.0 cm (8 ft 0.1 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	1.03e+08 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25

Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	5.0114e-010	1.8542e+001	4.8649e-012	1.8000e-007
Am-241	7.7955e-009	2.8844e+002	7.5676e-011	2.8000e-006
Am-243	4.7330e-012	1.7512e-001	4.5946e-014	1.7000e-009
Ba-137m	2.4366e-006	9.0155e+004	2.3654e-008	8.7518e-004
C-14	8.6308e-006	3.1934e+005	8.3784e-008	3.1000e-003
Cl-36	1.6426e-007	6.0777e+003	1.5946e-009	5.9000e-005
Co-60	3.6194e-003	1.3392e+008	3.5135e-005	1.3000e+000
Cs-135	1.1415e-010	4.2235e+000	1.1081e-012	4.1000e-008
Cs-137	2.5892e-006	9.5802e+004	2.5135e-008	9.3000e-004
H-3	3.8978e-001	1.4422e+010	3.7838e-003	1.4000e+002
I-129	2.5336e-007	9.3741e+003	2.4595e-009	9.1000e-005
Mo-93	1.1415e-012	4.2235e-002	1.1081e-014	4.1000e-010
Nb-94	4.1762e-008	1.5452e+003	4.0541e-010	1.5000e-005
Ni-59	4.7330e-010	1.7512e+001	4.5946e-012	1.7000e-007
Ni-63	1.2250e-007	4.5326e+003	1.1892e-009	4.4000e-005
Np-237	1.7540e-012	6.4898e-002	1.7027e-014	6.3000e-010
Pu-239	1.2250e-008	4.5326e+002	1.1892e-010	4.4000e-006
Pu-241	2.1995e-007	8.1380e+003	2.1351e-009	7.9000e-005
Pu-242	9.1876e-012	3.3994e-001	8.9189e-014	3.3000e-009
Ra-226	1.7818e-009	6.5928e+001	1.7297e-011	6.4000e-007
Se-79	6.6819e-011	2.4723e+000	6.4865e-013	2.4000e-008
Sn-126	2.0046e-011	7.4169e-001	1.9459e-013	7.2000e-009
Sr-90	2.6728e-005	9.8892e+005	2.5946e-007	9.6000e-003
Tc-99	1.5870e-005	5.8717e+005	1.5405e-007	5.7000e-003
Th-230	6.1251e-010	2.2663e+001	5.9459e-012	2.2000e-007
Th-232	2.6728e-009	9.8892e+001	2.5946e-011	9.6000e-007
U-233	8.0740e-011	2.9874e+000	7.8378e-013	2.9000e-008
U-234	2.1716e-008	8.0350e+002	2.1081e-010	7.8000e-006
U-235	9.1876e-010	3.3994e+001	8.9189e-012	3.3000e-007
U-238	2.1159e-008	7.8290e+002	2.0541e-010	7.6000e-006
Y-90	2.6588e-005	9.8376e+005	2.5810e-007	9.5499e-003
Zr-93	1.2250e-007	4.5326e+003	1.1892e-009	4.4000e-005

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0287	1.590e+04	3.698e-06	8.007e-06	4.196e-08	9.085e-08	3.663e-08	7.931e-08	3.663e-10	7.931e-10
0.0619	1.139e+02	1.114e-07	7.134e-07	2.130e-10	1.364e-09	1.859e-10	1.190e-09	1.859e-12	1.190e-11
0.1367	4.792e+00	1.321e-08	7.778e-08	2.125e-11	1.251e-10	1.855e-11	1.092e-10	1.855e-13	1.092e-12
0.1859	2.472e+01	1.020e-07	5.124e-07	1.770e-10	8.895e-10	1.546e-10	7.765e-10	1.546e-12	7.765e-12
0.2214	3.399e-02	1.770e-10	8.027e-10	3.191e-13	1.447e-12	2.786e-13	1.264e-12	2.786e-15	1.264e-14
0.3097	4.397e-03	3.609e-11	1.334e-10	6.873e-14	2.540e-13	6.000e-14	2.217e-13	6.000e-16	2.217e-15
0.4339	1.667e+01	2.188e-07	6.866e-07	4.281e-10	1.343e-09	3.737e-10	1.173e-09	3.737e-12	1.173e-11

0.6144	1.676e+01	3.609e-07	9.740e-07	7.033e-10	1.898e-09	6.140e-10	1.657e-09	6.140e-12	1.657e-11
0.6616	8.112e+04	1.944e-03	5.092e-03	3.768e-06	9.871e-06	3.289e-06	8.617e-06	3.289e-08	8.617e-08
0.6944	2.341e+04	6.014e-04	1.546e-03	1.161e-06	2.984e-06	1.014e-06	2.605e-06	1.014e-08	2.605e-08
0.8711	1.545e+03	5.530e-05	1.308e-04	1.041e-07	2.462e-07	9.085e-08	2.149e-07	9.085e-10	2.149e-09
1.1732	1.339e+08	7.462e+00	1.603e+01	1.333e-02	2.865e-02	1.164e-02	2.501e-02	1.164e-04	2.501e-04
1.3325	1.339e+08	9.038e+00	1.868e+01	1.568e-02	3.241e-02	1.369e-02	2.829e-02	1.369e-04	2.829e-04
Totals	2.680e+08	1.650e+01	3.472e+01	2.902e-02	6.107e-02	2.533e-02	5.331e-02	2.533e-04	5.331e-04

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	2.590e-004	5.451e-004

A.2.4 Membrane Filter Process Tank

Each membrane filter process tank requires maintenance for level instrumentation at an estimated frequency of once per month. This task is expected to have a duration of one hour per tank (two tanks), for a total of 24 hours/year.

The dose rate at 30 cm from the full membrane filter process tank is calculated, to support the estimate of WWTP worker radiological consequence presented in Section 14.2. The following inputs and assumptions are used in this calculation:

- Measurements for the membrane filter process tank are not available. Therefore, the membrane filter process tank is modelled with a height of 214 cm and radius of 91.5 cm and is conservatively assumed to be full.
- The source term is from WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90, and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the membrane filter process tank normal operations are shown in Table A-5. The normal operations annual radiological consequence to the WWTP worker is 9.94E-03 mSv/y based on the dose rate of 4.14E-04 mSv/h, and tank maintenance being 24 hours/year.

Table A-5
MicroShield Output – Membrane Filter Feed Tank

MicroShield 9.07
CNL (9.07-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
4-Mem Process activity in water.msd	May 21, 2019	8:25:07 PM	00:00:01

Project Info	
Case Title	4-Mem Process
Description	Dose rate outside Membrane Process tank filled with water
Geometry	7 - Cylinder Volume - Side Shields

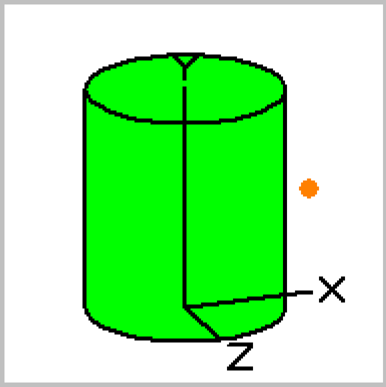
Source Dimensions	
Height	214.0 cm (7 ft 0.3 in)
Radius	91.5 cm (3 ft 0.0 in)

Dose Points

A	X	Y	Z
#1	121.5 cm (3 ft 11.8 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	5.63e+06 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ag-108m	2.7383e-011	1.0132e+000	4.8649e-012	1.8000e-007
Am-241	4.2595e-010	1.5760e+001	7.5676e-011	2.8000e-006
Am-243	2.5861e-013	9.5687e-003	4.5946e-014	1.7000e-009
Ba-137m	1.3239e-007	4.8984e+003	2.3521e-008	8.7026e-004
C-14	4.7159e-007	1.7449e+004	8.3784e-008	3.1000e-003
Cl-36	8.9754e-009	3.3209e+002	1.5946e-009	5.9000e-005
Co-60	1.9776e-004	7.3173e+006	3.5135e-005	1.3000e+000
Cs-135	6.2372e-012	2.3078e-001	1.1081e-012	4.1000e-008
Cs-137	1.4148e-007	5.2347e+003	2.5135e-008	9.3000e-004

H-3	2.1298e-002	7.8801e+008	3.7838e-003	1.4000e+002
I-129	1.3843e-008	5.1221e+002	2.4595e-009	9.1000e-005
Mo-93	6.2372e-014	2.3078e-003	1.1081e-014	4.1000e-010
Nb-94	2.2819e-009	8.4430e+001	4.0541e-010	1.5000e-005
Ni-59	2.5861e-011	9.5687e-001	4.5946e-012	1.7000e-007
Ni-63	6.6936e-009	2.4766e+002	1.1892e-009	4.4000e-005
Np-237	9.5840e-014	3.5461e-003	1.7027e-014	6.3000e-010
Pu-239	6.6936e-010	2.4766e+001	1.1892e-010	4.4000e-006
Pu-241	1.2018e-008	4.4466e+002	2.1351e-009	7.9000e-005
Pu-242	5.0202e-013	1.8575e-002	8.9189e-014	3.3000e-009
Ra-226	9.7361e-011	3.6023e+000	1.7297e-011	6.4000e-007
Se-79	3.6510e-012	1.3509e-001	6.4865e-013	2.4000e-008
Sn-126	1.0953e-012	4.0526e-002	1.9459e-013	7.2000e-009
Sr-90	1.4604e-006	5.4035e+004	2.5946e-007	9.6000e-003
Tc-99	8.6712e-007	3.2083e+004	1.5405e-007	5.7000e-003
Th-230	3.3468e-011	1.2383e+000	5.9459e-012	2.2000e-007
Th-232	1.4604e-010	5.4035e+000	2.5946e-011	9.6000e-007
U-233	4.4117e-012	1.6323e-001	7.8378e-013	2.9000e-008
U-234	1.1866e-009	4.3904e+001	2.1081e-010	7.8000e-006
U-235	5.0202e-011	1.8575e+000	8.9189e-012	3.3000e-007
U-238	1.1562e-009	4.2778e+001	2.0541e-010	7.6000e-006
Y-90	1.4446e-006	5.3449e+004	2.5664e-007	9.4959e-003
Zr-93	6.6936e-009	2.4766e+002	1.1892e-009	4.4000e-005

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0287	8.663e+02	2.971e-06	6.212e-06	3.372e-08	7.050e-08	2.944e-08	6.154e-08	2.944e-10	6.154e-10
0.0619	6.226e+00	8.795e-08	5.545e-07	1.681e-10	1.060e-09	1.468e-10	9.254e-10	1.468e-12	9.254e-12
0.1367	2.618e-01	1.038e-08	6.010e-08	1.670e-11	9.667e-11	1.458e-11	8.439e-11	1.458e-13	8.439e-13
0.1859	1.351e+00	8.004e-08	3.952e-07	1.389e-10	6.860e-10	1.213e-10	5.989e-10	1.213e-12	5.989e-12
0.2214	1.857e-03	1.387e-10	6.186e-10	2.502e-13	1.115e-12	2.184e-13	9.738e-13	2.184e-15	9.738e-15
0.3097	2.403e-04	2.824e-11	1.026e-10	5.378e-14	1.954e-13	4.695e-14	1.706e-13	4.695e-16	1.706e-15

0.4339	9.106e-01	1.708e-07	5.273e-07	3.343e-10	1.032e-09	2.918e-10	9.007e-10	2.918e-12	9.007e-12
0.6144	9.158e-01	2.810e-07	7.459e-07	5.478e-10	1.454e-09	4.782e-10	1.269e-09	4.782e-12	1.269e-11
0.6616	4.408e+03	1.504e-03	3.875e-03	2.916e-06	7.512e-06	2.546e-06	6.558e-06	2.546e-08	6.558e-08
0.6944	1.279e+03	4.679e-04	1.183e-03	9.034e-07	2.283e-06	7.887e-07	1.993e-06	7.887e-09	1.993e-08
0.8711	8.443e+01	4.293e-05	9.980e-05	8.079e-08	1.878e-07	7.053e-08	1.640e-07	7.053e-10	1.640e-09
1.1732	7.317e+06	5.773e+00	1.218e+01	1.032e-02	2.177e-02	9.006e-03	1.900e-02	9.006e-05	1.900e-04
1.3325	7.317e+06	6.980e+00	1.416e+01	1.211e-02	2.456e-02	1.057e-02	2.144e-02	1.057e-04	2.144e-04
Totals	**1.464e+07**	**1.275e+01**	**2.634e+01**	**2.243e-02**	**4.634e-02**	**1.958e-02**	**4.045e-02**	**1.958e-04**	**4.045e-04**

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	2.002e-004	4.136e-004

A.2.5 Membrane Filter Skid

Operations of the membrane filter skid includes replacement of membrane filter cartridges, and the manual addition of chemicals. The replacement of the membrane filter cartridges is performed infrequently (e.g. every 4-5 years), and is excluded from the normal operations radiological consequence analysis.

The membrane filter skid is cleaned intermittently using the CIP process. Most chemicals are provided via process lines, however some chemicals may be added manually. This task duration is estimated to be 20 minutes at 30 cm from the membrane filter skid. The CIP process is performed weekly for 35 weeks, and the total time spent in the vicinity of the membrane filter skid is 11.67 hours/year.

The dose rate near the membrane filter skid is conservatively estimated to be equivalent to that of the membrane filter process tank, 4.14E-04 mSv/h. This is considered conservative since the process tank contains a greater quantity of radioactive material, and residuals that may build up on the filter are continually pumped to the process tank.

The MicroShield dose rate results for the membrane filter process tank normal operations are shown in Table A-5. The membrane filter skid operations results in an annual radiological consequence to the WWTP worker of 4.83E-03 mSv, based on the dose rate of 4.14E-04 mSv/h and the estimated activity duration of 11.67 hours/year.

A.2.6 pH Adjust Tank

Normal operations for the pH adjust tanks includes routine sampling and routine maintenance activities. Sampling is performed at the polishing system pH adjustment tank, on the outlet of the membrane filtration unit, to analyze wastewater characteristics prior to treatment in the polishing system. This task duration is estimated to be 20 minutes/day during the WWTP process operation of 140 days/year. This results in an annual exposure duration of 46.67 hours.

Maintenance of the polishing system pH adjustment tank motor and level instrumentation is expected to occur on a monthly basis. This task is expected to have a duration of two hours per tank (two tanks), for a total of 48 hours/year.

The dose rate at 30 cm from the full polishing system pH adjust tank is calculated to support the estimate of WWTP worker radiological consequence presented in Section 14.2. The following inputs and assumptions are used in this calculation:

- The pH adjust tank has a height of 220 cm, radius of 84 cm and is conservatively assumed to be full [A-3].
- The source term is from WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the pH adjust tank normal operations are shown in Table A-6. The annual radiological consequences to the WWTP worker for the pH adjust tank normal operations activities, based on the dose rate of 1.18E-04 mSv/h are:

- Sampling task radiological consequence is 5.05E-03 mSv/y.
- Maintenance task radiological consequence is 5.66E-03 mSv/y.

Table A-6
MicroShield Output - pH Adjust Tank

MicroShield 9.07
CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
5-pH Polishing activity in water.msd	May 21, 2019	8:28:22 PM	00:00:01

Project Info	
Case Title	5-pH Polishing
Description	Dose rate outside pH adjust Polishing tank filled with water
Geometry	7 - Cylinder Volume - Side Shields

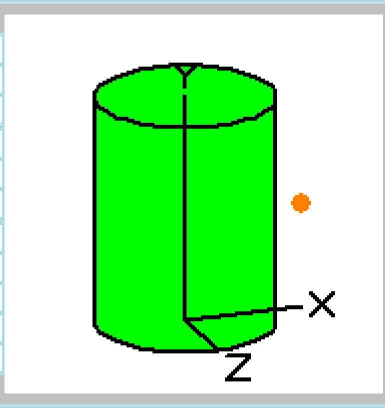
Source Dimensions	
Height	220.0 cm (7 ft 2.6 in)
Radius	84.0 cm (2 ft 9.1 in)

Dose Points

A	X	Y	Z
#1	114.0 cm (3 ft 8.9 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	4.88e+06 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	1.7794e-011	6.5838e-001	3.6487e-012	1.3500e-007
Am-241	2.7679e-010	1.0241e+001	5.6757e-011	2.1000e-006
Am-243	1.6871e-013	6.2422e-003	3.4595e-014	1.2800e-009
Ba-137m	1.1596e-007	4.2905e+003	2.3778e-008	8.7978e-004
C-14	4.0859e-007	1.5118e+004	8.3783e-008	3.1000e-003
Cl-36	7.7765e-009	2.8773e+002	1.5946e-009	5.9000e-005
Co-60	4.9954e-005	1.8483e+006	1.0243e-005	3.7900e-001
Cs-135	5.4040e-012	1.9995e-001	1.1081e-012	4.1000e-008
Cs-137	1.2258e-007	4.5354e+003	2.5135e-008	9.3000e-004
H-3	1.8453e-002	6.8276e+008	3.7839e-003	1.4000e+002
I-129	1.1994e-008	4.4378e+002	2.4595e-009	9.1000e-005
Mo-93	5.4040e-014	1.9995e-003	1.1081e-014	4.1000e-010
Nb-94	1.4894e-009	5.5107e+001	3.0541e-010	1.1300e-005
Ni-59	2.5175e-012	9.3146e-002	5.1622e-013	1.9100e-008
Ni-63	6.5243e-010	2.4140e+001	1.3378e-010	4.9500e-006
Np-237	6.2343e-014	2.3067e-003	1.2784e-014	4.7300e-010
Pu-239	4.3495e-010	1.6093e+001	8.9188e-011	3.3000e-006
Pu-241	7.8160e-009	2.8919e+002	1.6027e-009	5.9300e-005
Pu-242	3.2687e-013	1.2094e-002	6.7027e-014	2.4800e-009

Ra-226	6.3266e-011	2.3408e+000	1.2973e-011	4.8000e-007
Se-79	2.3725e-012	8.7783e-002	4.8649e-013	1.8000e-008
Sn-126	7.1174e-013	2.6334e-002	1.4595e-013	5.4000e-009
Sr-90	6.8406e-008	2.5310e+003	1.4027e-008	5.1900e-004
Tc-99	7.5128e-007	2.7797e+004	1.5405e-007	5.7000e-003
Th-230	2.1748e-011	8.0468e-001	4.4595e-012	1.6500e-007
Th-232	9.4899e-011	3.5113e+000	1.9459e-011	7.2000e-007
U-233	6.6561e-013	2.4628e-002	1.3649e-013	5.0500e-009
U-234	1.7925e-010	6.6324e+000	3.6757e-011	1.3600e-006
U-235	7.5656e-012	2.7993e-001	1.5514e-012	5.7400e-008
U-238	1.7398e-010	6.4373e+000	3.5676e-011	1.3200e-006
Y-90	6.8406e-008	2.5310e+003	1.4027e-008	5.1900e-004
Zr-93	4.3495e-009	1.6093e+002	8.9188e-010	3.3000e-005

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0289	7.457e+02	2.917e-06	6.152e-06	3.248e-08	6.849e-08	2.835e-08	5.979e-08	2.835e-10	5.979e-10
0.0615	3.979e+00	6.249e-08	3.934e-07	1.205e-10	7.585e-10	1.052e-10	6.622e-10	1.052e-12	6.622e-12
0.1334	4.655e-02	2.011e-09	1.182e-08	3.216e-12	1.890e-11	2.807e-12	1.650e-11	2.807e-14	1.650e-13
0.186	2.630e-01	1.753e-08	8.678e-08	3.044e-11	1.507e-10	2.657e-11	1.315e-10	2.657e-13	1.315e-12
0.2214	2.799e-04	2.353e-11	1.051e-10	4.242e-14	1.895e-13	3.703e-14	1.655e-13	3.703e-16	1.655e-15
0.3097	1.561e-04	2.065e-11	7.515e-11	3.933e-14	1.431e-13	3.434e-14	1.250e-13	3.434e-16	1.250e-15
0.4339	5.918e-01	1.250e-07	3.860e-07	2.446e-10	7.554e-10	2.135e-10	6.594e-10	2.135e-12	6.594e-12
0.6144	5.951e-01	2.057e-07	5.459e-07	4.008e-10	1.064e-09	3.499e-10	9.290e-10	3.499e-12	9.290e-12
0.6616	3.861e+03	1.484e-03	3.822e-03	2.876e-06	7.410e-06	2.511e-06	6.469e-06	2.511e-08	6.469e-08
0.6952	3.572e+02	1.474e-04	3.724e-04	2.846e-07	7.188e-07	2.484e-07	6.275e-07	2.484e-09	6.275e-09
0.8711	5.511e+01	3.156e-05	7.335e-05	5.939e-08	1.380e-07	5.185e-08	1.205e-07	5.185e-10	1.205e-09
1.1732	1.848e+06	1.642e+00	3.463e+00	2.935e-03	6.189e-03	2.562e-03	5.403e-03	2.562e-05	5.403e-05
1.3325	1.848e+06	1.986e+00	4.025e+00	3.445e-03	6.982e-03	3.007e-03	6.096e-03	3.007e-05	6.096e-05
Totals	3.702e+06	3.629e+00	7.492e+00	6.383e-03	1.318e-02	5.572e-03	1.151e-02	5.572e-05	1.151e-04

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	5.698e-005	1.177e-004

A.2.7 Polishing System Feed Tank

The two polishing system feed tanks are expected to require maintenance for level instrumentation at an estimated frequency of once per month. This task is expected to have a duration of one hour, for a total of 24 hours/year.

The dose rate at 30 cm from the full polishing system feed tank is calculated, to support the estimate of WWTP worker radiological consequence presented in Section 14.2. The following inputs and assumptions are used in this calculation:

- The polishing system feed tank has a height of 670.6 cm, radius of 213.5 cm and is conservatively assumed to be full [A-3].
- The source term is from WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

Table A-7 shows the MicroShield dose rate results for the polishing system feed tank normal operations. The polishing system feed tank normal operations annual radiological consequence to the WWTP worker is 3.82E-03 mSv/y, based on the dose rate of 1.59E-04 mSv/h and the estimated task duration of 24 hours/year.

Table A-7
MicroShield Output – Polishing System Feed Tank

MicroShield 9.07 CNL (9.07-0000)

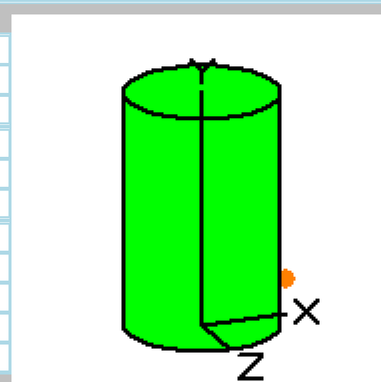
Filename	Run Date	Run Time	Duration
6-Polish Feed activity in water.msd	May 21, 2019	8:32:31 PM	00:00:01

Project Info	
Case Title	6-Polish Feed
Description	Dose rate outside Polishing feed tank filled with water
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	670.6 cm (22 ft 0.0 in)
Radius	213.5 cm (7 ft 0.1 in)

Dose Points			
A	X	Y	Z
#1	243.5 cm (7 ft 11.9 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	9.60e+07 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	3.5038e-010	1.2964e+001	3.6486e-012	1.3500e-007

Am-241	5.4504e-009	2.0166e+002	5.6757e-011	2.1000e-006
Am-243	3.3221e-012	1.2292e-001	3.4595e-014	1.2800e-009
Ba-137m	2.2834e-006	8.4486e+004	2.3778e-008	8.7978e-004
C-14	8.0458e-006	2.9769e+005	8.3784e-008	3.1000e-003
Cl-36	1.5313e-007	5.6658e+003	1.5946e-009	5.9000e-005
Co-60	9.8366e-004	3.6396e+007	1.0243e-005	3.7900e-001
Cs-135	1.0641e-010	3.9373e+000	1.1081e-012	4.1000e-008
Cs-137	2.4137e-006	8.9308e+004	2.5135e-008	9.3000e-004
H-3	3.6336e-001	1.3444e+010	3.7838e-003	1.4000e+002
I-129	2.3618e-007	8.7388e+003	2.4595e-009	9.1000e-005
Mo-93	1.0641e-012	3.9373e-002	1.1081e-014	4.1000e-010
Nb-94	2.9328e-008	1.0851e+003	3.0541e-010	1.1300e-005
Ni-59	4.9573e-011	1.8342e+000	5.1622e-013	1.9100e-008
Ni-63	1.2847e-008	4.7535e+002	1.3378e-010	4.9500e-006
Np-237	1.2276e-012	4.5422e-002	1.2784e-014	4.7300e-010
Pu-239	8.5649e-009	3.1690e+002	8.9189e-011	3.3000e-006
Pu-241	1.5391e-007	5.6946e+003	1.6027e-009	5.9300e-005
Pu-242	6.3899e-012	2.3643e-001	6.6540e-014	2.4620e-009
Ra-226	1.2458e-009	4.6095e+001	1.2973e-011	4.8000e-007
Se-79	4.6718e-011	1.7285e+000	4.8649e-013	1.8000e-008
Sn-126	1.4015e-011	5.1856e-001	1.4595e-013	5.4000e-009
Sr-90	1.3470e-006	4.9840e+004	1.4027e-008	5.1900e-004
Tc-99	1.4794e-005	5.4737e+005	1.5405e-007	5.7000e-003
Th-230	4.2824e-010	1.5845e+001	4.4595e-012	1.6500e-007
Th-232	1.8687e-009	6.9142e+001	1.9459e-011	7.2000e-007
U-233	1.3107e-011	4.8495e-001	1.3649e-013	5.0500e-009
U-234	3.5298e-009	1.3060e+002	3.6757e-011	1.3600e-006
U-235	1.4898e-010	5.5122e+000	1.5514e-012	5.7400e-008
U-238	3.4260e-009	1.2676e+002	3.5676e-011	1.3200e-006
Y-90	1.3470e-006	4.9840e+004	1.4027e-008	5.1900e-004
Zr-93	8.5649e-008	3.1690e+003	8.9189e-010	3.3000e-005

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0289	1.468e+04	3.724e-06	8.129e-06	4.146e-08	9.050e-08	3.620e-08	7.901e-08	3.620e-10	7.901e-10
0.0615	7.834e+01	8.127e-08	5.175e-07	1.567e-10	9.979e-10	1.368e-10	8.712e-10	1.368e-12	8.712e-12
0.1334	9.166e-01	2.624e-09	1.565e-08	4.196e-12	2.502e-11	3.663e-12	2.184e-11	3.663e-14	2.184e-13
0.186	5.179e+00	2.291e-08	1.151e-07	3.977e-11	1.998e-10	3.472e-11	1.744e-10	3.472e-13	1.744e-12
0.2214	5.512e-03	3.076e-11	1.395e-10	5.548e-14	2.516e-13	4.843e-14	2.197e-13	4.843e-16	2.197e-15
0.3097	3.075e-03	2.705e-11	9.996e-11	5.151e-14	1.904e-13	4.497e-14	1.662e-13	4.497e-16	1.662e-15
0.4339	1.165e+01	1.640e-07	5.146e-07	3.209e-10	1.007e-09	2.801e-10	8.791e-10	2.801e-12	8.791e-12
0.6144	1.172e+01	2.705e-07	7.300e-07	5.272e-10	1.423e-09	4.602e-10	1.242e-09	4.602e-12	1.242e-11
0.6616	7.602e+04	1.953e-03	5.115e-03	3.785e-06	9.916e-06	3.305e-06	8.657e-06	3.305e-08	8.657e-08
0.6952	7.034e+03	1.941e-04	4.986e-04	3.746e-07	9.624e-07	3.271e-07	8.402e-07	3.271e-09	8.402e-09
0.8711	1.085e+03	4.163e-05	9.847e-05	7.835e-08	1.853e-07	6.840e-08	1.618e-07	6.840e-10	1.618e-09
1.1732	3.640e+07	2.174e+00	4.671e+00	3.885e-03	8.347e-03	3.392e-03	7.287e-03	3.392e-05	7.287e-05

1.3325	3.640e+07	2.633e+00	5.442e+00	4.568e-03	9.441e-03	3.988e-03	8.242e-03	3.988e-05	8.242e-05
Totals	7.289e+07	4.809e+00	1.012e+01	8.458e-03	1.780e-02	7.384e-03	1.554e-02	7.384e-05	1.554e-04

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	7.550e-005	1.589e-004

A.2.8 Ion Exchange and Granular Activated Carbon Tanks

The IX and GAC tanks normal operations involve routine sampling and replacement of GAC and IX resins. During the WWTP process, sampling is performed at the outlet of each IX and GAC tank, to verify the polishing process efficiency. The sampling exposure duration is estimated to be 20 minutes for each tank type per day during the WWTP operation of 140 days/year. Therefore, the annual exposure duration for each of the GAC, Zeolite IX and SAC IX tanks is 46.67 hours/year.

The tanks containing GAC, Zeolite IX and SAC IX, require media volume changes approximately nine, seven and six times per year, respectively [A-5]. This task is estimated to have an exposure duration of one hour per media volume change. Therefore, the annual exposure duration for the GAC, Zeolite IX and SAC IX tank media volume changes are nine hours, seven hours, and six hours respectively.

The dose rate at 30 cm from the GAC, Zeolite IX and SAC IX tanks are calculated to support the estimated radiological consequences to the WWTP worker presented in Section 14.2. The following inputs and assumptions are used for the GAC, Zeolite IX and SAC IX tanks:

- Measurements are not available for the GAC or IX tanks, therefore, tank volumes are estimated based on the media volumes from [A-5].
- The GAC tank has a media volume of 1.93 m^3 [A-5]. The GAC tank is modelled as a cylinder with a height of 130 cm and a radius of 69 cm.
- The Zeolite IX tank has a media volume of 1.93 m^3 [A-5]. The Zeolite IX tank is modelled as a cylinder with a height of 130 cm and a radius of 69 cm.
- The SAC IX tank has a media volume of 2.55 m^3 [A-5]. The SAC IX tank is modelled as a cylinder with a height of 172 cm and a radius of 69 cm.
- The source term for the GAC, Zeolite IX, and SAC IX tanks are a combination of the water in the tank and the media. Therefore, the source term for the GAC, Zeolite IX and SAC IX tanks are estimated as the higher concentration between the spent media and the effluent from the WWTP Process Flow Diagram Table [A-4]. The Ba-137m concentration from the Zeolite IX tank is assumed to be the same as in the SAC IX tank (7.17E-01 Bq/cm^3) because Ba-137m is not captured by the Zeolite media. The effects are assumed to only be applicable to the SAC IX tanks because of the short half-life of Ba-137 m (2.55 minutes).
- Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.

- During the sampling task the GAC and IX resins will not be spent. Therefore, the dose rate from the media retrieval is divided by two to approximate the average dose rate during sampling.
- The GAC, Zeolite IX, and SAC IX tank walls are assumed to be 0.635 cm thick and are modelled as 316 SS with a density of 7.99 g/cm^3.
- The receptor height is at the mid-point of the tank; 65 cm for the GAC and Zeolite IX tanks, and 86 cm for the SAC IX tank.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the GAC, Zeolite IX, and SAC IX tanks normal operations are shown in Table A-8, Table A-9 and Table A-10, respectively. The estimated annual radiological consequences to the WWTP worker for routine sampling of the GAC, Zeolite IX, and SAC IX tanks are:

- GAC tank radiological consequence is 1.19E-03 mSv/y, based on the dose rate of 2.54E-05 mSv/h.
- Zeolite IX tank radiological consequence is 4.90E-03 mSv/y, based on dose rate of 1.05E-04 mSv/h.
- SAC IX tank radiological consequence is 2.66E+00 mSv/y, based on dose rate of 5.69E-02 mSv/h.

The estimated annual radiological consequences to the WWTP worker for the removal of the spent GAC and IX spent media are:

- GAC spent media change radiological consequence is 2.29E-04 mSv/y, based on an annual exposure of nine hours and a dose rate of 2.54E-05 mSv/h.
- Zeolite IX spent resin change radiological consequence is 7.35E-04 mSv/y, based on an annual exposure of seven hours at a dose rate of 1.05E-04 mSv/h.
- SAC IX spent resin change radiological consequence is 3.41E-01 mSv/y, based on an annual exposure of six hours at a dose rate of 5.69E-02 mSv/h.

Table A-8
MicroShield Output – GAC Tank

MicroShield 9.07 CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
11- Spent GAC in IX vessel-SAM.msd	May 21, 2019	8:38:43 PM	00:00:01

Project Info	
Case Title	10-GAC
Description	Dose rate from spent GAC inside IX vessel
Geometry	7 - Cylinder Volume - Side Shields

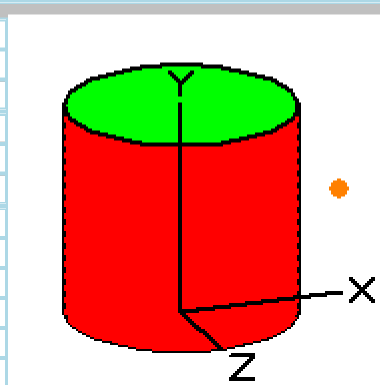
Source Dimensions	
Height	130.0 cm (4 ft 3.2 in)
Radius	69.0 cm (2 ft 3.2 in)

Dose Points

A	X	Y	Z
#1	99.635 cm (3 ft 3.2 in)	65.0 cm (2 ft 1.6 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	1.94e+06 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122
Wall Clad	.635 cm	SS316	7.99



Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	3.5400e-011	1.3098e+000	1.8206e-011	6.7362e-007
Am-241	9.1900e-012	3.4003e-001	4.7263e-012	1.7487e-007
Am-243	5.5300e-015	2.0461e-004	2.8440e-015	1.0523e-010
Ba-137m	8.1261e-009	3.0067e+002	4.1792e-009	1.5463e-004
C-14	5.1100e-008	1.8907e+003	2.6280e-008	9.7237e-004
Cl-36	4.3700e-010	1.6169e+001	2.2474e-010	8.3156e-006
Co-60	6.8200e-006	2.5234e+005	3.5075e-006	1.2978e-001
Cs-135	3.8500e-013	1.4245e-002	1.9800e-013	7.3261e-009
Cs-137	8.5900e-009	3.1783e+002	4.4178e-009	1.6346e-004
H-3	3.2100e-003	1.1877e+008	1.6509e-003	6.1082e+001
I-129	3.8700e-010	1.4319e+001	1.9903e-010	7.3641e-006
Mo-93	6.8000e-016	2.5160e-005	3.4972e-016	1.2940e-011
Nb-94	3.9000e-011	1.4430e+000	2.0057e-011	7.4212e-007
Ni-59	5.6500e-013	2.0905e-002	2.9057e-013	1.0751e-008
Ni-63	1.4100e-010	5.2170e+000	7.2515e-011	2.6831e-006
Np-237	3.1400e-013	1.1618e-002	1.6149e-013	5.9750e-009
Pu-239	3.5200e-011	1.3024e+000	1.8103e-011	6.6981e-007
Pu-241	6.2900e-010	2.3273e+001	3.2349e-010	1.1969e-005
Pu-242	2.5900e-014	9.5830e-004	1.3320e-014	4.9284e-010
Ra-226	3.3300e-012	1.2321e-001	1.7126e-012	6.3366e-008
Se-79	1.9100e-013	7.0670e-003	9.8230e-014	3.6345e-009

Sn-126	1.2500e-013	4.6250e-003	6.4286e-014	2.3786e-009
Sr-90	2.7000e-009	9.9900e+001	1.3886e-009	5.1378e-005
Tc-99	3.2100e-007	1.1877e+004	1.6509e-007	6.1082e-003
Th-230	1.5400e-013	5.6980e-003	7.9201e-014	2.9304e-009
Th-232	6.6100e-013	2.4457e-002	3.3995e-013	1.2578e-008
U-233	9.2000e-014	3.4040e-003	4.7315e-014	1.7506e-009
U-234	2.5000e-011	9.2500e-001	1.2857e-011	4.7572e-007
U-235	1.0600e-012	3.9220e-002	5.4515e-013	2.0170e-008
U-238	2.4400e-011	9.0280e-001	1.2549e-011	4.6430e-007
Y-90	2.7000e-009	9.9900e+001	1.3886e-009	5.1378e-005
Zr-93	1.0600e-010	3.9220e+000	5.4515e-011	2.0170e-006

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.015	4.785e+00	5.751e-132	1.064e-32	4.932e-133	9.122e-34	4.306e-133	7.964e-34	4.306e-135	7.964e-36
0.02	8.597e-01	7.389e-69	5.790e-33	2.560e-70	2.005e-34	2.235e-70	1.751e-34	2.235e-72	1.751e-36
0.03	2.776e+01	4.754e-27	1.966e-25	4.711e-29	1.948e-27	4.113e-29	1.701e-27	4.113e-31	1.701e-29
0.04	5.256e+00	6.365e-17	5.838e-15	2.815e-19	2.582e-17	2.458e-19	2.254e-17	2.458e-21	2.254e-19
0.05	1.108e-03	1.901e-16	2.295e-14	5.065e-19	6.114e-17	4.422e-19	5.337e-17	4.422e-21	5.337e-19
0.06	1.241e-01	1.971e-12	2.077e-10	3.914e-15	4.126e-13	3.417e-15	3.602e-13	3.417e-17	3.602e-15
0.08	1.672e-01	1.452e-10	8.310e-09	2.298e-13	1.315e-11	2.006e-13	1.148e-11	2.006e-15	1.148e-13
0.1	5.109e-03	2.395e-11	7.895e-10	3.663e-14	1.208e-12	3.198e-14	1.054e-12	3.198e-16	1.054e-14
0.15	6.261e-03	1.555e-10	2.279e-09	2.561e-13	3.753e-12	2.236e-13	3.277e-12	2.236e-15	3.277e-14
0.2	2.829e-02	1.437e-09	1.439e-08	2.536e-12	2.540e-11	2.214e-12	2.217e-11	2.214e-14	2.217e-13
0.3	8.218e-06	9.182e-13	5.865e-12	1.742e-15	1.112e-14	1.521e-15	9.712e-15	1.521e-17	9.712e-17
0.4	1.177e+00	2.183e-07	1.097e-06	4.253e-10	2.138e-09	3.713e-10	1.866e-09	3.713e-12	1.866e-11
0.6	3.129e+02	1.158e-04	4.359e-04	2.260e-07	8.508e-07	1.973e-07	7.428e-07	1.973e-09	7.428e-09
0.8	4.071e+00	2.449e-06	7.724e-06	4.659e-09	1.469e-08	4.067e-09	1.283e-08	4.067e-11	1.283e-10
1.0	2.523e+05	2.213e-01	6.192e-01	4.079e-04	1.141e-03	3.561e-04	9.963e-04	3.561e-06	9.963e-06
1.5	2.523e+05	4.372e-01	1.009e+00	7.356e-04	1.697e-03	6.421e-04	1.482e-03	6.421e-06	1.482e-05
Totals	5.050e+05	6.586e-01	1.628e+00	1.144e-03	2.839e-03	9.984e-04	2.479e-03	9.984e-06	2.479e-05

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	1.021e-005	2.537e-005

Table A-9
MicroShield Output – Zeolite IX Tank

MicroShield 9.07 CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
10-Spent zeolite in IX vessel - SAM.msd	May 21, 2019	8:45:51 PM	00:00:01

Project Info	
Case Title	11-Zeolite
Description	Dose rate from spent Zeolite inside IX vessel
Geometry	7 - Cylinder Volume - Side Shields

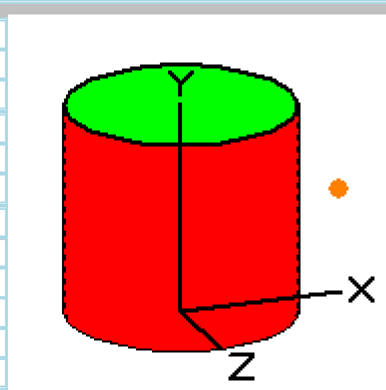
Source Dimensions	
Height	130.0 cm (4 ft 3.2 in)
Radius	69.0 cm (2 ft 3.2 in)

Dose Points

A	X	Y	Z
#1	99.635 cm (3 ft 3.2 in)	65.0 cm (2 ft 1.6 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	1.94e+06 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122
Wall Clad	.635 cm	SS316	7.99



Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ag-108m	7.0945e-012	2.6250e-001	3.6486e-012	1.3500e-007
Am-241	1.1036e-010	4.0833e+000	5.6757e-011	2.1000e-006
Am-243	6.7267e-014	2.4889e-003	3.4595e-014	1.2800e-009
Ba-137m	3.7683e-005	1.3943e+006	1.9380e-005	7.1707e-001
C-14	1.6291e-007	6.0277e+003	8.3784e-008	3.1000e-003
Cl-36	3.1006e-009	1.1472e+002	1.5946e-009	5.9000e-005
Co-60	1.9917e-005	7.3694e+005	1.0243e-005	3.7900e-001
Cs-135	1.7552e-009	6.4944e+001	9.0270e-010	3.3400e-005
Cs-137	3.9834e-005	1.4739e+006	2.0486e-005	7.5800e-001
H-3	7.3573e-003	2.7222e+008	3.7838e-003	1.4000e+002
I-129	4.7822e-009	1.7694e+002	2.4595e-009	9.1000e-005
Mo-93	2.1546e-014	7.9721e-004	1.1081e-014	4.1000e-010
Nb-94	5.9384e-010	2.1972e+001	3.0541e-010	1.1300e-005
Ni-59	1.0037e-012	3.7139e-002	5.1622e-013	1.9100e-008
Ni-63	2.6013e-010	9.6249e+000	1.3378e-010	4.9500e-006
Np-237	2.4857e-014	9.1971e-004	1.2784e-014	4.7300e-010
Pu-239	1.7342e-010	6.4166e+000	8.9189e-011	3.3000e-006
Pu-241	3.1163e-009	1.1530e+002	1.6027e-009	5.9300e-005
Pu-242	1.3033e-013	4.8222e-003	6.7027e-014	2.4800e-009
Ra-226	2.5225e-011	9.3332e-001	1.2973e-011	4.8000e-007

Se-79	9.4594e-013	3.5000e-002	4.8649e-013	1.8000e-008
Sn-126	2.8378e-013	1.0500e-002	1.4595e-013	5.4000e-009
Sr-90	2.7275e-008	1.0092e+003	1.4027e-008	5.1900e-004
Tc-99	2.9955e-007	1.1083e+004	1.5405e-007	5.7000e-003
Th-230	8.6711e-012	3.2083e-001	4.4595e-012	1.6500e-007
Th-232	3.7837e-011	1.4000e+000	1.9459e-011	7.2000e-007
U-233	2.6539e-013	9.8194e-003	1.3649e-013	5.0500e-009
U-234	7.1471e-011	2.6444e+000	3.6757e-011	1.3600e-006
U-235	3.0165e-012	1.1161e-001	1.5514e-012	5.7400e-008
U-238	6.9369e-011	2.5666e+000	3.5676e-011	1.3200e-006
Y-90	2.7275e-008	1.0092e+003	1.4027e-008	5.1900e-004
Zr-93	1.7342e-009	6.4166e+001	8.9189e-010	3.3000e-005

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.015	1.449e+04	1.742e-128	3.221e-29	1.494e-129	2.763e-30	1.304e-129	2.412e-30	1.304e-131	2.412e-32
0.02	1.774e-01	1.525e-69	1.195e-33	5.283e-71	4.139e-35	4.612e-71	3.613e-35	4.612e-73	3.613e-37
0.03	8.225e+04	1.408e-23	5.823e-22	1.396e-25	5.771e-24	1.218e-25	5.038e-24	1.218e-27	5.038e-26
0.04	1.939e+04	2.349e-13	2.154e-11	1.039e-15	9.527e-14	9.068e-16	8.317e-14	9.068e-18	8.317e-16
0.05	3.126e-03	5.364e-16	6.474e-14	1.429e-18	1.725e-16	1.247e-18	1.506e-16	1.247e-20	1.506e-18
0.06	1.481e+00	2.351e-11	2.478e-09	4.669e-14	4.922e-12	4.076e-14	4.297e-12	4.076e-16	4.297e-14
0.08	9.712e-02	8.436e-11	4.828e-09	1.335e-13	7.641e-12	1.165e-13	6.671e-12	1.165e-15	6.671e-14
0.1	1.459e-02	6.839e-11	2.255e-09	1.046e-13	3.449e-12	9.134e-14	3.011e-12	9.134e-16	3.011e-14
0.15	1.804e-02	4.481e-10	6.566e-09	7.379e-13	1.081e-11	6.442e-13	9.440e-12	6.442e-15	9.440e-14
0.2	9.949e-02	5.054e-09	5.061e-08	8.920e-12	8.933e-11	7.787e-12	7.798e-11	7.787e-14	7.798e-13
0.3	6.225e-05	6.956e-12	4.443e-11	1.319e-14	8.427e-14	1.152e-14	7.357e-14	1.152e-16	7.357e-16
0.4	2.359e-01	4.374e-08	2.199e-07	8.523e-11	4.284e-10	7.441e-11	3.740e-10	7.441e-13	3.740e-12
0.6	1.255e+06	4.643e-01	1.748e+00	9.062e-04	3.412e-03	7.911e-04	2.979e-03	7.911e-06	2.979e-05
0.8	4.418e+01	2.658e-05	8.382e-05	5.056e-08	1.594e-07	4.414e-08	1.392e-07	4.414e-10	1.392e-09
1.0	7.369e+05	6.462e-01	1.808e+00	1.191e-03	3.333e-03	1.040e-03	2.910e-03	1.040e-05	2.910e-05
1.5	7.369e+05	1.277e+00	2.946e+00	2.148e-03	4.956e-03	1.875e-03	4.327e-03	1.875e-05	4.327e-05
Totals	2.845e+06	2.387e+00	6.502e+00	4.246e-03	1.170e-02	3.706e-03	1.022e-02	3.706e-05	1.022e-04

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Anterior/Posterior Geometry	mSv/h	3.815e-005	1.054e-004

Table A-10
MicroShield Output – SAC IX Resin Tank

MicroShield 9.07 CNL (9.07-0000)

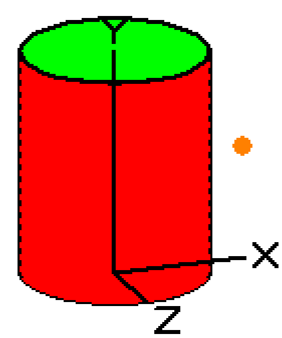
Filename	Run Date	Run Time	Duration
12-Spent SAC in IX vessel-SAM.msd	May 21, 2019	8:50:52 PM	00:00:01

Project Info	
Case Title	12-SAC
Description	Dose rate from spent SAC resins inside IX vessel
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	172.0 cm (5 ft 7.7 in)
Radius	69.0 cm (2 ft 3.2 in)

Dose Points			
A	X	Y	Z
#1	99.635 cm (3 ft 3.2 in)	86.0 cm (2 ft 9.9 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	2.57e+06 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122
Wall Clad	.635 cm	SS316	7.99



Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	6.5776e-009	2.4337e+002	2.5568e-009	9.4600e-005
Am-241	1.0221e-007	3.7818e+003	3.9730e-008	1.4700e-003
Am-243	6.2091e-011	2.2974e+000	2.4135e-011	8.9300e-007
Ba-137m	4.9853e-005	1.8446e+006	1.9378e-005	7.1700e-001
C-14	2.1554e-007	7.9751e+003	8.3784e-008	3.1000e-003
Cl-36	4.1023e-009	1.5178e+002	1.5946e-009	5.9000e-005
Co-60	1.8495e-002	6.8432e+008	7.1892e-003	2.6600e+002
Cs-135	1.7104e-014	6.3287e-004	6.6486e-015	2.4600e-010
Cs-137	3.8798e-010	1.4355e+001	1.5081e-010	5.5800e-006
H-3	9.7343e-003	3.6017e+008	3.7838e-003	1.4000e+002
I-129	6.3273e-009	2.3411e+002	2.4595e-009	9.1000e-005
Mo-93	2.8507e-014	1.0548e-003	1.1081e-014	4.1000e-010
Nb-94	5.4790e-007	2.0272e+004	2.1297e-007	7.8800e-003
Ni-59	1.3280e-012	4.9137e-002	5.1622e-013	1.9100e-008
Ni-63	3.4418e-010	1.2734e+001	1.3378e-010	4.9500e-006
Np-237	2.3015e-011	8.5154e-001	8.9459e-012	3.3100e-007
Pu-239	1.6062e-007	5.9428e+003	6.2432e-008	2.3100e-003
Pu-241	2.8855e-006	1.0676e+005	1.1216e-006	4.1500e-002
Pu-242	1.2029e-010	4.4506e+000	4.6757e-011	1.7300e-006
Ra-226	2.3362e-008	8.6440e+002	9.0811e-009	3.3600e-004
Se-79	8.7608e-010	3.2415e+001	3.4054e-010	1.2600e-005
Sn-126	2.6282e-010	9.7245e+000	1.0216e-010	3.7800e-006

Sr-90	2.6213e-005	9.6988e+005	1.0189e-005	3.7700e-001
Tc-99	3.9632e-007	1.4664e+004	1.5405e-007	5.7000e-003
Th-230	8.0655e-009	2.9842e+002	3.1351e-009	1.1600e-004
Th-232	3.5043e-008	1.2966e+003	1.3622e-008	5.0400e-004
U-233	3.5113e-013	1.2992e-002	1.3649e-013	5.0500e-009
U-234	9.4561e-011	3.4988e+000	3.6757e-011	1.3600e-006
U-235	3.9910e-012	1.4767e-001	1.5514e-012	5.7400e-008
U-238	9.1780e-011	3.3959e+000	3.5676e-011	1.3200e-006
Y-90	2.6213e-005	9.6988e+005	1.0189e-005	3.7700e-001
Zr-93	1.6062e-006	5.9428e+004	6.2432e-007	2.3100e-002

Buildup: The material reference is Transition
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.015	2.122e+04	1.927e-128	4.066e-29	1.653e-129	3.487e-30	1.443e-129	3.045e-30	1.443e-131	3.045e-32
0.02	1.644e+02	1.068e-66	8.937e-31	3.700e-68	3.096e-32	3.230e-68	2.702e-32	3.230e-70	2.702e-34
0.03	1.089e+05	1.409e-23	4.724e-22	1.397e-25	4.682e-24	1.219e-25	4.087e-24	1.219e-27	4.087e-26
0.04	2.566e+04	2.348e-13	1.734e-11	1.039e-15	7.667e-14	9.067e-16	6.693e-14	9.067e-18	6.693e-16
0.05	9.098e-03	1.180e-15	1.185e-13	3.143e-18	3.157e-16	2.744e-18	2.756e-16	2.744e-20	2.756e-18
0.06	1.369e+03	1.643e-08	1.496e-06	3.263e-11	2.971e-09	2.849e-11	2.594e-09	2.849e-13	2.594e-11
0.08	2.758e+01	1.814e-08	9.454e-07	2.870e-11	1.496e-09	2.505e-11	1.306e-09	2.505e-13	1.306e-11
0.1	4.081e+00	1.455e-08	4.531e-07	2.226e-11	6.932e-10	1.944e-11	6.051e-10	1.944e-13	6.051e-12
0.15	7.905e-01	1.514e-08	2.178e-07	2.493e-11	3.587e-10	2.176e-11	3.132e-10	2.176e-13	3.132e-12
0.2	2.845e+01	1.122e-06	1.092e-05	1.981e-09	1.927e-08	1.730e-09	1.682e-08	1.730e-11	1.682e-10
0.3	5.766e-02	5.045e-09	3.259e-08	9.571e-12	6.182e-11	8.355e-12	5.397e-11	8.355e-14	5.397e-13
0.4	2.187e+02	3.193e-05	1.630e-04	6.221e-08	3.175e-07	5.431e-08	2.772e-07	5.431e-10	2.772e-09
0.6	1.772e+06	5.200e-01	2.001e+00	1.015e-03	3.906e-03	8.861e-04	3.410e-03	8.861e-06	3.410e-05
0.8	4.076e+04	1.957e-02	6.320e-02	3.722e-05	1.202e-04	3.249e-05	1.049e-04	3.249e-07	1.049e-06
1.0	6.843e+08	4.811e+02	1.379e+03	8.869e-01	2.542e+00	7.743e-01	2.219e+00	7.743e-03	2.219e-02
1.5	6.843e+08	9.600e+02	2.272e+03	1.615e+00	3.822e+00	1.410e+00	3.337e+00	1.410e-02	3.337e-02
Totals	1.371e+09	1.442e+03	3.653e+03	2.503e+00	6.369e+00	2.185e+00	5.560e+00	2.185e-02	5.560e-02

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	2.235e-002	5.690e-002

A.2.9 Final pH Adjust Tank

Maintenance of the final pH adjust tank motor and level instrumentation is expected to occur on a monthly basis. This task is expected to have a duration of two hours per tank (two tanks), for a total of 48 hours/year.

The dose rate at 30 cm from the final pH adjust tank is calculated, to support the estimated radiological consequence to the WWTP worker presented in Section 14.2. The following inputs and assumptions are used in this calculation:

- The final pH adjust tank has a height of 220 cm, a radius of 84 cm and is conservatively assumed to be full [A-3].
- The source term is from WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the final pH adjust tank normal operations are shown in Table A-11. The final pH adjust tank annual normal operation radiological consequence to the WWTP worker is 2.83E-04 mSv/y, based on the dose rate of 5.90E-06 mSv/h and the estimated task duration of 48 hours/year.

Table A-11
MicroShield Output – Final pH Adjust Tank

MicroShield 9.07 CNL (9.07-0000)

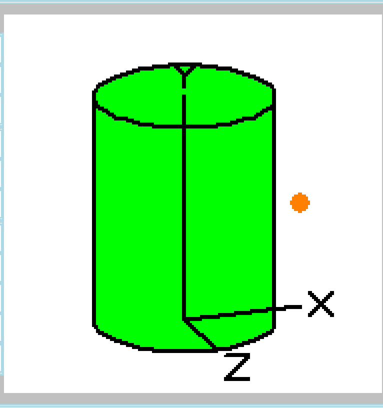
Filename	Run Date	Run Time	Duration
8-pH Final activity in water.msd	May 21, 2019	9:14:25 PM	00:00:01

Project Info	
Case Title	8-pH Final
Description	Dose rate outside pH Final tank filled with water
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	220.0 cm (7 ft 2.6 in)
Radius	84.0 cm (2 ft 9.1 in)

Dose Points			
A	X	Y	Z
#1	114.0 cm (3 ft 8.9 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	4.88e+06 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	8.8968e-013	3.2918e-002	1.8243e-013	6.7500e-009
Am-241	1.3839e-011	5.1204e-001	2.8377e-012	1.0500e-007
Am-243	8.4091e-015	3.1114e-004	1.7243e-015	6.3800e-011
Ba-137m	6.9575e-010	2.5743e+001	1.4267e-010	5.2787e-006
C-14	4.0859e-007	1.5118e+004	8.3783e-008	3.1000e-003
Cl-36	7.7765e-009	2.8773e+002	1.5946e-009	5.9000e-005
Co-60	2.5043e-006	9.2658e+004	5.1351e-007	1.9000e-002
Cs-135	3.2424e-014	1.1997e-003	6.6487e-015	2.4600e-010
Cs-137	7.3547e-010	2.7212e+001	1.5081e-010	5.5800e-006
H-3	1.8453e-002	6.8276e+008	3.7839e-003	1.4000e+002
I-129	1.1994e-008	4.4378e+002	2.4595e-009	9.1000e-005
Mo-93	5.4040e-014	1.9995e-003	1.1081e-014	4.1000e-010
Nb-94	7.4206e-011	2.7456e+000	1.5216e-011	5.6300e-007
Ni-59	2.5175e-012	9.3146e-002	5.1622e-013	1.9100e-008
Ni-63	6.5243e-010	2.4140e+001	1.3378e-010	4.9500e-006
Np-237	3.1106e-015	1.1509e-004	6.3784e-016	2.3600e-011
Pu-239	2.1748e-011	8.0468e-001	4.4595e-012	1.6500e-007
Pu-241	3.9014e-010	1.4435e+001	8.0000e-011	2.9600e-006
Pu-242	1.6344e-014	6.0472e-004	3.3514e-015	1.2400e-010
Ra-226	3.1633e-012	1.1704e-001	6.4865e-013	2.4000e-008
Se-79	1.1862e-013	4.3891e-003	2.4324e-014	9.0000e-010
Sn-126	3.5587e-014	1.3167e-003	7.2973e-015	2.7000e-010

Sr-90	1.0544e-009	3.9014e+001	2.1622e-010	8.0000e-006
Tc-99	7.5128e-007	2.7797e+004	1.5405e-007	5.7000e-003
Th-230	1.0874e-012	4.0233e-002	2.2297e-013	8.2500e-009
Th-232	4.7450e-012	1.7557e-001	9.7298e-013	3.6000e-008
U-233	6.6561e-013	2.4628e-002	1.3649e-013	5.0500e-009
U-234	1.7925e-010	6.6324e+000	3.6757e-011	1.3600e-006
U-235	7.5656e-012	2.7993e-001	1.5514e-012	5.7400e-008
U-238	1.7398e-010	6.4373e+000	3.5676e-011	1.3200e-006
Y-90	1.0544e-009	3.9014e+001	2.1622e-010	8.0000e-006
Zr-93	2.1748e-010	8.0468e+000	4.4595e-011	1.6500e-006

Buildup: The material reference is Source
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0286	3.850e+02	1.475e-06	3.076e-06	1.683e-08	3.508e-08	1.469e-08	3.062e-08	1.469e-10	3.062e-10
0.0749	3.829e-01	7.853e-09	5.422e-08	1.281e-11	8.845e-11	1.118e-11	7.722e-11	1.118e-13	7.722e-13
0.1376	3.779e-02	1.700e-09	9.836e-09	2.740e-12	1.585e-11	2.392e-12	1.384e-11	2.392e-14	1.384e-13
0.1859	1.895e-01	1.263e-08	6.252e-08	2.192e-11	1.085e-10	1.914e-11	9.474e-11	1.914e-13	9.474e-13
0.2214	2.799e-04	2.353e-11	1.051e-10	4.242e-14	1.895e-13	3.703e-14	1.655e-13	3.703e-16	1.655e-15
0.3097	7.807e-06	1.033e-12	3.758e-12	1.967e-15	7.156e-15	1.717e-15	6.248e-15	1.717e-17	6.248e-17
0.4339	2.959e-02	6.249e-09	1.930e-08	1.223e-11	3.777e-11	1.067e-11	3.297e-11	1.067e-13	3.297e-13
0.6144	2.976e-02	1.028e-08	2.730e-08	2.004e-11	5.320e-11	1.750e-11	4.645e-11	1.750e-13	4.645e-13
0.6616	2.316e+01	8.902e-06	2.293e-05	1.726e-08	4.446e-08	1.507e-08	3.882e-08	1.507e-10	3.882e-10
0.6952	1.789e+01	7.383e-06	1.865e-05	1.425e-08	3.600e-08	1.244e-08	3.143e-08	1.244e-10	3.143e-10
0.8711	2.746e+00	1.572e-06	3.654e-06	2.959e-09	6.877e-09	2.583e-09	6.004e-09	2.583e-11	6.004e-11
1.1732	9.266e+04	8.233e-02	1.736e-01	1.471e-04	3.103e-04	1.284e-04	2.709e-04	1.284e-06	2.709e-06
1.3325	9.266e+04	9.954e-02	2.018e-01	1.727e-04	3.500e-04	1.508e-04	3.056e-04	1.508e-06	3.056e-06
Totals	1.857e+05	1.819e-01	3.754e-01	3.199e-04	6.604e-04	2.792e-04	5.765e-04	2.792e-06	5.765e-06

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	2.855e-006	5.895e-006

A.2.10 Final Effluent Tank

Maintenance of each final effluent tank motor and level instrumentation is expected to occur on a monthly basis. A maintenance duration of two hours per tank (two tanks), for a total of 48 hours per year is estimated.

The dose rate at 30 cm from the final effluent tank is calculated, to support the estimated radiological consequence to the WWTP worker presented in Section 14.2. The following inputs and assumptions are used in this calculation:

- The final effluent tank has a height of 670.6 cm, a radius of 213.5 cm, and is conservatively assumed to be full [A-3].
- The source term is from the WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the final effluent tank normal operations are shown in Table A-12. The final effluent tank annual normal operation radiological consequence to the WWTP worker is 1.91E-04 mSv/y, based on the dose rate of 7.96E-06 mSv/h and the estimated task duration of 48 hours/year.

Table A-12
MicroShield Output – FINAL EFFLUENT TANK

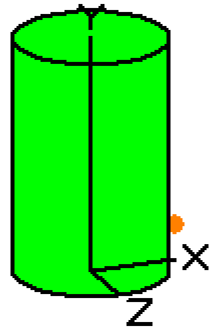
MicroShield 9.07 CNL (9.07-0000)

Filename		Run Date	Run Time	Duration
9-Final effluent activity in water.msd		May 21, 2019	9:17:45 PM	00:00:01
Project Info				
Case Title	9-Final effluent			
Description	Dose rate outside final effluent tank filled with water			
Geometry	7 - Cylinder Volume - Side Shields			

Source Dimensions				
Height	670.6 cm (22 ft 0.0 in)			
Radius	213.5 cm (7 ft 0.1 in)			

Dose Points			
A	X	Y	Z
#1	243.5 cm (7 ft 11.9 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	9.60e+07 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	1.7519e-011	6.4821e-001	1.8243e-013	6.7500e-009
Am-241	2.7356e-010	1.0122e+001	2.8486e-012	1.0540e-007
Am-243	1.6559e-013	6.1267e-003	1.7243e-015	6.3800e-011
Ba-137m	1.3700e-008	5.0691e+002	1.4267e-010	5.2787e-006
C-14	8.0458e-006	2.9769e+005	8.3784e-008	3.1000e-003
Cl-36	1.5313e-007	5.6658e+003	1.5946e-009	5.9000e-005
Co-60	4.9313e-005	1.8246e+006	5.1351e-007	1.9000e-002
Cs-135	6.3847e-013	2.3624e-002	6.6486e-015	2.4600e-010
Cs-137	1.4482e-008	5.3585e+002	1.5081e-010	5.5800e-006
H-3	3.6336e-001	1.3444e+010	3.7838e-003	1.4000e+002
I-129	2.3618e-007	8.7388e+003	2.4595e-009	9.1000e-005
Mo-93	1.0641e-012	3.9373e-002	1.1081e-014	4.1000e-010
Nb-94	1.4612e-009	5.4065e+001	1.5216e-011	5.6300e-007
Ni-59	4.9573e-011	1.8342e+000	5.1622e-013	1.9100e-008
Ni-63	1.2847e-008	4.7535e+002	1.3378e-010	4.9500e-006
Np-237	6.1252e-014	2.2663e-003	6.3784e-016	2.3600e-011
Pu-239	4.2824e-010	1.5845e+001	4.4595e-012	1.6500e-007
Pu-241	7.6824e-009	2.8425e+002	8.0000e-011	2.9600e-006
Pu-242	3.2183e-013	1.1908e-002	3.3514e-015	1.2400e-010
Ra-226	6.2290e-011	2.3047e+000	6.4865e-013	2.4000e-008
Se-79	2.3359e-012	8.6427e-002	2.4324e-014	9.0000e-010
Sn-126	7.0076e-013	2.5928e-002	7.2973e-015	2.7000e-010
Sr-90	2.0763e-008	7.6824e+002	2.1622e-010	8.0000e-006
Tc-99	1.4794e-005	5.4737e+005	1.5405e-007	5.7000e-003
Th-230	2.1412e-011	7.9225e-001	2.2297e-013	8.2500e-009
Th-232	9.3435e-011	3.4571e+000	9.7297e-013	3.6000e-008
U-233	1.3107e-011	4.8495e-001	1.3649e-013	5.0500e-009
U-234	3.5298e-009	1.3060e+002	3.6757e-011	1.3600e-006
U-235	1.4898e-010	5.5122e+000	1.5514e-012	5.7400e-008
U-238	3.4260e-009	1.2676e+002	3.5676e-011	1.3200e-006
Y-90	2.0763e-008	7.6824e+002	2.1622e-010	8.0000e-006
Zr-93	4.2824e-009	1.5845e+002	4.4595e-011	1.6500e-006

Buildup: The material reference is Source
Integration Parameters

Radial	20

Circumferential									20
Y Direction (axial)									40
Results									
Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0286	7.580e+03	1.882e-06	4.065e-06	2.147e-08	4.636e-08	1.874e-08	4.047e-08	1.874e-10	4.047e-10
0.0748	7.554e+00	1.024e-08	7.154e-08	1.671e-11	1.167e-10	1.458e-11	1.019e-10	1.458e-13	1.019e-12
0.1376	7.441e-01	2.219e-09	1.302e-08	3.576e-12	2.098e-11	3.122e-12	1.831e-11	3.122e-14	1.831e-13
0.1859	3.731e+00	1.650e-08	8.291e-08	2.865e-11	1.439e-10	2.501e-11	1.256e-10	2.501e-13	1.256e-12
0.2214	5.512e-03	3.076e-11	1.395e-10	5.548e-14	2.516e-13	4.843e-14	2.197e-13	4.843e-16	2.197e-15
0.3097	1.537e-04	1.352e-12	4.998e-12	2.576e-15	9.519e-15	2.249e-15	8.310e-15	2.249e-17	8.310e-17
0.4339	5.826e-01	8.199e-09	2.573e-08	1.604e-11	5.035e-11	1.401e-11	4.395e-11	1.401e-13	4.395e-13
0.6144	5.859e-01	1.352e-08	3.650e-08	2.636e-11	7.114e-11	2.301e-11	6.211e-11	2.301e-13	6.211e-13
0.6616	4.561e+02	1.172e-05	3.069e-05	2.271e-08	5.950e-08	1.983e-08	5.194e-08	1.983e-10	5.194e-10
0.6952	3.523e+02	9.720e-06	2.497e-05	1.876e-08	4.820e-08	1.638e-08	4.208e-08	1.638e-10	4.208e-10
0.8711	5.407e+01	2.074e-06	4.906e-06	3.904e-09	9.233e-09	3.408e-09	8.060e-09	3.408e-11	8.060e-11
1.1732	1.825e+06	1.090e-01	2.342e-01	1.948e-04	4.184e-04	1.700e-04	3.653e-04	1.700e-06	3.653e-06
1.3325	1.825e+06	1.320e-01	2.728e-01	2.290e-04	4.733e-04	1.999e-04	4.132e-04	1.999e-06	4.132e-06
Totals	3.658e+06	2.410e-01	5.070e-01	4.239e-04	8.919e-04	3.700e-04	7.786e-04	3.700e-06	7.786e-06

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	3.783e-006	7.961e-006

A.2.11 Residuals Storage Tank

Normal operations for the residual storage tanks includes routine maintenance activities and removal of supernatant. Maintenance of each residuals storage tank motor and level instrumentation is expected to occur on a monthly basis. This task is expected to have a duration of two hours per tank (two tanks), for a total of 48 hours/year.

Supernatant is removed from the residuals tank prior to filter press operation at a frequency of 0.41 cycles per day [A-5]. Assuming 140 days of operation, this results in approximately 58 cycles/year. The worker exposure duration is estimated at 30 minutes near the residuals storage tank per cycle. Therefore, the total worker exposure duration is approximately 29 hours/year.

The dose rate at 30 cm from the full residuals storage tank is calculated to support the estimated radiological consequence to the WWTP worker presented in Section 14.2. The following inputs and assumptions are used in this calculation:

- The residuals storage tank has a height of 670.6 cm, a radius of 213.5 cm, and is conservatively assumed to be full [A-3].
- The source term is from the WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.
- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the residuals storage tank normal operations are shown in Table A-13. The estimated annual radiological consequence to the WWTP worker for normal operations on residuals storage tank based on the dose rate of 7.88E-03 mSv/h are:

- Maintenance activities radiological consequence is 3.78E-01 mSv/y.
- Removal of supernatant activity radiological consequence is 2.29E-01 mSv/y.

Table A-13
MicroShield Output – Residual Storage Tank

MicroShield 9.07 CNL (9.07-0000)

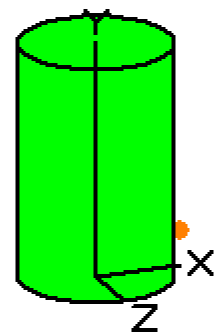
Filename	Run Date	Run Time	Duration
14-Residuals storage.msd	May 21, 2019	9:21:54 PM	00:00:01

Project Info	
Case Title	14-Residuals Storage
Description	Dose rate outside Residuals Storage tank filled with water
Geometry	7 - Cylinder Volume - Side Shields

Source Dimensions	
Height	670.6 cm (22 ft 0.0 in)
Radius	213.5 cm (7 ft 0.1 in)

Dose Points			
A	X	Y	Z
#1	243.5 cm (7 ft 11.9 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	9.60e+07 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	2.6733e-009	9.8911e+001	2.7838e-011	1.0300e-006
Am-241	4.1786e-008	1.5461e+003	4.3514e-010	1.6100e-005
Am-243	2.5305e-011	9.3630e-001	2.6351e-013	9.7500e-009
Ba-137m	2.2343e-006	8.2669e+004	2.3266e-008	8.6086e-004
C-14	7.8641e-006	2.9097e+005	8.1892e-008	3.0300e-003
Cl-36	1.4976e-007	5.5410e+003	1.5595e-009	5.7700e-005
Co-60	4.8794e-002	1.8054e+009	5.0811e-004	1.8800e+001
Cs-135	1.0408e-010	3.8508e+000	1.0838e-012	4.0100e-008
Cs-137	2.3618e-006	8.7388e+004	2.4595e-008	9.1000e-004
H-3	3.5557e-001	1.3156e+010	3.7027e-003	1.3700e+002
I-129	2.3099e-007	8.5467e+003	2.4054e-009	8.9000e-005
Mo-93	1.0408e-012	3.8508e-002	1.0838e-014	4.0100e-010
Nb-94	2.2321e-007	8.2586e+003	2.3243e-009	8.6000e-005
Ni-59	7.8901e-009	2.9193e+002	8.2162e-011	3.0400e-006
Ni-63	2.0400e-006	7.5480e+004	2.1243e-008	7.8600e-004
Np-237	9.3695e-012	3.4667e-001	9.7568e-014	3.6100e-009
Pu-239	6.5405e-008	2.4200e+003	6.8108e-010	2.5200e-005
Pu-241	1.1757e-006	4.3502e+004	1.2243e-008	4.5300e-004
Pu-242	4.9053e-011	1.8150e+000	5.1081e-013	1.8900e-008
Ra-226	9.5252e-009	3.5243e+002	9.9189e-011	3.6700e-006
Se-79	3.5817e-010	1.3252e+001	3.7297e-012	1.3800e-007
Sn-126	1.0719e-010	3.9661e+000	1.1162e-012	4.1300e-008
Sr-90	4.7237e-004	1.7478e+007	4.9189e-006	1.8200e-001
Tc-99	1.4456e-005	5.3489e+005	1.5054e-007	5.5700e-003
Th-230	3.2702e-009	1.2100e+002	3.4054e-011	1.2600e-006
Th-232	1.4275e-008	5.2817e+002	1.4865e-010	5.5000e-006
U-233	1.2562e-009	4.6479e+001	1.3081e-011	4.8400e-007
U-234	3.3740e-007	1.2484e+004	3.5135e-009	1.3000e-004
U-235	1.4301e-008	5.2913e+002	1.4892e-010	5.5100e-006
U-238	3.2962e-007	1.2196e+004	3.4324e-009	1.2700e-004
Y-90	4.7237e-004	1.7478e+007	4.9189e-006	1.8200e-001
Zr-93	6.5405e-007	2.4200e+004	6.8108e-009	2.5200e-004

Buildup: The material reference is Source
Integration Parameters

Radial	20

Circumferential								20	
Y Direction (axial)								40	
Results									
Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0259	1.783e+04	3.326e-06	6.328e-06	5.172e-08	9.838e-08	4.515e-08	8.589e-08	4.515e-10	8.589e-10
0.063	6.358e+02	6.826e-07	4.424e-06	1.280e-09	8.295e-09	1.117e-09	7.242e-09	1.117e-11	7.242e-11
0.1375	7.192e+01	2.142e-07	1.257e-06	3.450e-10	2.025e-09	3.012e-10	1.768e-09	3.012e-12	1.768e-11
0.1859	3.625e+02	1.603e-06	8.055e-06	2.783e-09	1.398e-08	2.430e-09	1.221e-08	2.430e-11	1.221e-10
0.2214	5.291e-01	2.953e-09	1.339e-08	5.325e-12	2.415e-11	4.649e-12	2.108e-11	4.649e-14	2.108e-13
0.3097	2.351e-02	2.068e-10	7.643e-10	3.939e-13	1.456e-12	3.438e-13	1.271e-12	3.438e-15	1.271e-14
0.4339	8.890e+01	1.251e-06	3.926e-06	2.448e-09	7.683e-09	2.137e-09	6.707e-09	2.137e-11	6.707e-11
0.6144	8.941e+01	2.064e-06	5.570e-06	4.022e-09	1.086e-08	3.511e-09	9.477e-09	3.511e-11	9.477e-11
0.6616	7.439e+04	1.911e-03	5.005e-03	3.704e-06	9.703e-06	3.234e-06	8.471e-06	3.234e-08	8.471e-08
0.6941	3.028e+05	8.336e-03	2.143e-02	1.609e-05	4.137e-05	1.405e-05	3.612e-05	1.405e-07	3.612e-07
0.8711	8.259e+03	3.168e-04	7.494e-04	5.963e-07	1.410e-06	5.206e-07	1.231e-06	5.206e-09	1.231e-08
1.1732	1.805e+09	1.078e+02	2.317e+02	1.927e-01	4.140e-01	1.682e-01	3.615e-01	1.682e-03	3.615e-03
1.3325	1.805e+09	1.306e+02	2.699e+02	2.266e-01	4.683e-01	1.978e-01	4.088e-01	1.978e-03	4.088e-03
Totals	3.611e+09	2.385e+02	5.016e+02	4.193e-01	8.824e-01	3.661e-01	7.703e-01	3.661e-03	7.703e-03

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	3.743e-003	7.877e-003

A.2.12 Filter Press Feed Tank

The filter press feed tank requires maintenance for level instrumentation, at an estimated frequency of once per month. This task is expected to have a duration of two hours per month, for a total of 24 hours per year.

The dose rate at 30 cm from the full filter press feed tank is calculated, to support the estimated radiological consequences to the WWTP worker presented in Section 14.2. The following inputs and assumptions are used in this calculation:

- The filter press feed tank has a height of 250 cm, a radius of 122 cm and is conservatively assumed to be full [A-3].
- The source term in the filter process tank is estimated using a combination of the filtrate discharge and filter cake from WWTP Process Flow Diagram Table [A-4]. The ratio of the average annual flow rate for the filtrate discharge to filter cake is 0.68:0.11 or 6.18:1 [A-3]. The filter press feed tank concentration is estimated to be a combination of the filtrate discharge and filter cake at a ratio of 6.18:1. The source term values are shown in Table A-14.
- Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided from the tank wall is conservatively excluded.

- Dose point height is 1 m.
- Source term is modelled as water with a density of 1 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (radial, circumferential, axial) is (20, 20, 40).

The MicroShield dose rate results for the filter press feed tank normal operations are shown in Table A-14. The normal operation annual radiological consequence to the WWTP worker is 3.05E-01 mSv/y, based on the dose rate of 1.27E-02 mSv/h, and the estimated task duration of 24 hours/year.

Table A-14
MicroShield Output – Filter Press Feed Tank

MicroShield 9.07 CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
15-filter press feed tank-estimate.msd	May 22, 2019	10:56:06 AM	00:00:01

Project Info	
Case Title	15-Filter Press Feed
Description	Filter Press Feed Tank
Geometry	7 - Cylinder Volume - Side Shields

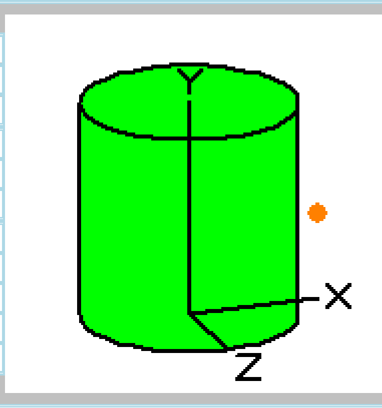
Source Dimensions	
Height	250.0 cm (8 ft 2.4 in)
Radius	122.0 cm (4 ft 0.0 in)

Dose Points

A	X	Y	Z
#1	152.0 cm (4 ft 11.8 in)	100.0 cm (3 ft 3.4 in)	0.0 cm (0 in)

Shields

Shield N	Dimension	Material	Density
Source	1.17e+07 cm³	Water	1
Transition		Air	0.00122
Air Gap		Air	0.00122



Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ag-108m	5.9081e-010	2.1860e+001	5.0541e-011	1.8700e-006
Am-241	9.1939e-009	3.4018e+002	7.8649e-010	2.9100e-005
Am-243	5.5922e-012	2.0691e-001	4.7838e-013	1.7700e-008
Ba-137m	2.6630e-007	9.8533e+003	2.2781e-008	8.4289e-004
C-14	9.3835e-007	3.4719e+004	8.0270e-008	2.9700e-003
Cl-36	1.7851e-009	6.6048e+001	1.5270e-010	5.6500e-006

Co-60	1.1374e-002	4.2084e+008	9.7297e-004	3.6000e+001
Cs-135	1.2417e-011	4.5941e-001	1.0622e-012	3.9300e-008
Cs-137	2.8150e-007	1.0416e+004	2.4081e-008	8.9100e-004
H-3	4.2336e-002	1.5664e+009	3.6216e-003	1.3400e+002
I-129	2.7550e-008	1.0194e+003	2.3568e-009	8.7200e-005
Mo-93	1.2417e-013	4.5941e-003	1.0622e-014	3.9300e-010
Nb-94	4.9287e-008	1.8236e+003	4.2162e-009	1.5600e-004
Ni-59	1.8451e-009	6.8269e+001	1.5784e-010	5.8400e-006
Ni-63	4.7707e-007	1.7652e+004	4.0811e-008	1.5100e-003
Np-237	2.0631e-012	7.6335e-002	1.7649e-013	6.5300e-009
Pu-239	1.4407e-008	5.3306e+002	1.2324e-009	4.5600e-005
Pu-241	2.5907e-007	9.5857e+003	2.2162e-008	8.2000e-004
Pu-242	1.0805e-011	3.9979e-001	9.2432e-013	3.4200e-008
Ra-226	2.0979e-009	7.7621e+001	1.7946e-010	6.6400e-006
Se-79	7.8670e-011	2.9108e+000	6.7297e-012	2.4900e-007
Sn-126	2.3601e-011	8.7323e-001	2.0189e-012	7.4700e-008
Sr-90	1.1090e-004	4.1031e+006	9.4865e-006	3.5100e-001
Tc-99	1.7250e-006	6.3827e+004	1.4757e-007	5.4600e-003
Th-230	7.2351e-010	2.6770e+001	6.1892e-011	2.2900e-006
Th-232	3.1436e-009	1.1631e+002	2.6892e-010	9.9500e-006
U-233	2.9351e-010	1.0860e+001	2.5108e-011	9.2900e-007
U-234	7.8986e-008	2.9225e+003	6.7568e-009	2.5000e-004
U-235	3.3490e-009	1.2391e+002	2.8649e-010	1.0600e-005
U-238	7.6774e-008	2.8406e+003	6.5676e-009	2.4300e-004
Y-90	1.1090e-004	4.1031e+006	9.4865e-006	3.5100e-001
Zr-93	1.4407e-007	5.3306e+003	1.2324e-008	4.5600e-004

Buildup: The material reference is Transition
Integration Parameters

Radial	20
Circumferential	20
Y Direction (axial)	40

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.015	9.904e+02	1.790e-07	2.139e-07	1.535e-08	1.834e-08	1.340e-08	1.601e-08	1.340e-10	1.601e-10
0.02	1.477e+01	8.779e-09	1.228e-08	3.041e-10	4.253e-10	2.655e-10	3.713e-10	2.655e-12	3.713e-12
0.03	1.304e+03	2.659e-06	5.840e-06	2.635e-08	5.788e-08	2.301e-08	5.052e-08	2.301e-10	5.052e-10
0.04	2.136e+02	8.078e-07	2.777e-06	3.573e-09	1.228e-08	3.119e-09	1.072e-08	3.119e-11	1.072e-10
0.05	3.449e+00	1.902e-08	9.123e-08	5.066e-11	2.430e-10	4.422e-11	2.122e-10	4.422e-13	2.122e-12
0.06	1.259e+02	9.079e-07	5.296e-06	1.803e-09	1.052e-08	1.574e-09	9.182e-09	1.574e-11	9.182e-11
0.08	6.357e+00	6.756e-08	4.446e-07	1.069e-10	7.035e-10	9.333e-11	6.142e-10	9.333e-13	6.142e-12
0.1	1.168e+01	1.656e-07	1.055e-06	2.533e-10	1.614e-09	2.211e-10	1.409e-09	2.211e-12	1.409e-11
0.15	1.918e+01	4.580e-07	2.449e-06	7.542e-10	4.032e-09	6.585e-10	3.520e-09	6.585e-12	3.520e-11
0.2	7.901e+01	2.754e-06	1.239e-05	4.860e-09	2.188e-08	4.243e-09	1.910e-08	4.243e-11	1.910e-10
0.3	5.177e-03	3.111e-10	1.131e-09	5.901e-13	2.145e-12	5.152e-13	1.873e-12	5.152e-15	1.873e-14
0.4	1.965e+01	1.757e-06	5.562e-06	3.423e-09	1.084e-08	2.988e-09	9.461e-09	2.988e-11	9.461e-11
0.6	7.753e+04	1.228e-02	3.277e-02	2.398e-05	6.397e-05	2.093e-05	5.584e-05	2.093e-07	5.584e-07
0.8	3.667e+03	8.796e-04	2.106e-03	1.673e-06	4.005e-06	1.461e-06	3.496e-06	1.461e-08	3.496e-08
1.0	4.208e+08	1.400e+02	3.116e+02	2.581e-01	5.743e-01	2.253e-01	5.014e-01	2.253e-03	5.014e-03
1.5	4.208e+08	2.565e+02	5.063e+02	4.316e-01	8.519e-01	3.768e-01	7.437e-01	3.768e-03	7.437e-03
Totals	8.418e+08	3.966e+02	8.179e+02	6.897e-01	1.426e+00	6.021e-01	1.245e+00	6.021e-03	1.245e-02

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	6.161e-003	1.274e-002

A.2.13 Filter Press

Filter press operations include operating and cleaning the filter press, and transferring of the residuals bins containing dewatered filter cake.

Operation of the filter press is estimated to occur at a frequency of 0.41 cycles per day [A-5], during the operation of 140 days per year. The WWTP worker is estimated to be in the proximity of the filter press for 15 minutes in order to initiate the filter press process, and is assumed to not remain in the vicinity for the duration of the filter press operation. Therefore, a total worker exposure duration of 14.35 hours per year is estimated for the filter press start-up.

Following each cycle, the worker manually scrapes the filter press plates to remove any remaining residuals. This may result in inhalation of airborne radioactive particulate. The filter press is located within a ventilated enclosure, which is conservatively assumed to have an air volume of 63 m^3 (half of total enclosure volume 126 m^3, to account for presence of filter press equipment). When the space is occupied, the ventilation system operates at 20 air changes per hour [A-6]. Assuming 0.41 cycles per day [A-6] for 140 days, this results in approximately 58 filter press cleanings per year.

De-watered residuals from the filter press are estimated to be generated at a rate of 0.28 m^3/cycle with approximately 15 residuals bins containing dewatered filter cake being generated annually [A-7]. The residuals bin volume is 2.70 m^3 [A-7]. Note that the generation of 15 residual bins from the filter press is based on the filter press operating 365 days/year [A-7], and approximately six residual bins will be generated annually based on 140 days of operation. The residuals bin containing dewatered filter cake is transferred to the ECM approximately 15 times per year [A-7]. The worker exposure duration is estimated to be 1 hour per transfer for a total of 15 hours/year based on 15 residual bin transfers. Note that the transfer of 15 residual bins is conservative, since there will be approximately six residual bin transfers based on 140 days of filter press operation.

The dose rate at 30 cm from the full residuals bin containing dewatered filter cake is calculated, to support estimating the radiological consequence to the WWTP worker presented in Section 14.2.

The filter press capacity per cycle is 0.28 m^3 [A-7], approximately one ninth (1/9th) of the volume from the dewatered residuals bin. Therefore, the dose rate from the filter press is assumed to be 1/9th the residuals bin dose rate, and assuming no shielding provided by the filter press. The following inputs and assumptions are used for the radiation field calculation for the filter press and the filter press residuals bin:

- The residuals bin is modelled as a soft-sided container with an approximate length of 122 cm, width of 183 cm, height of 122 cm, and is conservatively assumed to be full [A-7].
- The source term is from WWTP Process Flow Diagram Table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided the soft-sided container is conservatively excluded.
- Dose point height is 61 cm.
- Source term is modelled as soil with a density of 1.5 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (x, y, z) is (20, 20, 20).
- The filter press cleaning exposure is 1 hour/cleaning and there are 58 cleanings/year, which results in an annual filter press cleaning exposure of 58 hours/year.
- Worker is positioned at 30 cm from the filter press and the residuals bin.

The inhalation dose radiological consequence to the worker from the filter press cleaning is estimated using the instantaneous mixing with gradual removal model as per [A-8]. The inhalation dose radiological consequence calculation uses the following inputs and assumptions:

- The Material At Risk (MAR) is the volume of material in the full filter press of 0.28 m^3 [A-7] at the concentration from the process flow diagram table [A-4]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- The worker inhalation Dose Conversion Factor (DCF)s are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm Activity Median Aerodynamic Diameter (AMAD) (ICRP 119, Table A) [A-9]. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.
- Tritium and C-14 are considered to be HTO and CO_2, respectively (inhalation DCFs from ICRP 119 Table B for workers) [A-9].
- The Damage Ratio (DR) is conservatively assumed to be 1.
- The Leakpath Factor (LPF) is 1.
- The ARF is 1.0E-04. This is based on the bounding ARF of 5E-05 for a free-fall spill of slurries (<40% solids) from 3 m or less [A-10], and has been multiplied by two to conservatively account for the fact that a slurry may not be an exact representation of spilled resin media or filter press cake.
- The Respirable Fraction (RF) is 0.8. This is the bounding RF for a free fall spill from [A-10].
- Worker breathing rate is 3.33E-04 m^3/s [A-8].
- A total of 20 air changes an hour occur in the room [A-6].

- The total volume of the filter press enclosure is 126 m^3 [A-6], room volume is assumed to be half full with a volume 63 m^3.
- The exposure duration is 3 600 seconds for filter press cleaning cycle and transfer of residuals bin. Note that the dose remains unchanged for an exposure beyond this duration due to the ventilation removing airborne contamination.
- Decay of radionuclides is excluded.

The respirable source term for each radionuclide is calculated using the following equation, A-1 [A-8]:

$$Source\ Term_i\ (ST_i) = MAR_i * DR_i * LPF_i * ARF_i * RF_i \quad \text{(A-1)}$$

The committed effective dose is calculated using the instantaneous mixing with gradual removal using the following equation, A-2 [A-8]:

$$Committed\ Effective\ Dose = \sum_{All\ nuclides,i} \left[\frac{ST_i}{V} * \frac{\left[1-e^{-\lambda_{eff} t}\right]}{\lambda_{eff}} \right] * BR * DCF_i \qquad \text{(A-2)}$$

Where:

ST_i Respirable Source term (Bq) for nuclide, i.

V Volume of the room, m^3.

λ_{eff} Effective removal constant of the radionuclide, s^{-1}.

BR Breathing Rate, $m^3.s^{-1}$.

t Residence time, s.

DCF_i Dose conversion factor, $Sv.Bq^{-1}$for nuclide, i.

Where:

$$\lambda_{eff} = \lambda + \frac{F}{V} \qquad \text{(A-3)}$$

Note: The effective removal constant, λ_{eff}, is simplified in instances with negligible radioactive decay to just $\frac{F}{V}$.

F, is the ventilation system flow rate, m^3/hour, and V is the room volume, m^3. If the number of air changes per hour is known, then $\boldsymbol{\frac{F}{V}}$ may be calculated by equation A-4:

$$N = \frac{F}{V} \qquad \text{(A-4)}$$

Table A-15 shows the inhalation radiological consequence for the filter press cleaning. The MicroShield dose rate for the dewatered residuals bin is shown in Table A-16. The estimated dose rate at 30 cm from the residuals bin is 6.77E-02 mSv/h. The filter press dose rate is approximated at one ninth (1/9th) of the dose rate at 30 cm from the residuals bin, thus the estimated dose rate at 30 cm from the filter press is 7.52E-03 mSv/h.

The worker cleaning the filter press is exposed annually to 4.36E-01 mSv/y external radiation based on an exposure rate 58 hours/year and a dose rate of 7.52E-03 mSv/h. The overall annual radiological consequence to the worker from cleaning the filter press is 4.36E-01 mSv/y based on 4.36E-01 mSv/y due external radiation and 1.05E-05 mSv/y due to inhalation.

The normal operations radiological consequences are:

- Filter press started up for 14.35 hours/year, results in an annual radiological consequence of 1.08E-01 mSv/y.
- Filter press cleaning of 58 cleanings/year, results in an annual radiological consequence of 4.36E-01 mSv/y.
- Transfer of residuals bins for 15 hours/year, results in an annual radiological consequence of 1.02 mSv/y.

Table A-15
Inhalation Radiological Consequence for Filter Press Cleaning

Radionuclide	Inhalation DCF (Sv/Bq)	Concentration in filter press cake (Bq/m^3)	Activity in Filter Press (Bq)	Material at Risk (Bq)	Inhalation Radiological Consequence (mSv)
Ag-108m	1.90E-08	1.26E+01	3.53E+00	2.82E-04	5.10E-12
Am-241	2.70E-05	1.96E+02	5.49E+01	4.69E-04	1.20E-08
Am-243	2.70E-05	1.19E-01	3.33E-02	2.85E-07	7.32E-12
C-14	6.50E-12	2.17E+03	6.08E+02	5.20E-03	3.22E-14
Cl-36	5.10E-09	4.13E+01	1.16E+01	9.89E-05	4.80E-13
Co-60	1.70E-08	2.56E+08	7.17E+07	6.13E+02	9.91E-06
Cs-135	9.90E-10	2.87E-02	8.04E-03	6.87E-08	6.47E-17
Cs-137	6.70E-09	6.51E+02	1.82E+02	1.56E-03	9.94E-12
H-3	2.70E-11	9.80E+07	2.74E+07	2.35E+02	6.04E-09
I-129	5.10E-08	6.37E+01	1.78E+01	1.53E-04	7.42E-12
Mo-93	1.40E-09	2.87E-04	8.04E-05	6.87E-10	9.15E-19
Nb-94	2.50E-08	1.05E+03	2.94E+02	2.51E-03	5.97E-11
Ni-59	2.20E-10	4.18E+01	1.17E+01	1.00E-04	2.09E-14
Ni-63	5.20E-10	1.08E+04	3.02E+03	2.59E-02	1.28E-11
Np-237	1.50E-05	4.40E-02	1.23E-02	1.05E-07	1.50E-12
Pu-239	3.20E-05	3.07E+02	8.60E+01	7.35E-04	2.24E-08
Pu-241	5.80E-07	5.52E+03	1.55E+03	1.32E-02	7.28E-09
Pu-242	3.10E-05	2.30E-01	6.44E-02	5.51E-07	1.63E-11
Ra-226	2.20E-06	4.47E+01	1.25E+01	1.07E-04	2.24E-10
Se-79	3.10E-09	1.68E+00	4.70E-01	4.02E-06	1.19E-14
Sn-126	1.80E-08	5.03E-01	1.41E-01	1.20E-06	2.06E-14
Sr-90	7.70E-08	2.52E+06	7.06E+05	6.03E+00	4.42E-07
Tc-99	3.20E-09	3.99E+03	1.12E+03	9.55E-03	2.91E-11
Th-230	2.80E-05	1.54E+01	4.31E+00	3.69E-05	9.83E-10
Th-232	2.90E-05	6.70E+01	1.88E+01	1.60E-04	4.41E-09
U-233	6.90E-06	6.64E+00	1.86E+00	1.59E-05	1.04E-10
U-234	6.80E-06	1.79E+03	5.01E+02	4.29E-03	2.78E-08
U-235	6.10E-06	7.56E+01	2.12E+01	1.81E-04	1.05E-09
U-238	5.70E-06	1.74E+03	4.87E+02	4.17E-03	2.26E-08
Zr-93	2.90E-08	3.07E+03	8.60E+02	7.35E-03	2.03E-10
				Total Radiological Consequence	**1.05E-05 mSv**

Table A-16
MicroShield Output – Filter Press De-watered Residuals Bin

MicroShield 9.07 CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
13-Residuals box.msd	May 22, 2019	11:05:42 AM	00:00:00

Project Info	
Case Title	12-Residuals bin
Description	Dose rate outside full residuals bin
Geometry	13 - Rectangular Volume

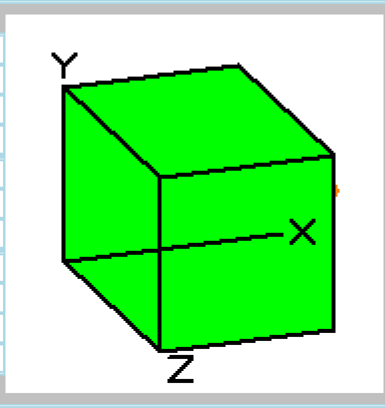
Source Dimensions	
Length	122.0 cm (4 ft 0.0 in)
Width	183.0 cm (6 ft 0.0 in)
Height	122.0 cm (4 ft 0.0 in)

Dose Points

A	X	Y	Z
#1	152.0 cm (4 ft 11.8 in)	61.0 cm (2 ft 0.0 in)	91.5 cm (3 ft 0.0 in)

Shields

Shield N	Dimension	Material	Density
Source	2.72e+06 cm³	Soil	1.5
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ag-108m	9.2755e-010	3.4320e+001	3.4054e-010	1.2600e-005
Am-241	1.4429e-008	5.3386e+002	5.2973e-009	1.9600e-004
Am-243	8.7602e-012	3.2413e-001	3.2162e-012	1.1900e-007
Ba-137m	4.5336e-008	1.6774e+003	1.6645e-008	6.1585e-004
C-14	1.5975e-007	5.9106e+003	5.8649e-008	2.1700e-003
Cl-36	3.0403e-009	1.1249e+002	1.1162e-009	4.1300e-005
Co-60	1.8846e-002	6.9729e+008	6.9189e-003	2.5600e+002
Cs-135	2.1128e-012	7.8174e-002	7.7569e-013	2.8700e-008
Cs-137	4.7924e-008	1.7732e+003	1.7595e-008	6.5100e-004
H-3	7.2143e-003	2.6693e+008	2.6486e-003	9.8000e+001
I-129	4.6893e-009	1.7350e+002	1.7216e-009	6.3700e-005
Mo-93	2.1128e-014	7.8174e-004	7.7569e-015	2.8700e-010
Nb-94	7.7296e-008	2.8600e+003	2.8378e-008	1.0500e-003
Ni-59	3.0771e-009	1.1385e+002	1.1297e-009	4.1800e-005
Ni-63	7.9505e-007	2.9417e+004	2.9189e-007	1.0800e-002
Np-237	3.2391e-012	1.1985e-001	1.1892e-012	4.4000e-008
Pu-239	2.2600e-008	8.3620e+002	8.2973e-009	3.0700e-004
Pu-241	4.0636e-007	1.5035e+004	1.4919e-007	5.5200e-003
Pu-242	1.6932e-011	6.2647e-001	6.2162e-012	2.3000e-007
Ra-226	3.2906e-009	1.2175e+002	1.2081e-009	4.4700e-005

Se-79	1.2367e-010	4.5759e+000	4.5405e-011	1.6800e-006
Sn-126	3.7029e-011	1.3701e+000	1.3595e-011	5.0300e-007
Sr-90	1.8551e-004	6.8639e+006	6.8108e-005	2.5200e+000
Tc-99	2.9373e-007	1.0868e+004	1.0784e-007	3.9900e-003
Th-230	1.1337e-009	4.1946e+001	4.1622e-010	1.5400e-005
Th-232	4.9322e-009	1.8249e+002	1.8108e-009	6.7000e-005
U-233	4.8881e-010	1.8086e+001	1.7946e-010	6.6400e-006
U-234	1.3177e-007	4.8756e+003	4.8378e-008	1.7900e-003
U-235	5.5653e-009	2.0592e+002	2.0432e-009	7.5600e-005
U-238	1.2809e-007	4.7394e+003	4.7027e-008	1.7400e-003
Y-90	1.8551e-004	6.8639e+006	6.8108e-005	2.5200e+000
Zr-93	2.2600e-007	8.3620e+003	8.2973e-008	3.0700e-003

Buildup: The material reference is Source
Integration Parameters

X Direction	20
Y Direction	20
Z Direction	20

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0161	1.655e+03	3.838e-11	4.104e-11	2.611e-12	2.793e-12	2.280e-12	2.438e-12	2.280e-14	2.438e-14
0.0632	2.212e+02	2.618e-06	4.812e-06	4.891e-09	8.992e-09	4.270e-09	7.850e-09	4.270e-11	7.850e-11
0.1375	2.794e+01	1.886e-06	5.185e-06	3.038e-09	8.353e-09	2.652e-09	7.293e-09	2.652e-11	7.293e-11
0.1859	1.406e+02	1.523e-05	4.265e-05	2.644e-08	7.404e-08	2.308e-08	6.463e-08	2.308e-10	6.463e-10
0.2214	2.059e-01	2.880e-08	7.969e-08	5.193e-11	1.437e-10	4.533e-11	1.254e-10	4.533e-13	1.254e-12
0.3097	8.121e-03	1.826e-09	4.797e-09	3.477e-12	9.136e-12	3.036e-12	7.976e-12	3.036e-14	7.976e-14
0.4339	3.085e+01	1.113e-05	2.721e-05	2.178e-08	5.324e-08	1.902e-08	4.648e-08	1.902e-10	4.648e-10
0.6144	3.102e+01	1.829e-05	4.092e-05	3.565e-08	7.975e-08	3.112e-08	6.962e-08	3.112e-10	6.962e-10
0.6616	1.509e+03	9.890e-04	2.171e-03	1.917e-06	4.210e-06	1.674e-06	3.675e-06	1.674e-08	3.675e-08
0.694	1.166e+05	8.181e-02	1.775e-01	1.580e-04	3.427e-04	1.379e-04	2.992e-04	1.379e-06	2.992e-06
0.8711	2.860e+03	2.780e-03	5.700e-03	5.232e-06	1.073e-05	4.568e-06	9.364e-06	4.568e-08	9.364e-08
1.1732	6.973e+08	1.045e+03	1.988e+03	1.868e+00	3.553e+00	1.630e+00	3.102e+00	1.630e-02	3.102e-02
1.3325	6.973e+08	1.259e+03	2.324e+03	2.184e+00	4.031e+00	1.907e+00	3.519e+00	1.907e-02	3.519e-02
Totals	1.395e+09	2.304e+03	4.312e+03	4.052e+00	7.585e+00	3.537e+00	6.621e+00	3.537e-02	6.621e-02

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	3.617e-002	6.770e-002

A.3 Normal Operations Radiological Consequence to Engineered Containment Mound Worker

The worker at the ECM is expected to receive a radiation consequence during normal waste placement operations. Operations where the ECM worker is expected to receive a radiological consequence include:

- Unloading and placement of bulk LLW.
- Packaged waste placement.
- Grouting packaged waste.
- Macroencapulation of drummed waste.
- Applying a daily cover.
- Moving and grading LLW.
- Repair/maintenance of cell.

Exposure durations are estimated based on consultation with ECM designers and operations regarding required O&M tasks. Dose rates are calculated using MicroShield Version 9.07 [A-1] and RESRAD-OFFSITE Version 3.2 [A-2].

A detailed discussion of ECM operations is located in Section 9 and Section 10. A summary of the dose to ECM workers during normal operations is provided in TableA-17. The task with the highest estimated radiological consequence is the ECM worker performing macroencapulation of the drummed waste.

Table A-17
Engineered Containment Mound Worker Normal Operations Radiological Consequence Summary

Section	Significant Tasks	Suggested Resources	Duration	Estimated Hours Near Source	Dose Rate (mSv/h)	4 Week Radiological Consequence (mSv)	Annual Radiological Consequence (mSv/y)
A.3.1	Unloading and placement of bulk LLW from shipment vehicle	2 Waste Technicians, 1 MSA 1 Driver, and 1 RP staff.	Work 8 hours/day, 4 days per week for an 8 month season spending 50% of time near the waste.	560	4.93E-03	0.32	2.76
A.3.1	Packaged waste placement	1 MSA, 1 Technician, 1 Driver, 2 RP staff, 1 Millwright, and 1 Hoisting	Work 8 hours/day, one day per week for an 8 month season spending 25% of the time near the waste package.	70	0.1	0.8	7.0
A.3.2	Grouting of packaged waste	1 Civil Engineer, 1 Technician, 1 MSA, 2 Carpenters, 2 RP staff, 1 Contamination Monitor, 1 Millwright, and 1 Hoisting Engineer.	Work 8 hours/day, 2 days per month for an 8 month season spending 50% of the time near the packaged waste containment area.	64	9.514E-02	0.76	6.09
A.3.3	Macroencapulation of drummed waste	1 Civil Engineer, 1 Technician, 1 MSA, 2 Carpenters, 2 RP staff, 1 Contamination Monitor, 1 Millwright, and 1 Hoisting Engineer.	Work 8 hours/day, 1 day per month for an 8 month season spending 25% of the time near macroencapulation containment area.	16	0.65	1.3	10.4

Section	Significant Tasks	Suggested Resources	Duration	Estimated Hours Near Source	Dose Rate (mSv/h)	4 Week Radiological Consequence (mSv)	Annual Radiological Consequence (mSv/y)
A.3.4	Apply a daily cover to the LLW.	2 Heavy equipment operators, and 1 RP staff.	Work 1 hour/day, 4 days per week for an 8 month season spending 100% of the time on the LLW.	140	5.69E-03	0.09	0.80
A.3.4	Moving and grading LLW	2 Heavy equipment operators, and 1 RP staff.	Work 8 hours/day, 4 days per week for an 8 month season spending 100% of the time on the LLW.	1120	5.69E-03	0.73	6.37
A.3.4	Maintenance activities to ECM	2 Heavy equipment operators, and 1 RP staff.	Work 8 hours/day, one day per week for an 8 month season spending 100% of the time on the LLW.	280	5.69E-03	0.18	1.59

A.3.1 Waste Unloading and Waste Placement

The NSDF ECM workers receive, monitor, handle, and place bulk waste and waste packages. The total estimated waste volume placed in Phase 1 of the NSDF operations is 525 000 m^3 over a 20-25 year period. Waste characterization estimates that, by volume, 87% of NSDF waste is bulk waste, and 13% is packaged waste [A-11].

Bulk waste and packaged waste is assumed to be transported in sealand containers (assuming a waste volume of 20 m^3) [A-12]. Assuming a uniform waste placement rate over 20 years this results in approximately:

- 1 142 placements of bulk waste in sealand containers per year, and
- 171 placements of packaged waste in sealand containers per year.

For waste placement, bulk waste placement is expected to occur eight hours/day, four days per week. Packaged waste placement is expected to occur eight hours/day for one day per week. The operating season is assumed to be eight months. For the worker unloading bulk LLW, they are assumed to spend approximately 50% of time near bulk waste, approximately 1 m away. For the worker unloading packaged waste they are assumed to spend 25% near the packaged waste, approximately 1 m away. This results in an estimated worker exposure duration of:

- 560 hours/year for bulk waste; and
- 70 hours/year for packaged waste.

MicroShield is used to calculate the dose rate from the bulk waste transportation packages. The largest expected bulk waste container is a 6.1 m sealand container, with external dimensions of 6.10 m x 2.44 m x 2.59 m [A-12]. The following inputs and assumptions are used for the radiation field calculation for a sealand container of bulk LLW:

- The sealand container of bulk LLW approximate length of 6.10 m, width of 2.44 m and height of 2.59 m, and is conservatively assumed to be full [A-12].
- The source term is from Table 3 of the Waste Characterization [A-11]. The density is assumed to be 1.5 g/ cm^3. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Shielding provided by the transportation container is conservatively excluded.
- Dose point height is 100 cm.
- Source term is modelled as soil with a density of 1.5 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (x, y, z) is (30, 30, 60).

Table A-18 shows the dose rate of 4.72E-03 mSv/h at 1 m from a sealand container filled with bulk LLW. For packaged wastes, the maximum dose rate at 1 m is 0.1 mSv/h [A-13].

The estimated annual radiological consequence to the NSDF ECM worker for receiving and placing waste is:

- 2.64 mSv/y for bulk waste (4.72E-03 mSv/h for 560 hours).
- 7.0 mSv/y for packaged waste (0.1 mSv/h for 70 hours is 7.0 mSv).

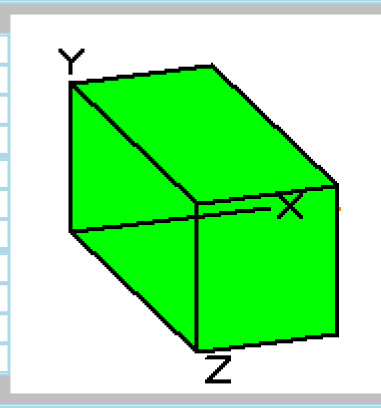
Table A-18
MicroShield Output – Dose Rate from LLW in a Sealand Container

MicroShield 9.07 CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
sealand container-bulk-SAM.msd	May 22, 2019	11:53:59 AM	00:00:02

Project Info	
Case Title	Sealand Container
Description	Dose rate at 1 m from bulk waste in SeaLand Container
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	244.0 cm (8 ft 0.1 in)
Width	610.0 cm (20 ft 0.2 in)
Height	259.0 cm (8 ft 6.0 in)



Dose Points

A	X	Y	Z
#1	344.0 cm (11 ft 3.4 in)	100.0 cm (3 ft 3.4 in)	304.8 cm (10 ft 0.0 in)

Shields

Shield N	Dimension	Material	Density
Source	3.85e+07 cm³	Soil	1.5
Air Gap		Air	0.00122

Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ag-108m	3.3028e-011	1.2220e+000	8.5676e-013	3.1700e-008
Am-241	2.2088e-005	8.1725e+005	5.7297e-007	2.1200e-002
Am-243	1.1252e-008	4.1634e+002	2.9189e-010	1.0800e-005
Ba-137m	1.1236e-003	4.1573e+007	2.9147e-005	1.0784e+000
C-14	3.6466e-004	1.3492e+007	9.4595e-006	3.5000e-001
Cl-36	1.0096e-006	3.7355e+004	2.6189e-008	9.6900e-004
Co-60	2.0838e-002	7.7099e+008	5.4054e-004	2.0000e+001
Cs-135	1.6878e-008	6.2450e+002	4.3784e-010	1.6200e-005
Cs-137	1.1877e-003	4.3946e+007	3.0811e-005	1.1400e+000
H-3	1.7191e-001	6.3607e+009	4.4595e-003	1.6500e+002
I-129	2.8443e-007	1.0524e+004	7.3784e-009	2.7300e-004
Mo-93	2.9381e-011	1.0871e+000	7.6216e-013	2.8200e-008
Nb-94	4.3967e-005	1.6268e+006	1.1405e-006	4.2200e-002
Ni-59	2.4588e-007	9.0977e+003	6.3784e-009	2.3600e-004
Ni-63	6.2200e-005	2.3014e+006	1.6135e-006	5.9700e-002
Np-237	3.7403e-009	1.3839e+002	9.7027e-011	3.5900e-006
Pu-239	1.8129e-005	6.7076e+005	4.7027e-007	1.7400e-002
Pu-241	3.5528e-004	1.3145e+007	9.2162e-006	3.4100e-001
Pu-242	1.3544e-008	5.0114e+002	3.5135e-010	1.3000e-005
Ra-226	3.3757e-007	1.2490e+004	8.7568e-009	3.2400e-004
Se-79	2.0004e-008	7.4015e+002	5.1892e-010	1.9200e-005
Sn-126	2.6776e-008	9.9072e+002	6.9459e-010	2.5700e-005

Sr-90	1.2919e-003	4.7801e+007	3.3514e-005	1.2400e+000
Tc-99	1.1252e-007	4.1634e+003	2.9189e-009	1.0800e-004
Th-230	1.4065e-006	5.2042e+004	3.6486e-008	1.3500e-003
Th-232	5.5324e-006	2.0470e+005	1.4351e-007	5.3100e-003
U-233	5.8033e-008	2.1472e+003	1.5054e-009	5.5700e-005
U-234	1.6462e-005	6.0908e+005	4.2703e-007	1.5800e-002
U-235	6.8764e-007	2.5443e+004	1.7838e-008	6.6000e-004
U-238	1.5003e-005	5.5511e+005	3.8919e-007	1.4400e-002
Y-90	1.2919e-003	4.7801e+007	3.3514e-005	1.2400e+000
Zr-93	2.4693e-004	9.1362e+006	6.4054e-006	2.3700e-001

Buildup: The material reference is Source
Integration Parameters

X Direction	30
Y Direction	30
Z Direction	60

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0273	4.016e+06	6.146e-05	7.310e-05	8.125e-07	9.665e-07	7.094e-07	8.437e-07	7.094e-09	8.437e-09
0.0599	2.993e+05	1.717e-04	3.041e-04	3.414e-07	6.046e-07	2.980e-07	5.279e-07	2.980e-09	5.279e-09
0.1355	3.806e+03	1.442e-05	4.045e-05	2.314e-08	6.493e-08	2.020e-08	5.668e-08	2.020e-10	5.668e-10
0.1859	1.732e+04	1.084e-04	3.115e-04	1.882e-07	5.407e-07	1.643e-07	4.720e-07	1.643e-09	4.720e-09
0.2214	2.544e+01	2.061e-07	5.861e-07	3.717e-10	1.057e-09	3.245e-10	9.226e-10	3.245e-12	9.226e-12
0.3097	8.331e-01	1.090e-08	2.950e-08	2.077e-11	5.618e-11	1.813e-11	4.904e-11	1.813e-13	4.904e-13
0.4339	1.098e+00	2.320e-08	5.849e-08	4.540e-11	1.144e-10	3.963e-11	9.991e-11	3.963e-13	9.991e-13
0.6144	1.105e+00	3.836e-08	8.866e-08	7.476e-11	1.728e-10	6.527e-11	1.509e-10	6.527e-13	1.509e-12
0.6616	3.741e+07	1.446e+00	3.281e+00	2.803e-03	6.361e-03	2.447e-03	5.553e-03	2.447e-05	5.553e-05
0.702	1.753e+06	7.379e-02	1.651e-01	1.423e-04	3.184e-04	1.242e-04	2.780e-04	1.242e-06	2.780e-06
0.8711	1.627e+06	9.385e-02	1.992e-01	1.766e-04	3.749e-04	1.542e-04	3.273e-04	1.542e-06	3.273e-06
1.1732	7.710e+08	6.913e+01	1.364e+02	1.235e-01	2.437e-01	1.079e-01	2.128e-01	1.079e-03	2.128e-03
1.3325	7.710e+08	8.361e+01	1.602e+02	1.451e-01	2.779e-01	1.266e-01	2.426e-01	1.266e-03	2.426e-03
Totals	1.587e+09	1.544e+02	3.002e+02	2.717e-01	5.287e-01	2.372e-01	4.615e-01	2.372e-03	4.615e-03

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	2.426e-003	4.721e-003

A.3.2 Grouting Packaged Waste

Packaged waste in steel or metal containers are stored in a containment area with a maximum dimensions of 30 m by 60 m [A-14]. Packaged waste primarily consists of sealand containers modified to allow for internal grouting to reduce void space. The grouting occurs when the sealand container is placed in the containment area.

Grouting is estimated to occur for eight hours, over two days per month, for up to eight months per year. This corresponds to 128 hours per year. The worker is assumed to spend approximately 50% of their time, approximately 64 hours, approximately 1 m from the packaged waste, and the remainder of the time at a distance with guidance as required from RP staff.

The highest dose rates for grouting occur when the containment area is almost full, because the source term is the largest at this point. To estimate the dose to the worker performing grouting operations the following methodology is used:

- Using the MicroShield Infer Source tool, determine the maximum source term of Co-60 for a sealand container of packaged waste that meets the dose rate requirements at near contact and 1 m. Using Co-60 is considered conservative because of the isotope's high gamma energy.
- Using MicroShield, estimate the dose rate at 1 m from the containment area. The containment area is assumed to be full of packaged waste meeting the WAC. This is considered conservative since not all sealand container packages will be at the maximum permissible value.

The following assumptions/inputs are used to estimate the radiological consequences to the worker preforming grouting operations:

- Part 1 Source Inference:
  - The sealand container of packaged LLW approximate length of 6.10 m, width of 2.44 m and height of 2.59 m and is conservatively assumed to be full [A-12].
  - The dose point is assessed at a (length, width, height) of (305 cm, 245 cm, 129.5 cm) at a distance of 1 cm (near contact) and (305 cm, 344 cm, 129.5 cm) for a distance of 1 m.
  - The source is modelled as soil, with a density of 1.5 g/cm^3.
  - The transition and air gap are modelled as air with a density of 0.00122 g/cm^3.
  - Source inference is used.
  - Build-up is assumed in the source.
  - Source term integration (x, y, z) is (30, 30, 60).
  - The external source used is Co-60 with a Bq/cm^3 distribution.
  - A correction factor of 1 is used.
  - The exposure rate for near contact is 2 mSv/h (200 mR/h) for near contact and 0.1 mSv/h (10 mR/h) for 1 m [A-13].

- Part 2 Containment Area Source Dose Rate:
  - The source term is modelled as a rectangular slab.
  - The most restrictive Co-60 concentration between near contact and 1 m is selected.
  - For the largest containment area size of 30 m by 60 m [A-14], 108 sealand containers fit this area, resulting in an area 29.28 m by 54.9 m with a height of 2.59 m.
  - The dose point (x,y,z) of (30.28, 1, 27.45) is at the centre of the long edge of the containment area, 1 m from the source term.
  - The source is modelled in MicroShield as soil with a density of 1.5 g/cm^3.
  - The air gap is molded as 0.00122 g/cm^3.
  - The Co-60 concentration is 3.7761E+02 Bq/cm^3.
  - Build-up occurs in the source.
  - Source term integration (x, y, z) is (60, 20, 60).

Table A-19 shows the inferred source term Co-60 concentrations in a sealand container that meet the packaged waste dose rate limits. The Co-60 concentration of 3.7761E+02 Bq/cm^3 at 1 m is the limiting concentration for a sealand container. Therefore, this concentration is used to model grouting operations.

Table A-20 shows the dose rate at 1 m from the containment area to be 9.51E-02 mSv/h. Therefore, the estimated annual radiological consequence to the NSDF ECM worker grouting packaged waste in sealand containers is 6.09 mSv/y.

Table A-19
Sealand Container Co-60 Activity Concentration to Meet Packaged Waste Criteria

Dose Point	**Dose Rate Limit (mSv/h)**	**Packaged Waste Co-60 Activity Concentration (Bq/cm^3)**
Near Contact (1 cm)	2 mSv/h	3.8584E+03
1 m	0.1 mSv/h	3.7761E+02

Table A-20
MicroShield Output – Dose Rate Estimate for Sealand Grouting

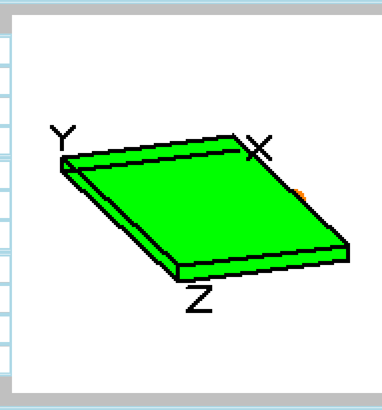
MicroShield 9.07 CNL (9.07-0000)			
Filename	Run Date	Run Time	Duration
Case2	May 14, 2019	9:30:55 PM	00:00:01
Project Info			
Case Title	Sealand Grouting		

Description	Grouting Sealand Containers at 1m
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	2.9e+3 cm (96 ft 0.8 in)
Width	5.5e+3 cm (180 ft 1.4 in)
Height	259.0 cm (8 ft 6.0 in)

Dose Points			
A	X	Y	Z
#1	3.0e+3 cm (99 ft 4.1 in)	100.0 cm (3 ft 3.4 in)	2.7e+3 cm (90 ft 0.7 in)

Shields			
Shield N	Dimension	Material	Density
Source	4163.352 m³	Soil	1.5
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Co-60	4.2490e+001	1.5721e+012	1.0206e-002	3.7761e+002

Buildup: The material reference is Source
Integration Parameters

X Direction	60
Y Direction	20
Z Direction	60

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.6938	2.564e+08	1.054e-01	2.381e-01	2.035e-04	4.597e-04	1.777e-04	4.013e-04	1.777e-06	4.013e-06
1.1732	1.572e+12	1.404e+03	2.786e+03	2.509e+00	4.978e+00	2.190e+00	4.346e+00	2.190e-02	4.346e-02
1.3325	1.572e+12	1.699e+03	3.274e+03	2.948e+00	5.680e+00	2.574e+00	4.958e+00	2.574e-02	4.958e-02
Totals	3.145e+12	3.103e+03	6.060e+03	5.457e+00	1.066e+01	4.764e+00	9.304e+00	4.764e-02	9.304e-02

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	4.871e-002	9.514e-002

A.3.3 Macroencapsulation

Drummed waste to be macroencapsulated is stored in a containment area. Drummed waste is placed into the dedicated area on an individual basis using a hydraulic excavator equipped with a hydraulic grapple or other drum-handling equipment. Two layers of drums are placed in each operational lift, with the layers separated vertically by a 0.15 m thick grout layer. Drums are placed in an upright position on the prepared base, evenly spaced with no separation between adjacent drums. The void space between drums will be grouted or flowable fill may be used to meet compaction requirements [A-14].

Macroencapsulation is estimated to occur for eight hours, for one day per month, for up to eight months per year. This corresponds to 64 hours per year. The ECM worker is assumed to spend approximately 25% of their time, 16 hours near the packaged waste, approximately 1 m away, and the remainder of the time at a distance with guidance as required from RP staff.

To estimate the radiological consequence to the worker performing grouting operations the following methodology is used:

- Using the MicroShield Infer Source tool, determine the maximum source term of Co-60 for drummed waste that meets the dose rate requirements at near contact and 1 m. Using Co-60 is considered conservative because of the isotope's high gamma energy.
- Using MicroShield, estimate the dose rate at 1 m from the containment area. The containment area source term assumes the containment area is full of Co-60 drums meeting the WAC given packing efficiencies. This is considered conservative since not all drums will be at the maximum permissible value.

The following assumptions/inputs are used to estimate the radiological consequence to the worker performing macroencapsulation operations:

- Part 1 Source Inference:
  - The drum is modelled as a cylindrical source with a height of 87.6 cm, and a radius of 30 cm.
  - The dose point is assessed at a height of 48.3 cm at a distance of 1 cm (near contact) and 1 m.
  - The source is modelled as soil, with a density of 1.5 g/cm^3.
  - The transition and air gap are modelled as air with a density of 0.00122 g/cm^3.
  - Source inference (PPS) is used.
  - Build-up is assumed in the source.
  - Source term integration (radial, circumferential, axial) is (20, 20, 40).
  - The external source is Co-60 with a Bq/cm^3 distribution.
  - A correction factor of 1 is used.
  - The exposure rate for near contact is 2 mSv/h (200 mR/h) for near contact and 0.1 mSv/h (10 mR/h) for 1 m [A-13].
- Part 2 Containment Area Source Dose Rate:
  - The source term is modelled as a rectangular slab.
  - The most restrictive Co-60 concentration between near contact and 1 m is selected.
  - A packaging efficiency of 78.54% is assumed, which is optimal for drums in a rectangular area.

- The containment area size is assumed to be the maximum of 30 m by 60 m, stacked two drums high (~1.752 m) [A-14].
- The dose point (x,y,z) of (31, 0.876, 30) is at the centre of the long edge of the containment area, 1 m from the source term.
- The source is modelled in MicroShield as soil with a density of 1.5 g/cm^3.
- The air gap is molded as 0.00122 g/cm^3.
- The Co-60 concentration is 3.006E+03 Bq/cm^3. This is the source term concentration for the drum at 1 m accounting for the 78.54% packing efficiency.
- Build-up occurs in the source.
- Source term integration (x, y, z) is (60, 20, 60).

Table A-21 shows the inferred source term Co-60 concentrations in a drum that meet the packaged waste dose rate limits. The 1 m dose point concentration is more restrictive, showing the Co-60 concentration, which would meet both the near contact and 1 cm dose rate requirements for packaged waste. The average concentration of the containment area is estimated assuming 78.54% packing efficiency.

Table A-22 shows the dose rate at 1 m from the containment area to be 6.50E-01 mSv/h. Therefore, the estimated annual radiological consequence to the NSDF ECM worker performing the macroencapsulation activity is 10.4 mSv/y.

Table A-21
Packaged Waste Co-60 Activity Concentrations

Dose Point	Dose Rate Limit (mSv/h)	Packaged Waste Co-60 Activity Concentration (Bq/cm^3)	Containment Area Concentration (Bq/cm^3)
Near Contact (1 cm)	2 mSv/h	5.2675E+003	NA
1 m	0.1 mSv/h	4.2025E+003	3.3006E+03

Table A-22
MicroShield Output – Dose Rate from Grouting ECM Containment Area

MicroShield 9.07 CNL (9.07-0000)

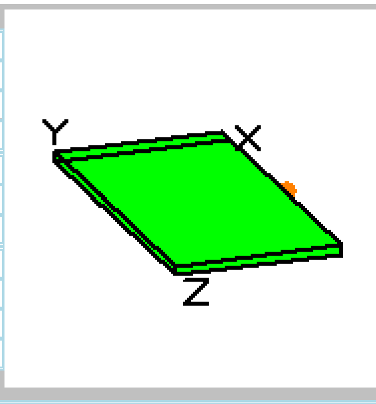
Filename	Run Date	Run Time	Duration
NSDF-ContainmentArea.msd	April 29, 2019	4:06:47 PM	00:00:01

Project Info	
Case Title	Containment Area
Description	NSDF Drum Containment Area for Grouting
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	3.0e+3 cm (98 ft 5.1 in)
Width	6.0e+3 cm (196 ft 10.2 in)
Height	175.2 cm (5 ft 9.0 in)

Dose Points			
A	X	Y	Z
#1	3.1e+3 cm (101 ft 8.5 in)	87.6 cm (2 ft 10.5 in)	3.0e+3 cm (98 ft 5.1 in)

Shields			
Shield N	Dimension	Material	Density
Source	3.15e+09 cm³	Soil	1.5
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Co-60	2.8132e+002	1.0409e+013	8.9205e-002	3.3006e+003

Buildup: The material reference is Source
Integration Parameters

X Direction	60
Y Direction	20
Z Direction	60

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.6938	1.698e+09	7.305e-01	1.634e+00	1.410e-03	3.156e-03	1.231e-03	2.755e-03	1.231e-05	2.755e-05
1.1732	1.041e+13	9.692e+03	1.905e+04	1.732e+01	3.405e+01	1.512e+01	2.973e+01	1.512e-01	2.973e-01
1.3325	1.041e+13	1.172e+04	2.237e+04	2.033e+01	3.881e+01	1.775e+01	3.388e+01	1.775e-01	3.388e-01
Totals	2.082e+13	2.141e+04	4.142e+04	3.765e+01	7.286e+01	3.287e+01	6.361e+01	3.287e-01	6.361e-01

Effective Dose Equivalent Rate (ICRP 51 - 1987)

Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	3.361e-001	6.504e-001

A.3.4 Engineered Containment Mound Operations

Engineered Containment Mound operations involve:

- Applying a daily cover to the LLW.
- Moving and grading the LLW.
- Performing maintenance activities to the ECM.

A daily cover is applied to the ECM placed waste at the end of each day. The type of daily cover may vary depending on operations (e.g. soil, fixative, or tarp). The estimated time for the ECM worker to apply the daily cover is one hour per day for 140 days per year.

Moving and grading the LLW requires the heavy equipment operator to work inside heavy equipment over top of the LLW. The heavy equipment operator is expected to work eight hours per day, four days per week for 35 weeks per year, resulting in the heavy equipment operator spending 1 120 hours a year on the LLW in the ECM.

Performing maintenance activities to the ECM is performed by the heavy equipment operators. Heavy equipment operators are expected to work eight hours per day, once a week for 35 weeks per year, resulting in the heavy equipment operator spending 280 hours per year on the ECM.

RESRAD-OFFSITE Version 3.2, is used to estimate the radiological consequence to ECM workers during normal operations. RESRAD-OFFSITE models the radiological consequence to workers from multiple exposure pathways including external gamma, inhalation, soil ingestion and radon. Unless stated, RESRAD-OFFSITE default values are used. The previous version of the NSDF SAR used MicroShield as the methodology to estimate the radiological consequence to ECM workers during normal operations, however, RESRAD was determined to be a better methodology for this radiological consequence estimate.

The following assumptions and inputs are used to calculate the radiological consequence to ECM workers during normal operations:

- The size of the contaminated zone is 122.5 m by 122.5 m for a surface area of ~15000 m^2 [A-15]. This is the largest allowable surface area of open excavation.
- The contaminated zone is modelled as uniformly distributed bulk waste with an average density of 1.5 g/cm^3 [A-11].
- Packaged waste is placed in dedicated containment areas within the disposal cells [A-14]. Packaged waste is covered with bulk waste, providing shielding. Therefore, the packaged waste source term is excluded.
- Reporting times are assessed up to 25 years to identify the peak dose over the operational period of the cell. This is considered conservative since Phase 1 consists of six cells with an estimated operations period of 20 - 25 years [A-14].
- Dose from other cells is excluded since these cells will be closed.
- Precipitation is set to 0.1 m/year. This reduces the migration rate of waste away from the receptor.
- Irrigation applied per year is set to 0 m/year since no irrigation is applied to the waste.
- The support practice factor is set to 0. This conservatively assumes no reduction of the waste due to erosion.
- The thickness of the waste is assumed to be 10 m, resulting in ~150 000 m^3 of waste in the disposal cell.
- Thickness of clean cover is modelled at 0 m, representing an uncovered cell.

- Exposure pathways are external gamma, inhalation, soil ingestion and radon. Plant ingestion, meat ingestion, milk ingestion, aquatic foods, and drinking water exposure pathways are not applicable to the ECM worker.
- The inhalation rate is 10 500 m^3/year (~3.3E-04 m^3/s for an adult worker [A-8]).
- Soil ingestion rate of 36.5 g/year.
- The ECM worker is conservatively assumed to stand outdoors, directly on top of the waste, with no PPE&C, for 1 120 hours per year. This results in an outdoor occupancy factor on the primary contamination of 0.128. Other occupancy factors are set to 0 since they are not applicable.
- RESRAD-OFFSITE default values are used for radon and C-14 dose.
- Radionuclide transformations based on ICRP 107.
- The dose coefficient factors in DCFPAK 302 are used. The DCFPAK 3.02 external exposure library is based on ICRP 60. The DCFPAK 3.02 internal exposure dose library (adult), is based on ICRP 72.

The peak radiological consequence to the ECM worker with no cover occurred at time 0 with a maximum dose of 6.37 mSv/y (for ~1 120 hours, this corresponds to a dose rate of approximately 5.69E-03 mSv/h). The dose contributions at time 0 are:

- 6.36 mSv from ground gamma.
- 1.24E-02 mSv from inhalation.
- 7.41E-07 mSv from radon.
- 4.27E-04 mSv from soil ingestion.

These dose estimates conservatively exclude the distance and shielding provided by the heavy equipment to the receptor.

Table A-23 and Figure A-1 shows the annual dose rate to an on-site receptor, ECM worker, spending 1 120 hours a year on top of the ECM. Note that in Table A-23 and Figure A-1, the downtrend of the annual radiological consequence (annual dose), decreases is due to radioactive decay of the 150 000 m^3 placed bulk waste modelled in the disposal cell. In addition, this RESRAD model does not include the addition of new placed waste into the ECM. In this RESRAD model the ECM worker is assumed to be on the same placed waste for the 30 year duration.

Table A-23
Engineered Containment Mound Worker Annual Radiological Consequence using RESRAD-OFFSITE

Exposure Pathway	Annual Dose (mSv)**							Primary Contributing Radionuclides
	Year 0	Year 1	Year 3	Year 6	Year 15	Year 25	Year 30	
External Gamma	6.36E+00	5.58E+00	4.31E+00	2.93E+00	9.36E-01	2.86E-01	1.68E-01	Co-60 Cs-137
Inhalation (dust)*	1.24E-02	1.14E-02	9.69E-03	7.60E-03	3.72E-03	1.74E-03	1.22E-03	H-3
Radon	7.41E-07	1.96E-06	6.28E-06	1.38E-05	2.87E-05	3.46E-05	3.57E-05	Ra-226 Th-232
Soil Ingestion	4.27E-04	3.99E-04	3.50E-04	2.96E-04	2.04E-04	1.58E-04	1.44E-04	Co-60 Sr-90 Cs-137
Total	6.37E+00	5.59E+00	4.32E+00	2.93E+00	9.403E-01	2.882E-01	1.70E-01	Co-60

*Inhalation excludes Radon
** Annual dose assuming 1120 h / year

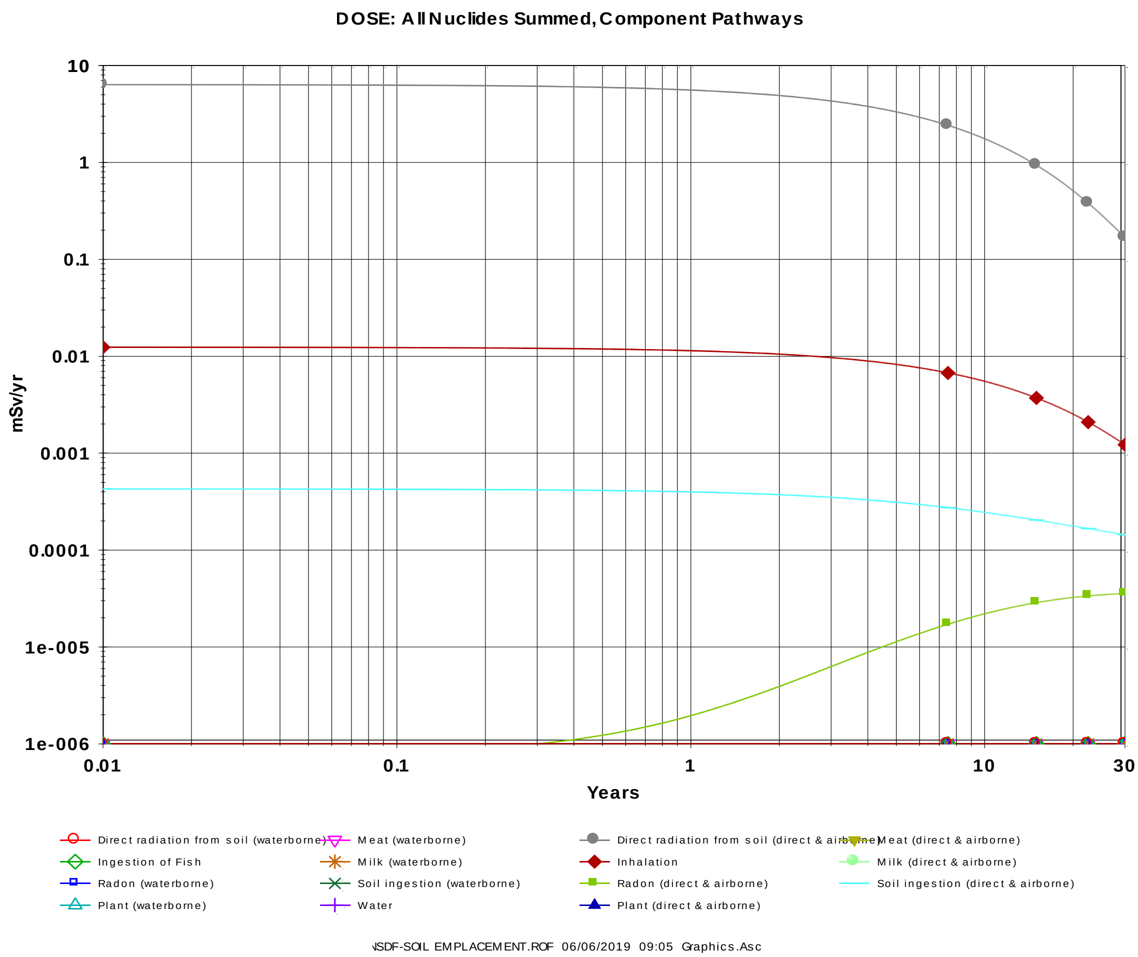


Figure A-1 RESRAD-OFFSITE Model - Engineered Containment Mound Worker Annual Radiological Consequence

A.4 Dose Rate at Engineered Containment Mound Fence Line

The dose rate at the NSDF fence line from the ECM is calculated to support the estimate of fence line dose presented in Section 14.2. MicroShield is used to estimate the dose rate at the NSDF fence line. The following inputs and assumptions are used to estimate the radiation fields at the NSDF fence line:

- The source term is from Table 3 of the Waste Characterization [A-11]. The density is assumed to be 1.5 g/ cm^3. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.

- The ECM is modelled as a rectangular volume 122.5 m by 122.5 m with a height of 10 m for a volume of ~150 000 m^3. This is the largest allowable surface area of open active disposal [A-15].
- The fence line is approximately 14 m from the ECM, and the receptor is assumed to be 1 m high resulting in a dose point of (136.65, 1, 61.25) m.
- ECM shielding is provided by a 15 cm soil cover with a density of 1.5 g/cm^3 [A-14].
- Source term is modelled as soil with a density of 1.5 g/cm^3.
- The air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (x, y, z) is (100, 20, 100).

Table A-24 shows the estimated dose rate at the NSDF fence line is 6.25E-04 mSv/h.

Table A-24
MicroShield Output – Dose Rate at the NSDF Fence Line

MicroShield 9.07 CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
Mound dose rate at fence-SAM.msd	May 23, 2019	8:50:54 PM	00:00:13

Project Info	
Case Title	Dose rate from ECM
Description	Dose rate at the fence line
Geometry	13 - Rectangular Volume

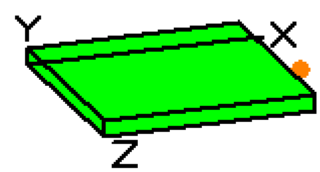
Source Dimensions	
Length	1.2e+4 cm (401 ft 10.8 in)
Width	1.2e+4 cm (401 ft 10.8 in)
Height	1.0e+3 cm (32 ft 9.7 in)

Dose Points

A	X	Y	Z
#1	1.4e+4 cm (448 ft 3.9 in)	100.0 cm (3 ft 3.4 in)	6.1e+3 cm (200 ft 11.4 in)

Shields

Shield N	Dimension	Material	Density
Source	1.50e+11 cm^3	Soil	1.5
Shield 1	15.0 cm	Soil	1.5
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm^3	Bq/cm^3
Ag-108m	1.2857e-007	4.7570e+003	8.5676e-013	3.1700e-008
Am-241	8.5982e-002	3.1813e+009	5.7297e-007	2.1200e-002
Am-243	4.3802e-005	1.6207e+006	2.9189e-010	1.0800e-005
Ba-137m	4.3737e+000	1.6183e+011	2.9146e-005	1.0784e+000
C-14	1.4195e+000	5.2522e+010	9.4595e-006	3.5000e-001

Cl-36	3.9300e-003	1.4541e+008	2.6189e-008	9.6900e-004
Co-60	8.1115e+001	3.0013e+012	5.4054e-004	2.0000e+001
Cs-135	6.5703e-005	2.4310e+006	4.3784e-010	1.6200e-005
Cs-137	4.6235e+000	1.7107e+011	3.0811e-005	1.1400e+000
H-3	6.6920e+002	2.4760e+013	4.4595e-003	1.6500e+002
I-129	1.1072e-003	4.0967e+007	7.3784e-009	2.7300e-004
Mo-93	1.1437e-007	4.2318e+003	7.6216e-013	2.8200e-008
Nb-94	1.7115e-001	6.3326e+009	1.1405e-006	4.2200e-002
Ni-59	9.5716e-004	3.5415e+007	6.3784e-009	2.3600e-004
Ni-63	2.4213e-001	8.9587e+009	1.6135e-006	5.9700e-002
Np-237	1.4560e-005	5.3872e+005	9.7027e-011	3.5900e-006
Pu-239	7.0570e-002	2.6111e+009	4.7027e-007	1.7400e-002
Pu-241	1.3830e+000	5.1171e+010	9.2162e-006	3.4100e-001
Pu-242	5.2725e-005	1.9508e+006	3.5135e-010	1.3000e-005
Ra-226	1.3141e-003	4.8620e+007	8.7568e-009	3.2400e-004
Se-79	7.7870e-005	2.8812e+006	5.1892e-010	1.9200e-005
Sn-126	1.0423e-004	3.8566e+006	6.9459e-010	2.5700e-005
Sr-90	5.0291e+000	1.8608e+011	3.3514e-005	1.2400e+000
Tc-99	4.3802e-004	1.6207e+007	2.9189e-009	1.0800e-004
Th-230	5.4753e-003	2.0258e+008	3.6486e-008	1.3500e-003
Th-232	2.1536e-002	7.9683e+008	1.4351e-007	5.3100e-003
U-233	2.2590e-004	8.3585e+006	1.5054e-009	5.5700e-005
U-234	6.4081e-002	2.3710e+009	4.2703e-007	1.5800e-002
U-235	2.6768e-003	9.9041e+007	1.7838e-008	6.6000e-004
U-238	5.8403e-002	2.1609e+009	3.8919e-007	1.4400e-002
Y-90	5.0291e+000	1.8608e+011	3.3514e-005	1.2400e+000
Zr-93	9.6121e-001	3.5565e+010	6.4054e-006	2.3700e-001

Buildup: The material reference is Source
Integration Parameters

X Direction	100
Y Direction	20
Z Direction	100

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate MeV/cm²/sec No Buildup	Fluence Rate MeV/cm²/sec With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.0273	1.563e+10	1.209e-42	1.228e-26	1.599e-44	1.624e-28	1.396e-44	1.418e-28	1.396e-46	1.418e-30
0.0599	1.165e+09	3.128e-10	1.950e-09	6.221e-13	3.878e-12	5.431e-13	3.385e-12	5.431e-15	3.385e-14
0.1355	1.482e+07	5.479e-08	7.097e-07	8.794e-11	1.139e-09	7.677e-11	9.945e-10	7.677e-13	9.945e-12
0.1859	6.742e+07	8.423e-07	1.078e-05	1.462e-09	1.872e-08	1.276e-09	1.634e-08	1.276e-11	1.634e-10
0.2214	9.904e+04	2.129e-09	2.585e-08	3.839e-12	4.662e-11	3.351e-12	4.070e-11	3.351e-14	4.070e-13
0.3097	3.243e+03	1.764e-10	1.807e-09	3.359e-13	3.442e-12	2.933e-13	3.004e-12	2.933e-15	3.004e-14
0.4339	4.276e+03	5.544e-10	4.554e-09	1.085e-12	8.911e-12	9.471e-13	7.779e-12	9.471e-15	7.779e-14
0.6144	4.300e+03	1.320e-09	8.406e-09	2.573e-12	1.638e-11	2.246e-12	1.430e-11	2.246e-14	1.430e-13
0.6616	1.456e+11	5.358e-02	3.231e-01	1.039e-04	6.264e-04	9.068e-05	5.469e-04	9.068e-07	5.469e-06
0.702	6.822e+09	2.899e-03	1.675e-02	5.592e-06	3.230e-05	4.881e-06	2.820e-05	4.881e-08	2.820e-07
0.8711	6.333e+09	4.533e-03	2.242e-02	8.531e-06	4.220e-05	7.448e-06	3.684e-05	7.448e-08	3.684e-07
1.1732	3.001e+12	4.369e+00	1.759e+01	7.808e-03	3.144e-02	6.816e-03	2.745e-02	6.816e-05	2.745e-04
1.3325	3.001e+12	5.887e+00	2.184e+01	1.021e-02	3.788e-02	8.917e-03	3.307e-02	8.917e-05	3.307e-04
Totals	6.178e+12	1.032e+01	3.979e+01	1.814e-02	7.002e-02	1.584e-02	6.113e-02	1.584e-04	6.113e-04

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	Units	Without Buildup	With Buildup
Anterior/Posterior Geometry	mSv/h	1.619e-004	6.252e-004

A.5 Packaged Waste Containment Area Radiological Consequence

Dose assessments for normal operations of the ECM have assumed that the radiological consequence from packaged waste is negligible due to the shielding provided by bulk waste. This section assesses the dose impact directly above a covered packaged waste containment area to determine the validity of excluding the dose from packaged waste.

Dose rates from containment areas are assessed for grouting packaged waste in Section A.3.2 and macroencapulation in Section A.3.3. The macroencapulation containment area is assessed since this containment area has higher dose rates compared to the grouting of packaged waste containment area. The following inputs and assumptions are used to estimate the dose rate above a packaged waste containment area:

- The source term is modelled as all drummed waste that meets the packaged WAC limit with a Co-60 concentration 3.3006E+06 Bq/cm^3. See Table A-21 of Section A.3.3 for derivation of source term.
- The source term is modelled as a rectangular slab. The containment area size is assumed to be the maximum of 30 m by 60 m, and 1.752 m high [A-14].
- Shielding provided by grout macroencapulation is conservatively excluded.
- A 1.8 m thick layer of bulk waste is modelled as shielding above the packaged waste containment area. The bulk waste is modelled as soil with a density of 1.5 g/cm^3. A thickness of 1.8 m is the same separation thickness required for packaged waste from the primary liner [A-14].
- The dose point (x, y, z) of (455.2, 1500, 3000) is at the centre of the containment area, 1 m from the shielding.
- The source is modelled in MicroShield as soil with a density of 1.5 g/cm^3.
- The air gap is modelled as 0.00122 g/cm^3.
- Build-up occurs in the source.
- Source term integration (x, y, z) is (60, 20, 60).

Table A-25 shows that the estimated dose rate above the containment area covered by bulk waste is 5.235E-07 mSv/h. This is approximately four orders of magnitude less than the dose rate calculated for moving and grading LLW calculated in Section A.3.4; therefore, the assumption of excluding the dose rate from packaged waste is considered valid.

Table A-25
MicroShield Output – Dose Rate from Buried Containment Area

MicroShield 9.07 CNL (9.07-0000)

Filename	Run Date	Run Time	Duration
NSDF-Macroencapsulation - dose above.msd	May 31, 2019	2:28:29 PM	00:00:01

Project Info	
Case Title	Buried Packages
Description	Dose Rate from Buried Containment Area
Geometry	13 - Rectangular Volume

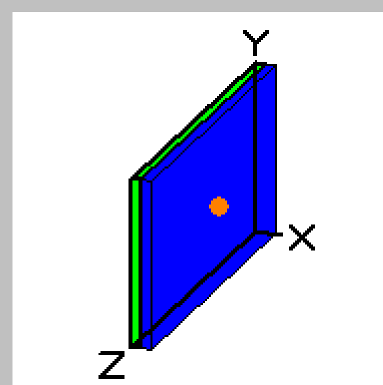
Source Dimensions	
Length	175.2 cm (5 ft 9.0 in)
Width	6.0e+3 cm (196 ft 10.2 in)
Height	3.0e+3 cm (98 ft 5.1 in)

Dose Points

A	X	Y	Z
#1	455.2 cm (14 ft 11.2 in)	1.5e+3 cm (49 ft 2.6 in)	3.0e+3 cm (98 ft 5.1 in)

Shields

Shield N	Dimension	Material	Density
Source	3.15e+09 cm^3	Soil	1.5
Shield 1	180.0 cm	Soil	1.5
Air Gap		Air	0.00122



Source Input: Grouping Method - Actual Photon Energies
Library: Grove

Nuclide	Ci	Bq	$\mu Ci/cm^3$	Bq/cm^3
Co-60	2.8132e+002	1.0409e+013	8.9205e-002	3.3006e+003

Buildup: The material reference is Source
Integration Parameters

X Direction	60
Y Direction	20
Z Direction	60

Results

Energy (MeV)	Activity (Photons/sec)	Fluence Rate $MeV/cm^2/sec$ No Buildup	Fluence Rate $MeV/cm^2/sec$ With Buildup	Exposure Rate mR/h No Buildup	Exposure Rate mR/h With Buildup	Absorbed Dose Rate mrad/h No Buildup	Absorbed Dose Rate mrad/h With Buildup	Absorbed Dose Rate mGy/h No Buildup	Absorbed Dose Rate mGy/h With Buildup
0.6938	1.698e+09	1.623e-10	1.641e-08	3.134e-13	3.168e-11	2.736e-13	2.765e-11	2.736e-15	2.765e-13
1.1732	1.041e+13	2.379e-04	8.988e-03	4.251e-07	1.606e-05	3.711e-07	1.402e-05	3.711e-09	1.402e-07

1.3325	1.041e+13	8.074e-04	2.456e-02	1.401e-06	4.261e-05	1.223e-06	3.720e-05	1.223e-08	3.720e-07
Totals	**2.082e+13**	**1.045e-03**	**3.355e-02**	**1.826e-06**	**5.868e-05**	**1.594e-06**	**5.123e-05**	**1.594e-08**	**5.123e-07**

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	**Units**	**Without Buildup**	**With Buildup**
Anterior/Posterior Geometry	mSv/h	1.629e-008	5.235e-007

A.6 References

[A-1] *Grove Software*, MicroShield User Manual, 2012.

[A-2] *User's Guide for RESRAD*-OFFSITE, NUREG/CR-7189, ANL/EVS/TM-14/2, 2015 April.

[A-3] AECOM, *Near Surface Disposal Facility Wastewater Treatment Plant Process Tank Details*, 232-106470-230-000, Revision 0, 2019 April.

[A-4] AECOM, *Near Surface Disposal Facility Wastewater Treatment Plant Process Flow Diagram Table*, B1551-106400-002-01-FS-D, Revision 2, 2018 December.

[A-5] AECOM, *WWTP Material and Energy Balance Report*, B1551-503212-REPT-001, Revision 2, 2018 November.

[A-6] AECOM, *HVAC Design*, B1551-508243-REPT-001, Revision 1, 2019 September.

[A-7] AECOM, *Material Handling Design,* 232-508500-REPT-001, Revision 1, 2018 August.

[A-8] *Dose Calculations Pertaining to Respirable Radiation Sources*, 900-508770-FID-008, Revision 0, 2018 December.

[A-9] ICRP, *Compendium of Dose Coefficients based on ICRP 60*, ICRP Publication 119, Volume 41 Supplement 1, 2012.

[A-10] U.S. DOE, *Airborne Release Fractions/Rates and Respirable Fractions for Non-Reactor Nuclear Facilities*, DOE-HDBK-3010-94, Volume I, 1994 December (Reaffirmed 2013).

[A-11] AECOM, *Waste Characterization*, 232-508600-REPT-002, Revision 4, 2020 February.

[A-12] *Standard Freight Containers*, CRL-106000-TS-001, Revision 0, 2016 June.

[A-13] *Near Surface Disposal Facility Waste Acceptance Criteria*, 232-508600-WAC-000, Revision 1, 2020 April.

[A-14] AECOM, *Waste Placement and Compaction Plan*, B1550-508600-PLA-001, Revision 2, 2019 October.

[A-15] AECOM, *Leachate Management Plan*, 232-508600-PLA-001, Revision 1, 2018 September.

Appendix B

Equalization Tank Airborne Emissions

B.1 Introduction

Emissions from storage tanks occur because of evaporative loss of the liquid in storage and as a result of changes in liquid level. The Equalization Tanks are fixed roof tanks so therefore, are subject to evaporative losses during storage (also known as breathing losses or standing storage losses), which occur due to diurnal variations in ambient temperature, and evaporative losses during filling and emptying operations (known as working losses).

Estimation of the radioactive inventory released from a single Equalization Tank is based on the following assumptions:

- Losses will occur from the water phase and the organic phase.
- The organic phase losses are calculated as per the U.S. Environmental Protection Agency methodology described in Methods for Estimating Fugitive Air Emissions of Radionuclides from Diffuse Sources at DOE Facilities [B-1]. As such, the calculation methodology uses imperial units; SI units are provided in parentheses throughout.
- The water phase losses are calculated based on empirical data for undisturbed water pools in the ASHRAE technical paper [B-2].
- The radionuclide concentration is evenly distributed throughout these phases and throughout the tank.
- The water phase working losses are estimated using the same ratio of standard to working losses as calculated for the organic phase.
- The Equalization Tank is modelled as a fixed-dome roof vertical tank (this is conservative as it overestimates the vapor space volume and therefore the standing storage loss) [B-3] and [B-4].
- Tank dimensions are taken from [B-3], [B-4] and [B-5].
- The organics quantities within the waste are taken from the CRL NSDF Wastewater Treatment Material Balance Table, Column G “Chemical Precipitation” [B-6].
- The radionuclide concentrations within the waste are taken from the CRL NSDF Wastewater Treatment Material Balance Table, Column G “Chemical Precipitation” [B-6].

B.2 Organic Phase Losses

Organic phase losses are the sum of the standing storage loss, L_S, and the working storage loss, L_W. Each loss is calculated separately in the applicable subsection below.

B.2.1 Organic Phase Standing Storage Loss

Tank standing storage losses, (lb/y), for the organics can be estimated using the following equation B1:

$$L_S = 365 * V_V * W_V * K_E * K_S \qquad \text{(B1)}$$

Where:

L_S	Standing storage loss (lb/y)
365	Constant, (days/y)
V_V	Vapor space volume, (ft^3)
W_V	Vapor density, (lb of Volatile Organic Compounds (VOC/ft^3))
K_E	Vapor space expansion factor (dimensionless)
K_S	Vented vapor saturation factor (dimensionless)

Calculating for each component in turn.

B.2.1.1 Tank Vapor Space, V_v, Calculation

The tank vapor space volume, V_V, is calculated using the following equation B2:

$$V_V = \frac{\pi}{4} * D^2 * H_{VO} \qquad \text{(B2)}$$

Where:

D	Diameter of the tank, (ft)
H_{VO}	Vapor space outage, (ft)

The vapor space outage, H_{VO}, is calculated using the following equation B3:

$$H_{VO} = H_S - H_L + H_{RO} \qquad \text{(B3)}$$

Where:

H_S	Tank shell height, (ft)
H_L	Stock liquid height, (ft)
H_{RO}	Roof outage, (ft)

For a dome roof, where the tank dome roof radius is unknown, then using equation B4:

$$H_{RO} = 0.137 * R_S \qquad \text{(B4)}$$

Where:

R_S Tank shell radius, ft.

This is used as a conservative approximation as a spherical roof will result in a higher value of tank vapor space volume than a convex roof. The tank shell diameter is 62.01 ft (18.9 m), and the tank height (up to the concave area) is 26.48 ft (8.07 m) [B-3], [B-4] and [B-5]. Accordingly, the tank shell radius, R_S, is 31.01 ft (9.45 m).

$$H_{RO} = 0.137 * R_S = 0.137 * 31.01 = 4.25\ ft\ (1.30\ m)$$

As mentioned previously, the tank shell height, H_S, is 26.48 ft (8.07 m), and the operating level or stock liquid height H_L, of the tank is 22.21 ft (6.77 m). Therefore:

$$H_{VO} = H_S - H_L + H_{RO} = 26.48 - 22.21 + 4.25 = 8.51\ ft\ (2.59\ m)$$

Using this value[4] and the tank shell diameter, D, of 62.01 ft (18.9 m), then

$$V_V = \frac{\pi}{4} * D^2 * H_{VO} = \frac{\pi}{4} * 62.01^2 * 8.51 = 2.57E4\ ft^3\ (7.28E2\ m^3)$$

B.2.1.2 Vapor Density, W_v, Calculation

The vapor density, W_V, is calculated using the following equation B5:

$$W_v = \frac{M_v * P_{VA}}{R * T_{LA}} \qquad \text{(B5)}$$

Where:

W_v Vapor density, (lb/ft^3)

M_v Stock vapor molecular weight, (lb/lb-mole)

P_{VA} Stock vapor pressure at the daily average liquid surface temperature, (psia)

R Ideal gas constant, 10.731 (psia.ft^3/lb-mole.^{o}R)

T_{LA} Daily average liquid surface temperature, (^{o}R)

Firstly calculate the daily average liquid surface temperature, T_{LA}, using the following equation B6:

$$T_{LA} = 0.44 * T_{AA} + 0.56 * T_B + 0.0079 * \alpha * I \qquad \text{(B6)}$$

Where:

T_{AA} Daily average ambient temperature, (^{o}R)

[4] 8.52 is the value of H_{VO} with the numbers shown for H_S, H_L and H_{RO}. The more exact value of 8.51 is given as this matches the excel spreadsheet used for the calculation where more significant figures are carried.

T_B Liquid bulk temperature, (^oR)

α Tank paint solar absorptance (dimensionless)

I Daily total solar insolation, (Btu/ft^2.d)

The daily average ambient temperature is calculated using the following equation B7:

$$T_{AA} = \frac{T_{AX}+T_{AN}}{2} \qquad \text{(B7)}$$

Where:

T_{AX} Daily maximum ambient temperature, (^oR)

T_{AN} Daily minimum ambient temperature, (^oR)

The Government of Canada Canadian Climate Normals 1971-2000 Station Data [B-7], give the daily maximum and minimum temperatures as 10.5 ^oC (510.6 ^oR) and -0.2 ^OC (491.3 ^oR) respectively. Therefore:

$$T_{AA} = \frac{T_{AX} + T_{AN}}{2} = \frac{510.6 + 491.3}{2} = 501\ ^oR\ (5.2\ ^oC)$$

The liquid bulk temperature is calculated using the following equation B8:

$$T_B = T_{AA} + 6 * \alpha - 1 \qquad \text{(B8)}$$

The paint solar absorptance, α, has been assumed to be 0.17, which represents a white shell and roof with the paint in good condition. This is the recommended default when specific information is not known [B-7].

$$T_B = 501 + 6 * 0.17 - 1 = 501\ ^oR\ (5.2\ ^oC)$$

The daily solar insolation on a horizontal surface. From solar horizontal irradiation maps, see Figure B-1, the average annual for the area would be around 1086 Btu/ft^2-d (1250 kWh/m^2).

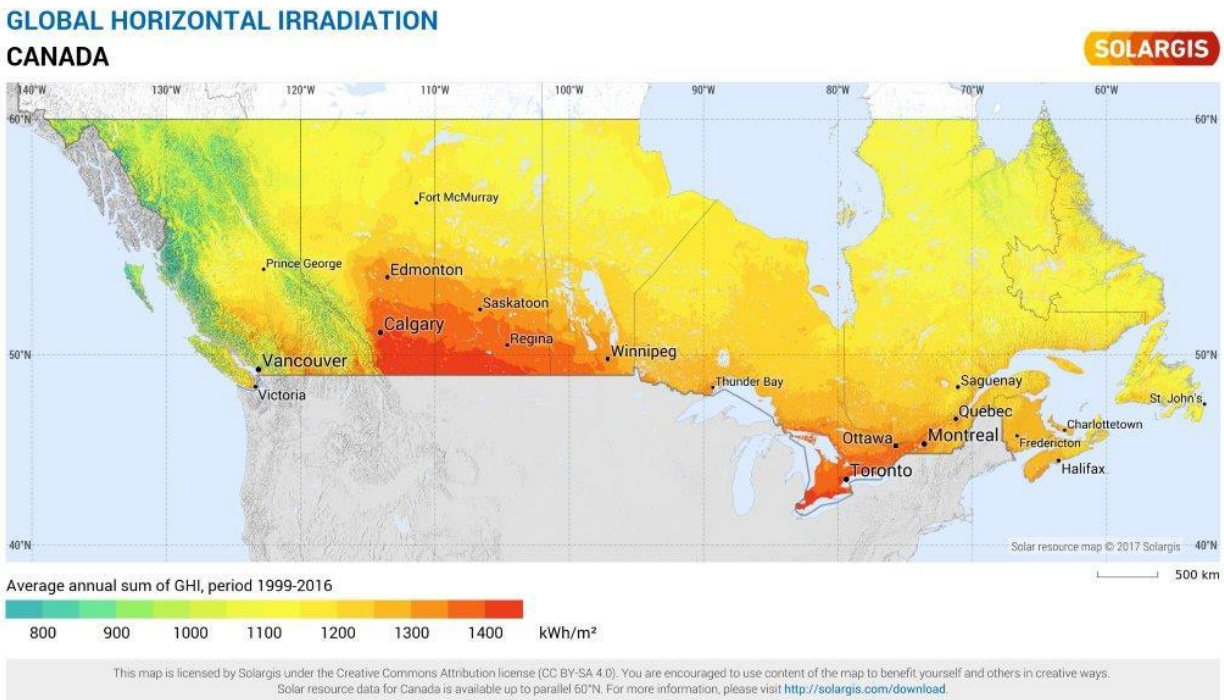


Figure B-1 Average Horizontal Irradiation Map for Canada

Therefore:

$$T_{LA} = 0.44 * T_{AA} + 0.56 * T_B + 0.0079 * \alpha * I$$

$$T_{LA} = 0.44 * 501 + 0.56 * 501 + 0.0079 * 0.17 * 1086 = 502.4\ {}^{O}R\ (6.0\ {}^{O}C)$$

Secondly calculate the stock vapor pressure, P_{VA}, at the daily average liquid surface temperature, P_{VA}, using Raoult's Law.

According to Raoult's Law, the partial pressure of a component is the product of its pure vapor pressure and its liquid mole fraction. The sum of the partial pressures is equal to the total vapor pressure of the component mixture stock.

The pure vapor pressures for the organics were calculated from Antoine's equation B9:

$$logP = A - \frac{B}{T+C} \qquad \text{(B9)}$$

Where:

P	Vapor pressure, (mm Hg)
A, B, C	Antoine coefficients.
T	Temperature, (^{o}C), 6 ^{o}C from above.

Antoine coefficients were taken from Reference [B-8], with the following exceptions:

- Antoine coefficients for Anthracene were taken from the NIST webbook [B-9]. Though Anthracene was included in reference [B-8], it was identified that vapor pressure, when calculated for room temperature, was significantly different from the published standard vapor pressures at room temperature. For all other organics in the assessment, it was confirmed that the room temperature vapor pressure calculated using Antoine Coefficients from [B-8], were in line with the referenced values listed on the U.S. National Library of Medicine (PubChem) website. This issue was isolated to just Anthracene. Note: The NIST webbook uses different units.
- EDTA and Dioxin (2,3,7,8-Tetrachlorodibenzo-P-Dioxin) were taken at standard vapor pressure as Antoine coefficients were not published.
- All Phenolic compounds were treated as Phenol. Tannic Acid was also treated as Phenol as it is a phenolic acid. This was done as there is no available information on vapor pressure of Tannic Acid, however, it is present in the waste stream in a relatively high concentration.
- For PCBs the Antoine coefficients for 2,2’,5,5’-tetrachlorobiphenyl were used.

The calculated vapor pressures are shown in Table B-1 and the liquid mole fractions in Table B-2. The stock vapor pressure at the daily average liquid surface temperature P_{VA}, is the sum of the partial vapor pressures shown in Table B-3 and calculated to be 0.515 psia (3.55 kPa).

Table B-1
Antoine Coefficients and Calculated Vapor Pressure

Organic	Antoine Coefficients			Vapor Pressure (psia)
	A	B	C	
Acetone	7.117	1210.595	229.664	1.84E+00
Anthracene*	4.72997	2759.53	-30.753	6.03E-06
Benzene	6.905	1211.033	220.79	7.09E-01
Benzo(a)pyrene	12.4818	6181	273.15	4.20E-12
Bis(2-ethylhexyl)phthalate	7.58822	2393.17	124.385	3.28E-13
Carbon tetrachloride	6.934	1242.43	230	9.02E-01
Chlorobenzene	6.978	1431.05	217.55	7.28E-02
Chloroform	6.493	929.44	196.03	1.51E+00
Chrysene	7.30847	2609.83	148.439	4.93E-12
1,4-Dichlorobenzene	7.26566	1806.06	237.826	1.39E-02
Dioxin				2.90E-11
EDTA (ethylenediaminetetraacetic)				2.90E-14
Ethylene dibromide (1,2-Dibromoethane)	7.22206	1605.23	238.402	8.70E-02
Fluoranthene	7.85111	3122.76	245.485	5.23E-07

Fluorene	7.33382	2292.7	217.575	2.31E-05
Furan	7.13277	1145.36	238.023	5.31E+00
Methylene chloride	7.409	1325.9	252.6	3.69E+00
PCBs	11.7951	4920	273.15	2.85E-08
Phenol	7.133	1516.79	174.95	1.09E-03
Phenolic compounds	7.133	1516.79	174.95	1.09E-03
Tannic acid	7.133	1516.79	174.95	1.09E-03
1,1,2,2-Tetrachloroethane	6.631	1228.1	179.9	2.04E-02
Tetrachloroehylene	6.98	1386.92	217.53	1.15E-01
1,1,2-Trichloroethane	6.951	1314.41	209.2	1.34E-01

* Antoine coefficients calculate pressure in different units. Pressure is calculated in bar, and the temperature is in Kelvin.

Table B-2
Equalization Tank Liquid Mole Fraction

Organic	Equalization Tank concentration (mg/L)	Molecular weight (g/mol)	Molecular concentration (mol/L)	Liquid Mole Fraction (χ_i)
Acetone	6.90E-01	58.08	1.19E-05	2.63E-01
Anthracene	4.30E-06	178.234	2.41E-11	5.34E-07
Benzene	1.50E-03	78.114	1.92E-08	4.25E-04
Benzo(a)pyrene	1.10E-07	252.316	4.36E-13	9.64E-09
Bis(2-ethylhexyl)phthalate	4.40E-06	390.564	1.13E-11	2.49E-07
Carbon tetrachloride	2.90E-03	153.811	1.89E-08	4.17E-04
Chlorobenzene	7.60E-04	112.556	6.75E-09	1.49E-04
Chloroform	6.60E-03	119.369	5.53E-08	1.22E-03
Chrysene	3.70E-07	228.294	1.62E-12	3.58E-08
1,4-Dichlorobenzene	3.50E-04	146.998	2.38E-09	5.27E-05
Dioxin	2.70E-13	321.962	8.39E-19	1.85E-14
EDTA (ethylenediaminetetraacetic)	1.00E+00	292.244	3.42E-06	7.57E-02
Ethylene dibromide (1,2-Dibromoethane)	8.10E-03	187.862	4.31E-08	9.54E-04
Fluoranthene	1.20E-06	187.862	6.39E-12	1.41E-07
Fluorene	7.80E-06	166.223	4.69E-11	1.04E-06
Furan	2.70E-13	68.075	3.97E-18	8.77E-14
Methylene chloride	2.80E-02	84.927	3.30E-07	7.29E-03
PCBs	2.50E-08	291.98	8.56E-14	1.89E-09
Phenol	5.70E-04	94.113	6.06E-09	1.34E-04
Phenolic compounds	7.00E-04	94.113	7.44E-09	1.64E-04
Tannic acid	5.00E+01	1701.206	2.94E-05	6.50E-01
1,1,2,2-Tetrachloroethane	1.40E-03	167.838	8.34E-09	1.84E-04

Tetrachloroehylene	1.40E-03	165.822	8.44E-09	1.87E-04
1,1,2-Trichloroethane	2.20E-03	133.396	1.65E-08	3.65E-04
Totals	5.17E+01	-	4.52E-05	1.00E+00

Table B-3
Vapor Partial Pressure

Organic	Vapor Pressure (psia)	Liquid Mole Fraction (χ_i)	Partial Pressure (psia)
Acetone	1.84E+00	2.63E-01	4.84E-01
Anthracene	6.03E-06	5.34E-07	3.22E-12
Benzene	7.09E-01	4.25E-04	3.01E-04
Benzo(a)pyrene	4.20E-12	9.64E-09	4.05E-20
Bis(2-ethylhexyl)phthalate	3.28E-13	2.49E-07	8.16E-20
Carbon tetrachloride	9.02E-01	4.17E-04	3.76E-04
Chlorobenzene	7.28E-02	1.49E-04	1.09E-05
Chloroform	1.51E+00	1.22E-03	1.84E-03
Chrysene	4.93E-12	3.58E-08	1.77E-19
1,4-Dichlorobenzene	1.39E-02	5.27E-05	7.33E-07
Dioxin	2.90E-11	1.85E-14	5.38E-25
EDTA (ethylenediaminetetraacetic)	2.90E-14	7.57E-02	2.20E-15
Ethylene dibromide (1,2-Dibromoethane)	8.70E-02	9.54E-04	8.30E-05
Fluoranthene	5.23E-07	1.41E-07	7.39E-14
Fluorene	2.31E-05	1.04E-06	2.40E-11
Furan	5.31E+00	8.77E-14	4.66E-13
Methylene chloride	3.69E+00	7.29E-03	2.69E-02
PCBs	2.85E-08	1.89E-09	5.39E-17
Phenol	1.09E-03	1.34E-04	1.45E-07
Phenolic compounds	1.09E-03	1.64E-04	1.78E-07
Tannic acid	1.09E-03	6.50E-01	7.05E-04
1,1,2,2-Tetrachloroethane	2.04E-02	1.84E-04	3.77E-06
Tetrachloroehylene	1.15E-01	1.87E-04	2.15E-05
1,1,2-Trichloroethane	1.34E-01	3.65E-04	4.90E-05
Totals		1.00E+00	**5.15E-01**

The vapor pressure of the mixture at the daily average liquid surface temperature P_{VA}, is 0.515 psia (3.55 kPa).

Third, calculate the molecular weight of the vapor, M_V using equation B10. The molecular weight of the vapor depends upon the mole fractions of the components in the vapor,

$$M_V = \sum_i M_i * y_i \qquad \text{(B10)}$$

Where:

M_i Molecular weight of the component

y_i Vapor mole fraction

The vapor mole fractions, y_i, are equal to the partial pressure of the component divided by the total vapor pressure of the mixture. These are shown in Table B-4 alongside the calculation for the molecular weight of the vapor. The molecular weight of the vapor, M_V, is 62.1 lb/lb-mole (62.1 g/g-mol).

Table B-4
Vapor Mole Fractions

Organic	Molecular weight	Partial Pressure (psia)	Vapor Mole Fraction	Vapor molecular weight
Acetone	58.08	4.84E-01	9.41E-01	5.47E+01
Anthracene	178.234	3.22E-12	6.26E-12	1.11E-09
Benzene	78.114	3.01E-04	5.85E-04	4.57E-02
Benzo(a)pyrene	252.316	4.05E-20	7.87E-20	1.99E-17
Bis(2-ethylhexyl)phthalate	390.564	8.16E-20	1.59E-19	6.19E-17
Carbon tetrachloride	153.811	3.76E-04	7.30E-04	1.12E-01
Chlorobenzene	112.556	1.09E-05	2.11E-05	2.38E-03
Chloroform	119.369	1.84E-03	3.58E-03	4.27E-01
Chrysene	228.294	1.77E-19	3.43E-19	7.83E-17
1,4-Dichlorobenzene	146.998	7.33E-07	1.42E-06	2.09E-04
Dioxin	321.962	5.38E-25	1.05E-24	3.36E-22
EDTA (ethylenediaminetetraacetic)	292.244	2.20E-15	4.26E-15	1.25E-12
Ethylene dibromide (1,2-Dibromoethane)	187.862	8.30E-05	1.61E-04	3.03E-02
Fluoranthene	187.862	7.39E-14	1.44E-13	2.70E-11
Fluorene	166.223	2.40E-11	4.66E-11	7.75E-09
Furan	68.075	4.66E-13	9.04E-13	6.16E-11
Methylene chloride	84.927	2.69E-02	5.23E-02	4.44E+00
PCBs	291.98	5.39E-17	1.05E-16	3.06E-14
Phenol	94.113	1.45E-07	2.82E-07	2.66E-05
Phenolic compounds	94.113	1.78E-07	3.47E-07	3.26E-05
Tannic acid	1701.206	7.05E-04	1.37E-03	2.33E+00
1,1,2,2-Tetrachloroethane	167.838	3.77E-06	7.32E-06	1.23E-03

Tetrachloroehylene	165.822	2.15E-05	4.17E-05	6.92E-03
1,1,2-Trichloroethane	133.396	4.90E-05	9.53E-05	1.27E-02
Totals		**5.15E-01**	1.00E+00	**6.21E+01**

Since all variable have now been solved, the stock density, W_v, can be calculated:

$$W_v = \frac{M_v * P_{VA}}{R * T_{LA}} = \frac{62.1 * 0.515}{10.731 * 502.4} = 5.931E-3 \frac{lb}{ft^3}\ (9.5E-2 \frac{kg}{m^3})$$

B.2.1.3 Vapor Space Expansion Factor, K_E, Calculation

The vapor space expansion factor, K_E, is calculated using the following equation B11:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V - \Delta P_B}{P_A - P_{VA}} \qquad \text{(B11)}$$

Where:

ΔT_V Daily vapor temperature range, (°R)

ΔP_V Daily vapor pressure range, (psia)

ΔP_B Breather vent pressure setting range, (psia)

P_A Atmospheric pressure, 14.7 psia

P_{VA} Vapor pressure at daily average liquid surface temperature (0.515 psia from previously)

T_{LA} Daily average liquid surface temperature, (502.4 °R from previously)

Firstly, calculate the daily vapor range using the following equation B12:

$$\Delta T_V = 0.72 * \Delta T_A + 0.028 * \alpha * I \qquad \text{(B12)}$$

Where:

ΔT_V Daily vapor temperature range, (°R)

ΔT_A Daily ambient temperature range, $T_{AX} - T_{AN}$

α Tank paint solar absorptance, 0.17 as previously

I Daily total solar insolation, (Btu/ft^2-d), 1086 as previously

T_{AX} Daily maximum ambient temperature, (°R), 510.6 as previously

T_{AN} Daily minimum ambient temperature, (°R), 491.3 as previously

Using the same daily maximum and minimum temperatures as before from the Government of Canada Canadian Climate Normals [B-7], the same paint solar absorptance as before, and the same daily solar insolation, then the daily vapor temperature range can be calculated:

$$\Delta T_A = T_{AX} - T_{AN} = 510.6 - 491.3 = 19.3\ ^OR$$

$$\Delta T_V = 0.72 * \Delta T_A + 0.028 * \alpha * I$$

$$\Delta T_V = 0.72 * 19.3 + 0.028 * 0.17 * 1086 = 19.04\ ^oR$$

Secondly, calculate the daily vapor pressure range using the following equation B13:

$$\Delta P_V = P_{VX} - P_{VN} \qquad \text{(B13)}$$

Where:

P_{VX} Vapor pressure at daily maximum temperature

P_{VN} Vapor pressure at daily minimum temperature

T_{LX} Maximum liquid temperature, ^oR

$$T_{LX} = T_{LA} + 0.25\Delta T_V = 502.4 + 0.25 * 19.0 = 507.2\ ^oR\ (8.6\ ^oC)$$

T_{LN} Minimum liquid temperature, ^oR

$$T_{LN} = T_{LA} - 0.25\Delta T_V = 502.4 - 0.25 * 19.0 = 497.7\ ^oR\ (3.3\ ^oC)$$

Using Antoine's equations with these new values the true vapor pressure is calculated, and then the partial pressure, to provide the total mixture pressure as shown in Table B-5.

Therefore, the vapor pressure range for the mixture:

$$\Delta P_V = P_{LX} - P_{LN} = 0.586 - 0.450 = 0.136\ psia\ (0.94\ kPa)$$

Specific information on the breather vent pressure setting and the vacuum setting are not available, so default values are used [B-1]. Given the very low emissions, even a significant change to this value would be insignificant.

The breather vent pressure equation B14:

$$\Delta P_B = P_{BP} - P_{BV} \qquad \text{(B14)}$$

Where:

ΔP_B Breather vent pressure, (psig)

P_{BP} Breather vent pressure setting, 0.03 psia (default)

P_{BV} Breather vent vacuum setting, -0.03 psig (default)

Therefore:

$$\Delta P_B = P_{BP} - P_{BV} = 0.03 - -0.03 = 0.06\ psig\ (0.41\ kPa)$$

Table B-5
Vapor Pressure at Daily Maximum Temperature and Daily Minimum Temperature

Organic	Daily Maximum Temperature Vapor Pressure (psia)	Daily Maximum Temperature Partial Pressure (psia)	Daily Minimum Temperature Partial Pressure (psia)	Daily Minimum Temperature Partial Pressure (psia)
Acetone	2.10E+00	5.52E-01	1.61E+00	4.24E-01
Anthracene	7.90E-06	4.22E-12	4.58E-06	2.45E-12
Benzene	8.17E-01	3.47E-04	6.13E-01	2.60E-04
Benzo(a)pyrene	6.78E-12	6.54E-20	2.58E-12	2.49E-20
Bis(2-ethylhexyl)phthalate	7.59E-13	1.89E-19	1.37E-13	3.40E-20
Carbon tetrachloride	1.03E+00	4.30E-04	7.86E-01	3.28E-04
Chlorobenzene	8.65E-02	1.29E-05	6.10E-02	9.11E-06
Chloroform	1.73E+00	2.11E-03	1.31E+00	1.60E-03
Chrysene	9.48E-12	3.40E-19	2.50E-12	8.96E-20
1,4-Dichlorobenzene	1.67E-02	8.81E-07	1.16E-02	6.08E-07
Dioxin	1.45E-01	2.69E-15	1.45E-01	2.69E-15
EDTA (ethylenediaminetetraacetic)	2.90E-14	2.20E-15	2.90E-14	2.20E-15
Ethylene dibromide (1,2-Dibromoethane)	1.02E-01	9.76E-05	7.37E-02	7.03E-05
Fluoranthene	7.04E-07	9.95E-14	3.86E-07	5.45E-14
Fluorene	3.05E-05	3.16E-11	1.74E-05	1.81E-11
Furan	5.96E+00	5.23E-13	4.71E+00	4.14E-13
Methylene chloride	4.16E+00	3.04E-02	3.27E+00	2.38E-02
PCBs	4.17E-08	7.89E-17	1.93E-08	3.66E-17
Phenol	1.43E-03	1.92E-07	8.15E-04	1.09E-07
Phenolic compounds	1.43E-03	2.36E-07	8.15E-04	1.34E-07
Tannic acid	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1,1,2,2-Tetrachloroethane	2.53E-02	4.66E-06	1.64E-02	3.02E-06
Tetrachloroehylene	1.36E-01	2.54E-05	9.69E-02	1.81E-05
1,1,2-Trichloroethane	1.59E-01	5.82E-05	1.13E-01	4.12E-05
Totals		**5.86E-01**		**4.50E-01**

Finally, the vapor space expansion factor can be calculated

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V - \Delta P_B}{P_A - P_{VA}} = \frac{19.04}{502.4} + \frac{0.136 - 0.06}{14.7 - 0.515} = 4.33E - 2\ (dimensionless)$$

B.2.1.4 Vented Vapor Space Saturation Factor, K_S, Calculation

The vented vapor space saturation factor, K_S, is calculated using the following equation B15:

$$K_s = \frac{1}{1+0.053*P_{VA}*H_{VO}} \qquad \text{(B15)}$$

Where P_{VA} has been previously calculated as 0.515 psia, and H_{VO} has been previously calculated as 8.5 ft.

$$K_s = \frac{1}{1 + 0.053 * 0.515 * 8.5} = 0.812\ (dimensionless)$$

B.2.1.5 Organic Standing Storage Losses

Standing storage losses are calculated through the following equation B16:

$$L_S = 365 * W_V * V_v * K_E * K_s \qquad \text{(B16)}$$

Using the values calculated above:

W_V	$5.93E-3\frac{lb}{ft^3}$
V_v	$2.57E4\ ft^3$
K_E	$4.33E-2$
K_s	$8.12E-1$

$$L_S = 365 * 5.93E-3 * 2.57E4 * 4.33E-2 * 8.12E-1 = 1956\frac{lb}{yr}(equates\ to\ 890\frac{kg}{yr})$$

B.2.2 Organic Working Losses

The amount of VOCs emitted as a result of filling operations can be calculated from the following equation B17:

$$L_w = 0.0010 * M_V * P_{VA} * Q * K_N * K_P \qquad \text{(B17)}$$

Where:

M_V	62.1 lb/lb-mole, as previously calculated
P_{VA}	0.515 psia, as previously calculated
Q	Annual net throughput 70 712 bbl/y, (30.8 m^3/day or 11 240 m^3/y)
K_N	Turnover factor, (dimensionless) K_N=1 for tank turnovers, N ≤36 N=number of turnovers per year (dimensionless)

N=5.614*Q/V_{LX} where V_{LX} is the tank maximum liquid volume, ft^3.

(Tank volume (m^3) = π*R^2*H where R is the tank radius which is 31.01 ft and H is the tank operating height which is 22.21 ft, as such the tank volume is 67084 ft^3)

N=5.61*Q/Vl_x =5.61*70712/67084=5.913

Annual net throughput is just under six tank turnovers.

K_P Product factor, (dimensionless) K_P = 1 for volatile organic liquids

$$L_w = 0.0010 * 62.1 * 0.515 * 70712 * 1 * 1 = 2261\ lb/yr$$

B.2.3 Organic Total Losses

The total losses from a fixed roof tank is calculated through the following equation B18:

$$L_T = L_S + L_W \qquad \text{(B18)}$$

Where:

L_T Total losses, (lb/y)

L_S Standing storage losses (lb/y) as calculated above

L_W Working losses (lb/y) as calculated above

$$L_{T\ ORGANICS} = L_S + L_W = 1956 + 2261 = 4217\frac{lb}{yr}(equates\ to\ 1910\frac{kg}{yr})$$

The total loss is 4 217 lb (1 910 kg) organics/y.

B.3 Water Phase Losses

B.3.1 Standing Losses

For the water component, the standing losses will be due to evaporation. An evaporation rate for undisturbed water pools of 0.002 lb/h-ft^2 is assumed from reference [B-2]. The standing storage loss over the course of a year can be calculated through the following equation:

$$L_S = 0.002\frac{lb}{hour - ft^2} * \left(365\frac{days}{year} * 24\frac{hours}{day}\right) * (\pi * R^2)$$

Where:

R Tank radius, (ft) which is 31.01 ft

Therefore:

$$L_S = 0.002\frac{lb}{hour.ft^2} * \left(365\frac{days}{year} * 24\frac{hours}{day}\right) * (\pi * 31.01^2)$$

$$L_S = 5.29E4\frac{lb}{yr}\ (equates\ to\ 2.40E4\frac{kg}{yr})$$

B.3.2 Water Working Losses

Assuming the same ratio of standing storage loss and working loss as for organics, where for organics:

$$\frac{L_w}{L_s} = \frac{2261}{1956} = 1.16$$

Then for the water phase

$$L_w = L_s * 1.16 = 5.29E4 * 1.16 = 6.12E4\frac{lb}{yr}(equates\ to\ 2.78E4\frac{kg}{yr})$$

B.3.3 Water Total Losses

As previously, the total losses from a fixed roof tank is calculated through the following equation B18:

$$L_T = L_S + L_W \qquad \text{(B18)}$$

Where:

L_T Total losses, (lb/y)

L_S Standing storage losses (lb/y) as calculated above

L_W Working losses (lb/y) as calculated above

$$L_{T\ WATER} = L_S + L_W = 5.29E4 + 6.12E4 = 1.14E5\frac{lb}{yr}(equates\ to\ 5.18E4\frac{kg}{yr})$$

B.3.4 Total Activity Losses

The total activity losses are: 1 910 kg/year organic phase and 5.18E+04 kg/y water phase.

The total activity loss from organics per year is calculated using the equation B19:

$$Q_{ORGANICS}\left(\frac{Bq}{yr}\right) = C\left(\frac{Bq}{mg}\right) * 1E6(\frac{mg}{kg}) * L_{T\ organics}\left(\frac{kg}{yr}\right) \qquad \text{(B19)}$$

Where:

$Q_{ORGANICS}$ Radioactive material losses term from organic phase (Bq/y)

C Concentration of radionuclides within the waste stream (Bq/L)

$L_{T\ organics}$ Total organic losses (kg/y) as calculated above, 1.91E+03 kg/y.

The total activity loss from the water phase material per year is calculated using the equation B20 below:

$$Q_{WATER}\left(\frac{Bq}{yr}\right) = C\left(\frac{Bq}{l}\right) * 1(\frac{l}{kg}) * L_{T\ WATER}\left(\frac{kg}{yr}\right) \qquad (B20)$$

Where:

Q_{WATER}	Radioactive material losses from water phase (Bq/y)
C	Concentration of radionuclides within the waste stream (Bq/L), ignoring the small quantity of organics.
$L_{T\ WATER}$	Total water losses (kg/y) as calculated above, 5.18E+04 kg

B.4 Conclusion

The total radioactive material losses per year for organics and water phases are shown in Table B-6. The organics phase contributes almost twice that of the water phase to the radioactive releases.

The comparison of the total radioactive material losses to the DRL for roof vents on the CRL site [B-10] are shown in Table B-7. Derived Release Limits represent release rates that correspond to critical groups at the public dose limits. If the gross alpha, gross beta and gross gamma values are compared to the most restrictive radionuclide DRL for that main emission type, (i.e. the lowest DRL which for alpha is Ra-226, for beta is Cl-36 and for gamma is Co-60), total radioactive material loss is 0.04% of the DRL. From the individual radionuclide comparison with the DRLs, it is apparent that this is entirely from the Co-60 release.

In conclusion, there are no appreciable radiological airborne releases from a single Equalization Tank vent.

Non-radioactive airborne effluent levels is accomplished through estimation and are typically calculated annually. Currently, the only non-radioactive airborne effluent levels are Regulatory Levels outlined in CRL's LCH, of which none have yet been set for NSDF [B-11]. The calculated value above of 1 910 kg of organic release per Equalization Tanks is below the (VOC compound emission reporting threshold of the National Pollution Release Inventory), which is 10 tonnes [B-12].

Table B-6
Total Radioactive Material Losses per Year

Radionuclides	Concentration in Chemical Precipitation Non-organic Waste Stream (Bq/L)	Concentration in Chemical Precipitation Organic Waste Stream (Bq/mg)	Organic Phase Radioactive Material Losses (Bq/y)	Water Phase Radioactive Material Losses (Bq/y)	Total Radioactive Material Losses (Bq/y)
Gross alpha	2.48E-02	1.28E-06	2.45E+03	1.28E+03	3.74E+03
Gross beta	1.87E+01	9.68E-04	1.85E+06	9.69E+05	2.82E+06
Gross gamma	1.30E+03	6.73E-02	1.28E+08	6.73E+07	1.96E+08
Ag-108m	1.80E-04	9.31E-09	1.78E+01	9.32E+00	2.71E+01
Am-241	2.80E-03	1.45E-07	2.77E+02	1.45E+02	4.22E+02
Am-243	1.70E-06	8.80E-11	1.68E-01	8.81E-02	2.56E-01
C-14	3.10E+00	1.60E-04	3.06E+05	1.61E+05	4.67E+05
Cl-36	5.90E-02	3.05E-06	5.83E+03	3.06E+03	8.89E+03
Co-60	1.30E+03	6.73E-02	1.28E+08	6.73E+07	1.96E+08
Cs-135	4.10E-05	2.12E-09	4.05E+00	2.12E+00	6.18E+00
Cs-137	9.30E-01	4.81E-05	9.19E+04	4.82E+04	1.40E+05
H-3	1.40E+05	7.24E+00	1.38E+10	7.25E+09	2.11E+10
I-129	9.10E-02	4.71E-06	8.99E+03	4.71E+03	1.37E+04
Mo-93	4.10E-07	2.12E-11	4.05E-02	2.12E-02	6.18E-02
Nb-94	1.50E-02	7.76E-07	1.48E+03	7.77E+02	2.26E+03
Ni-59	1.70E-04	8.80E-09	1.68E+01	8.81E+00	2.56E+01
Ni-63	4.40E-02	2.28E-06	4.35E+03	2.28E+03	6.63E+03
Np-237	6.30E-07	3.26E-11	6.23E-02	3.26E-02	9.49E-02
Pu-239	4.40E-03	2.28E-07	4.35E+02	2.28E+02	6.63E+02
Pu-241	7.90E-02	4.09E-06	7.81E+03	4.09E+03	1.19E+04
Pu-242	3.30E-06	1.71E-10	3.26E-01	1.71E-01	4.97E-01
Ra-226	6.40E-04	3.31E-08	6.33E+01	3.32E+01	9.64E+01
Se-79	2.40E-05	1.24E-09	2.37E+00	1.24E+00	3.62E+00
Sn-126	7.20E-06	3.73E-10	7.12E-01	3.73E-01	1.08E+00
Sr-90	9.60E+00	4.97E-04	9.49E+05	4.97E+05	1.45E+06
Tc-99	5.70E+00	2.95E-04	5.63E+05	2.95E+05	8.59E+05
Th-230	2.20E-04	1.14E-08	2.17E+01	1.14E+01	3.31E+01
Th-232	9.60E-04	4.97E-08	9.49E+01	4.97E+01	1.45E+02
U-233	2.90E-05	1.50E-09	2.87E+00	1.50E+00	4.37E+00
U-234	7.80E-03	4.04E-07	7.71E+02	4.04E+02	1.17E+03
U-235	3.30E-04	1.71E-08	3.26E+01	1.71E+01	4.97E+01
U-238	7.60E-03	3.93E-07	7.51E+02	3.94E+02	1.14E+03
Zr-93	4.40E-02	2.28E-06	4.35E+03	2.28E+03	6.63E+03

Table B-7
Radioactive Releases as Percentage of Roof Vent DRL

Radionuclides	Radioactive Material Losses (Bq/wk)	Roof Vent DRL (Bq/wk) [B-10]	Percentage of DRL
Gross alpha	7.18E+01	7.88E+08	0.00%
Gross beta	5.42E+04	3.12E+09	0.00%
Gross gamma	3.77E+06	1.03E+10	0.04%
Ag-108m	5.21E-01	No calculated DRL	NV
Am-241	8.11E+00	1.48E+09	0.00%
Am-243	4.92E-03	No calculated DRL	NV
C-14	8.98E+03	1.35E+13	0.00%
Cl-36	1.71E+02	3.12E+09	0.00%
Co-60	3.77E+06	1.03E+10	0.04%
Cs-135	1.19E-01	No calculated DRL	NV
Cs-137	2.69E+03	1.00E+10	0.00%
H-3	4.06E+08	3.98E+14	0.00%
I-129	2.64E+02	4.32E+09	0.00%
Mo-93	1.19E-03	No calculated DRL	NV
Nb-94	4.35E+01	No calculated DRL	NV
Ni-59	4.92E-01	No calculated DRL	NV
Ni-63	1.27E+02	No calculated DRL	NV
Np-237	1.82E-03	1.40E+09	0.00%
Pu-239	1.27E+01	1.23E+09	0.00%
Pu-241	2.29E+02	6.83E+10	0.00%
Pu-242	9.56E-03	No calculated DRL	NV
Ra-226	1.85E+00	7.88E+08	0.00%
Se-79	6.95E-02	No calculated DRL	NV
Sn-126	2.09E-02	No calculated DRL	NV
Sr-90	2.78E+04	1.01E+10	0.00%
Tc-99	1.65E+04	1.40E+11	0.00%
Th-230	6.37E-01	No calculated DRL	NV
Th-232	2.78E+00	8.97E+08	0.00%
U-233	8.40E-02	1.06E+10	0.00%
U-234	2.26E+01	1.09E+10	0.00%
U-235	9.56E-01	7.99E+09	0.00%
U-238	2.20E+01	9.25E+09	0.00%
Zr-93	1.27E+02	No calculated DRL	NV

B.5 References

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[B-2] Shah, M. Mohamad, *Methods for Calculation of Evaporation from Swimming Pools and Other Water Surfaces*, ASHRA Transactions 118, 2012 January.

[B-3] *Near Surface Disposal Facility Wastewater Treatment Plant Process – Equalization Tank Detail Layout TK-302*, B1555-106400-502-01-GA-D, Revision 0, 2017 March.

[B-4] *Near Surface Disposal Facility Wastewater Treatment Plant Process – Equalization Tank Detail Layout TK-102 & TK-202*, B1555-106400-501-01-GA-D, Revision 0, 2017 March.

[B-5] Memo from Barber, Brendan to Kingsbury, R and Birchall, R, *Near Surface Disposal Facility Wastewater Treatment Plant Process Tank Details*, 232-106470-230-00 (Atom ID: 48061952), 2019 April 15.

[B-6] WWTP Process Design Report, B1551-508233-DRP-001, Revision 1, 2019 January.

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[B-9] NIST webbook https://webbook.nist.gov/cgi/cbook.cgi?ID=C123911&Mask=4&Type=ANTOINE&Plot=on

[B-10] *Derived Release Limits (DRL's) for CNL's Chalk River Laboratories*, CRL-509200-RRD-001, Revision 2, 2018 August.

[B-11] *Effluent Levels for CRL Air and Liquid Non-Radioactive Effluents,* 900-509200-STD-014, ATOM ID: 44161841, Revision 0, 2019 February.

[B-12] Letter from Murthy, K., to Dolinar, G., *CNSC Staff Review of CNL's Request for a Change of the Level for Volatile Organic Compound Emission in the Chalk River Licence Condition Handbook,* ENVP-NOCN-18-0002-L, ATOM ID: 42035678, 2018 December 21.

Appendix C

Filter Press Feed Tank Airborne Emissions

C.1 Introduction

Emissions from storage tanks occur because of evaporative loss of the liquid in storage and as a result of changes in liquid level. The filter press feed tank is a fixed roof tank so therefore, is subject to evaporative losses during storage (also known as breathing losses or standing storage losses), which occur due to diurnal variations in ambient temperature, and evaporative losses during filling and emptying operations (known as working losses).

Estimation of the radioactive inventory released from a single filter press feed tank is based on the following assumptions:

- Losses will occur from the water phase and the organic phase.
- The organic phase losses are calculated as per the U.S. Environmental Protection Agency methodology described in Reference [C-1]. As such, the calculation methodology uses imperial units; SI units are provided in parentheses throughout.
- The water phase losses are calculated based on empirical data for undisturbed water pools in the ASHRAE technical paper [C-2].
- The radionuclide concentration is evenly distributed throughout these phases and throughout the tank.
- The water phase working losses are estimated using the same ratio of standing to working losses as calculated for the organic phase.
- The filter press feed tank is modelled as a flat roof vertical tank [C-3].
- Tank dimensions are taken from [C-4].
- The organics quantities within the waste are taken from the CRL NSDF Wastewater Treatment Material Balance Table, Column N “membrane filter residues” [C-5].
- The radionuclide concentrations within the waste are taken from the CRL NSDF Wastewater Treatment Material Balance Table, Column N “membrane filter residues” [C-5].

C.2 Organic Phase Losses

Organic phase losses are the sum of the standing storage loss, L_S, and the working storage loss, L_W. Each loss is calculated separately in the applicable subsection below.

C.2.1 Organic Phase Standing Storage Loss

Tank standing storage losses, (lb/y) for the organics can be estimated using the following equation C1:

$$L_S = 365 * V_V * W_V * K_E * K_S \qquad (C1)$$

Where:

L_S	Standing storage loss (lb/y)
365	Constant, (days/y)
V_V	Vapor space volume, (ft^3)
W_V	Vapor density, (lb of VOC/ft^3)
K_E	Vapor space expansion factor (dimensionless)
K_S	Vented vapor saturation factor (dimensionless)

Calculating for each component in turn.

C.2.1.1 Tank Vapor Space, V_V, Calculation

The tank vapor space volume, V_V, is calculated using the following equation C2:

$$V_V = \frac{\pi}{4} * D^2 * H_{VO} \qquad \text{(C2)}$$

Where:

D	Diameter of the tank, (ft)
H_{VO}	Vapor space outage, (ft)

The vapor space outage, H_{VO}, is calculated using the following equation C3:

$$H_{VO} = H_S - H_L + H_{RO} \qquad \text{(C3)}$$

Where:

H_S	Tank shell height, (ft)
H_L	Stock liquid height, (ft)
H_{RO}	Roof outage, (ft)

For a flat roof, where there is no additional roof outage, therefore:

$$H_{RO} = 0$$

The tank shell height, H_S, is 8.20 ft (2.5 m), and the operating level or stock liquid height H_L, of the tank is 6.63 ft (2.02 m) [C-4]. Therefore:

$$H_{VO} = H_S - H_L + H_{RO} = 8.20 - 6.63 + 0 = 1.58\, ft\ (0.48\, m)$$

Using this value and the tank shell diameter, D, of 8.01 ft (2.44 m), then:

$$V_V = \frac{\pi}{4} * D^2 * H_{VO} = \frac{\pi}{4} * 8.01^2 * 1.57 = 79.27\, ft^3 \; (2.25\, m^3)$$

C.2.1.2 Vapor Density, W_v, Calculation

The vapor density, W_V, is calculated using the following equation C5:

$$W_v = \frac{M_v * P_{VA}}{R * T_{LA}} \quad \text{(C5)}$$

Where:

W_v Vapor density, (lb/ft^3)

M_v Stock vapor molecular weight, (lb/lb-mole)

P_{VA} Stock vapor pressure at the daily average liquid surface temperature, (psia)

R Ideal gas constant, 10.731 (psia.ft^3/lb-mole.^{o}R)

T_{LA} Daily average liquid surface temperature, (^{o}R)

Firstly, calculate the daily average liquid surface temperature, T_{LA}, using the following equation C6:

$$T_{LA} = 0.44 * T_{AA} + 0.56 * T_B + 0.0079 * \alpha * I \qquad \text{(C6)}$$

Where:

T_{AA} Daily average ambient temperature, (^{o}R)

T_B Liquid bulk temperature, (^{o}R)

α Tank paint solar absorptance

I Daily total solar insolation, (Btu/ft^2.d)

The daily average ambient temperature is calculated using the following equation C7:

$$T_{AA} = \frac{T_{AX} + T_{AN}}{2} \qquad \text{(C7)}$$

Where:

T_{AX} Daily maximum ambient temperature, (^{o}R)

T_{AN} Daily minimum ambient temperature, (^{o}R)

The Design Requirements [C-6], give the ambient condition temperatures within the WWTP building as 542.1 ^{o}R (28 ^{o}C) and 524.1 ^{o}R (18 ^{o}C), respectively. Therefore:

$$T_{AA} = \frac{T_{AX} + T_{AN}}{2} = \frac{542.1 + 524.1}{2} = 533\, ^oR \; (23\, ^oC)$$

The liquid bulk temperature is calculated using the following equation C8:

$$T_B = T_{AA} + 6 * \alpha - 1 \qquad \text{(C8)}$$

The paint solar absorptance, α, has been assumed to be 0, as the filter press feed tank is located inside the WWTP.

$$T_B = 533 + 6 * 0 - 1 = 532\ ^oR\ (22.4^oC)$$

The daily solar insolation, I, on a horizontal surface is also assumed to be 0, as the filter press feed tank is located inside the WWTP. Therefore:

$$T_{LA} = 0.44 * T_{AA} + 0.56 * T_B + 0.0079 * \alpha * I$$

$$T_{LA} = 0.44 * 533 + 0.56 * 532 + 0.0079 * 0 * 0 = 532.5\ ^oR\ (22.7\ ^oC)$$

Secondly, calculate the stock vapor pressure, P_{VA}, at the daily average liquid surface temperature, T_{LA}, using Raoult's Law.

According to Raoult's Law, the partial pressure of a component is the product of its pure vapor pressure and its liquid mole fraction. The sum of the partial pressures is equal to the total vapor pressure of the component mixture stock.

The pure vapor pressures for the organics were calculated from Antoine's equation C9:

$$logP = A - \frac{B}{T+C} \qquad \text{(C9)}$$

Where:

P	Vapor pressure, (mmHg).
A, B, C	Antoine coefficients.
T	Temperature, (^{o}C), 22.7 ^{o}C from above.

Antoine coefficients were taken from Reference [C-7], with the following exceptions:

- Antoine coefficients for Anthracene were taken from the NIST webbook [C-8]. Though Anthracene was included in reference [C-7], it was identified that vapor pressure, when calculated for room temperature, was significantly different from the published standard vapor pressures at room temperature. For all other organics in the assessment, it was confirmed that the room temperature vapor pressure calculated using Antoine Coefficients from [C-7] were in line with the referenced values listed on the U.S. National Library of Medicine (PubChem) website. This issue was isolated to just Anthracene. Note: The NIST webbook uses different units.
- EDTA and Dioxin (2, 3,7,8-Tetrachlorodibenzo-P-Dioxin) were taken at standard vapor pressure as Antoine coefficients were not published.
- All Phenolic compounds were treated as Phenol. Tannic Acid was also treated as Phenol as it is a phenolic acid. This was done as there is no available information on vapor pressure of Tannic Acid, however, it is present in the waste stream in a relatively high concentration.

- For PCBs the Antoine coefficients for 2,2',5,5'-tetrachlorobiphenyl were used.

The calculated vapor pressures are shown in Table C-1 and the liquid mole fractions in Table C-2. The stock vapor pressure at the daily average liquid surface temperature P_{VA}, is the sum of the partial vapor pressures shown in Table C-3 and calculated to be 1.13 psia (7.79 kPa).

Table C-1

Antoine Coefficients and Calculated Vapor Pressure

Organic	Antoine Coefficients			Vapor Pressure (psia)
	A	B	C	
Acetone	7.117	1210.595	229.664	4.04E+00
Anthracene*	4.72997	2759.53	-30.753	3.03E-05
Benzene	6.905	1211.033	220.79	1.65E+00
Benzo(a)pyrene	12.4818	6181	273.15	7.50E-11
Bis(2-ethylhexyl)phthalate	7.58822	2393.17	124.385	4.01E-11
Carbon tetrachloride	6.934	1242.43	230	2.01E+00
Chlorobenzene	6.978	1431.05	217.55	2.03E-01
Chloroform	6.493	929.44	196.03	3.39E+00
Chrysene	7.30847	2609.83	148.439	2.21E-10
1,4-Dichlorobenzene	7.26566	1806.06	237.826	4.16E-02
Dioxin	-	-	-	2.90E-11
EDTA (ethylenediaminetetraacetic)	-	-	-	2.90E-14
Ethylene dibromide (1,2-Dibromoethane)	7.22206	1605.23	238.402	2.29E-01
Fluoranthene	7.85111	3122.76	245.485	3.11E-06
Fluorene	7.33382	2292.7	217.575	1.20E-04
Furan	7.13277	1145.36	238.023	1.06E+01
Methylene chloride	7.409	1325.9	252.6	7.57E+00
PCBs	11.7951	4920	273.15	2.82E-07
Phenol	7.133	1516.79	174.95	5.56E-03
Phenolic compounds	7.133	1516.79	174.95	5.56E-03
Tannic acid	-	-	-	5.56E-03
1,1,2,2-Tetrachloroethane	6.631	1228.1	179.9	7.17E-02
Tetrachloroehylene	6.98	1386.92	217.53	3.11E-01
1,1,2-Trichloroethane	6.951	1314.41	209.2	3.71E-01

* Antoine coefficients calculate pressure in different units. Pressure is calculated in bar, and the temperature is in Kelvin.

Table C-2

Filter Press Feed Tank Liquid Mole Fraction

Organic	Membrane Filter Residuals concentration mg/L	Molecular weight (lb/lb-mol or g/g-mol)	Molecular concentration (mol/L)	Liquid Mole Fraction (χ_i)
Acetone	6.75E-01	58.08	1.16E-05	2.63E-01
Anthracene	4.21E-06	178.234	2.36E-11	5.34E-07
Benzene	1.47E-03	78.114	1.88E-08	4.26E-04
Benzo(a)pyrene	1.08E-07	252.316	4.28E-13	9.68E-09
Bis(2-ethylhexyl)phthalate	4.30E-06	390.564	1.10E-11	2.49E-07
Carbon tetrachloride	2.84E-03	153.811	1.85E-08	4.18E-04
Chlorobenzene	7.43E-04	112.556	6.60E-09	1.49E-04
Chloroform	6.45E-03	119.369	5.40E-08	1.22E-03
Chrysene	3.62E-07	228.294	1.59E-12	3.59E-08
1,4-Dichlorobenzene	3.42E-04	146.998	2.33E-09	5.26E-05
Dioxin	2.64E-13	321.962	8.20E-19	1.85E-14
EDTA (ethylenediaminetetraacetic)	9.78E-01	292.244	3.35E-06	7.57E-02
Ethylene dibromide (1,2-Dibromoethane)	7.92E-03	187.862	4.22E-08	9.53E-04
Fluoranthene	1.17E-06	187.862	6.23E-12	1.41E-07
Fluorene	7.63E-06	166.223	4.59E-11	1.04E-06
Furan	2.64E-13	68.075	3.88E-18	8.77E-14
Methylene chloride	2.74E-02	84.927	3.23E-07	7.30E-03
PCBs	2.45E-08	291.98	8.39E-14	1.90E-09
Phenol	5.57E-04	94.113	5.92E-09	1.34E-04
Phenolic compounds	6.85E-04	94.113	7.28E-09	1.65E-04
Tannic acid	4.89E+01	1701.206	2.87E-05	6.50E-01
1,1,2,2-Tetrachloroethane	1.37E-03	167.838	8.16E-09	1.85E-04
Tetrachloroehylene	1.37E-03	165.822	8.26E-09	1.87E-04
1,1,2-Trichloroethane	2.15E-03	133.396	1.61E-08	3.64E-04
Totals	**5.06E+01**	**-**	**-**	**1.00E+00**

Table C-3

Vapor Partial Pressure

Organic	Vapor Pressure (psia)	Liquid Mole Fraction (χ_i)	Partial Pressure (psia)
Acetone	4.04E+00	2.63E-01	1.06E+00
Anthracene	3.03E-05	5.34E-07	1.62E-11
Benzene	1.65E+00	4.26E-04	7.02E-04
Benzo(a)pyrene	7.50E-11	9.68E-09	7.26E-19
Bis(2-ethylhexyl)phthalate	4.01E-11	2.49E-07	9.97E-18
Carbon tetrachloride	2.01E+00	4.18E-04	8.40E-04
Chlorobenzene	2.03E-01	1.49E-04	3.03E-05
Chloroform	3.39E+00	1.22E-03	4.14E-03
Chrysene	2.21E-10	3.59E-08	7.92E-18
1,4-Dichlorobenzene	4.16E-02	5.26E-05	2.19E-06
Dioxin	2.90E-11	1.85E-14	5.38E-25
EDTA (ethylenediaminetetraacetic)	2.90E-14	7.57E-02	2.20E-15
Ethylene dibromide (1,2-Dibromoethane)	2.29E-01	9.53E-04	2.19E-04
Fluoranthene	3.11E-06	1.41E-07	4.38E-13
Fluorene	1.20E-04	1.04E-06	1.24E-10
Furan	1.06E+01	8.77E-14	9.31E-13
Methylene chloride	7.57E+00	7.30E-03	5.52E-02
PCBs	2.82E-07	1.90E-09	5.36E-16
Phenol	5.56E-03	1.34E-04	7.44E-07
Phenolic compounds	5.56E-03	1.65E-04	9.15E-07
Tannic acid	5.56E-03	6.50E-01	3.61E-03
1,1,2,2-Tetrachloroethane	7.17E-02	1.85E-04	1.32E-05
Tetrachloroehylene	3.11E-01	1.87E-04	5.81E-05
1,1,2-Trichloroethane	3.71E-01	3.64E-04	1.35E-04
	Totals	1.00E+00	**1.13E+00**

Third, calculate the molecular weight of the vapor, M_V. The molecular weight of the vapor depends upon the mole fractions of the components in the vapor, equation C10:

$$M_V = \sum_i M_i * y_i \qquad \text{(C10)}$$

Where:

M_i Molecular weight of the component

y_i Vapor mole fraction (partial pressure/P_{VA})

The vapor mole fractions, y_i, are equal to the partial pressure of the component divided by the total vapor pressure of the mixture. These are shown in Table C-4 alongside the calculation for the molecular weight of the vapor. The molecular weight of the vapor, $M_{V'}$ is 65 lb/lb-mole (65 g/g-mol).

Table C-4
Vapor Mole Fractions

Organic	Molecular weight (lb/lb-mole)	Partial Pressure (psia)	Vapor Mole Fraction	Vapor molecular weight
Acetone	58.08	1.06E+00	9.42E-01	5.47E+01
Anthracene	178.234	1.62E-11	1.44E-11	2.56E-09
Benzene	78.114	7.02E-04	6.24E-04	4.87E-02
Benzo(a)pyrene	252.316	7.26E-19	6.45E-19	1.63E-16
Bis(2-ethylhexyl)phthalate	390.564	9.97E-18	8.86E-18	3.46E-15
Carbon tetrachloride	153.811	8.40E-04	7.46E-04	1.15E-01
Chlorobenzene	112.556	3.03E-05	2.69E-05	3.03E-03
Chloroform	119.369	4.14E-03	3.68E-03	4.39E-01
Chrysene	228.294	7.92E-18	7.03E-18	1.61E-15
1,4-Dichlorobenzene	146.998	2.19E-06	1.94E-06	2.86E-04
Dioxin	321.962	5.38E-25	4.78E-25	1.54E-22
EDTA (ethylenediaminetetraacetic)	292.244	2.20E-15	1.95E-15	5.70E-13
Ethylene dibromide (1,2-Dibromoethane)	187.862	2.19E-04	1.94E-04	3.65E-02
Fluoranthene	187.862	4.38E-13	3.89E-13	7.31E-11
Fluorene	166.223	1.24E-10	1.10E-10	1.83E-08
Furan	68.075	9.31E-13	8.27E-13	5.63E-11
Methylene chloride	84.927	5.52E-02	4.90E-02	4.16E+00
PCBs	291.98	5.36E-16	4.76E-16	1.39E-13
Phenol	94.113	7.44E-07	6.60E-07	6.22E-05
Phenolic compounds	94.113	9.15E-07	8.12E-07	7.64E-05
Tannic acid	1701.206	3.61E-03	3.21E-03	5.46E+00
1,1,2,2-Tetrachloroethane	167.838	1.32E-05	1.17E-05	1.97E-03
Tetrachloroehylene	165.822	5.81E-05	5.16E-05	8.56E-03
1,1,2-Trichloroethane	133.396	1.35E-04	1.20E-04	1.60E-02
Totals	-	**1.13E+00**	-	**6.50E+01**

Since all variable have now been solved, the stock density, W_v, can be calculated:

$$W_v = \frac{M_v * P_{VA}}{R * T_{LA}} = \frac{65 * 1.13}{10.731 * 532.5} = 0.01285 \frac{lb}{ft^3} \ (0.206 \frac{kg}{m^3})$$

Vapor Space Expansion Factor, K_E, Calculation

The vapor space expansion factor, K_E, is calculated using the following equation C11:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V - \Delta P_B}{P_A - P_{VA}} \qquad \text{(C11)}$$

Where:

ΔT_V Daily vapor temperature range, (°R)

ΔP_V Daily vapor pressure range, (psia)

ΔP_B Breather vent pressure setting range, (psia)

P_A Atmospheric pressure, 14.7 psia

P_{VA} Vapor pressure at daily average liquid surface temperature (1.13 psia from previously)

T_{LA} Daily average liquid surface temperature, (532.5 °R from previously)

Firstly, calculate the daily vapor range using the following equation C12:

$$\Delta T_V = 0.72 * \Delta T_A + 0.028 * \alpha * I \qquad \text{(C12)}$$

Where:

ΔT_V Daily vapor temperature range, (°R)

ΔT_A Daily ambient temperature range, $T_{AX} - T_{AN}$

α Tank paint solar absorptance, set to 0 as the tank is located inside the WWTP

I Daily total solar insolation, (Btu/ft^2-d), set to 0 as the tank is located inside the WWTP

T_{AX} Daily maximum ambient temperature, (°R), 542.1 as previously

T_{AN} Daily minimum ambient temperature, (°R), 524.1 as previously

Using the same daily maximum and minimum temperatures as before from the ambient conditions for the WWTP in the Design Requirements [C-6], no paint solar absorptance or daily solar insolation as the tank is located inside the WWTP, then the daily vapor temperature range can be calculated:

$$\Delta T_A = T_{AX} - T_{AN} = 542.1 - 524.1 = 18 \ ^O R$$

$$\Delta T_V = 0.72 * \Delta T_A + 0.028 * \alpha * I = 0.72 * 18 + 0.028 * 0 * 0 = 12.96\ ^oR$$

Secondly, calculate the daily vapor pressure range using the following equation C13:

$$\Delta P_V = P_{VX} - P_{VN} \qquad \text{(C13)}$$

Where:

P_{VX} Vapor pressure at daily maximum temperature

P_{VN} Vapor pressure at daily minimum temperature

T_{LX} Maximum liquid temperature, °R

$$T_{LX} = T_{LA} + 0.25\Delta T_V = 532.5 + 0.25 * 12.96 = 535.8\ ^oR\ (24.5\ ^oC)$$

T_{LN} Minimum liquid temperature, °R

$$T_{LN} = T_{LA} - 0.25\Delta T_V = 532.5 - 0.25 * 12.96 = 529.3\ ^oR\ (20.9\ ^oC)$$

Using Antoine's equations with these new values the true vapor pressure is calculated, and then the partial pressure, to provide the total mixture pressure as shown in Table C-5.

Therefore the vapor pressure range for the mixture:

$$\Delta P_V = P_{LX} - P_{LN} = 1.22 - 1.04 = 0.18\ psia\ (1.24\ kPa)$$

Specific information on the breather vent pressure setting and the vacuum setting are not available, so default values from [C-1] are used. Given the very low emissions even a significant change to this value would be insignificant.

The breather vent pressure equation C14 is:

$$\Delta P_B = P_{BP} - P_{BV} \qquad \text{(C14)}$$

Where:

ΔP_B Breather vent pressure, (psig)

P_{BP} Breather vent pressure setting, 0.03 psia (default)

P_{BV} Breather vent vacuum setting, -0.03 psig (default)

Therefore:

$$\Delta P_B = P_{BP} - P_{BV} = 0.03 - -0.03 = 0.06\ psig\ (0.41\ kPa)$$

Table C-5
Vapor Pressure at Daily Maximum Temperature and Daily Minimum Temperature

Organic	Daily Maximum Temperature Vapor Pressure (psia)	Daily Maximum Temperature Partial Pressure (psia)	Daily Minimum Temperature Partial Pressure (psia)	Daily Minimum Temperature Partial Pressure (psia)
Acetone	4.37E+00	1.15E+00	3.73E+00	9.80E-01
Anthracene	3.56E-05	1.90E-11	2.57E-05	1.37E-11
Benzene	1.79E+00	7.64E-04	1.52E+00	6.45E-04
Benzo(a)pyrene	1.00E-10	9.71E-19	5.59E-11	5.41E-19
Bis(2-ethylhexyl)phthalate	6.30E-11	1.57E-17	2.52E-11	6.27E-18
Carbon tetrachloride	2.18E+00	9.10E-04	1.85E+00	7.74E-04
Chlorobenzene	2.25E-01	3.36E-05	1.83E-01	2.73E-05
Chloroform	3.67E+00	4.48E-03	3.12E+00	3.82E-03
Chrysene	3.18E-10	1.14E-17	1.52E-10	5.45E-18
1,4-Dichlorobenzene	4.64E-02	2.44E-06	3.73E-02	1.96E-06
Dioxin	2.90E-11	5.38E-25	2.90E-11	5.38E-25
EDTA (ethylenediaminetetraacetic)	2.90E-14	2.20E-15	2.90E-14	2.20E-15
Ethylene dibromide (1,2-Dibromoethane)	2.53E-01	2.41E-04	2.08E-01	1.98E-04
Fluoranthene	3.72E-06	5.24E-13	2.60E-06	3.66E-13
Fluorene	1.41E-04	1.46E-10	1.01E-04	1.05E-10
Furan	1.14E+01	9.98E-13	9.89E+00	8.68E-13
Methylene chloride	8.13E+00	5.93E-02	7.04E+00	5.13E-02
PCBs	3.56E-07	6.75E-16	2.23E-07	4.24E-16
Phenol	6.52E-03	8.72E-07	4.72E-03	6.32E-07
Phenolic compounds	6.52E-03	1.07E-06	4.72E-03	7.77E-07
Tannic acid	6.52E-03	4.24E-03	4.72E-03	3.07E-03
1,1,2,2-Tetrachloroethane	8.10E-02	1.50E-05	6.32E-02	1.17E-05
Tetrachloroehylene	3.43E-01	6.41E-05	2.81E-01	5.26E-05
1,1,2-Trichloroethane	4.10E-01	1.49E-04	3.35E-01	1.22E-04
Totals	-	**1.22E+00**	-	**1.04E+00**

Finally, the vapor space expansion factor can be calculated:

$$K_E = \frac{\Delta T_V}{T_{LA}} + \frac{\Delta P_V - \Delta P_B}{P_A - P_{VA}} = \frac{12.96}{532.5} + \frac{0.18 - 0.06}{14.7 - 1.13} = 0.033\ (dimensionless)$$

C.2.1.3 Vented Vapor Space Saturation Factor, K_S, Calculation

The vented vapor space saturation factor, K_S, is calculated using the following equation C15:

$$K_s = \frac{1}{1+0.053*P_{VA}*H_{VO}} \qquad \text{(C15)}$$

Where P_{VA} has been previously calculated as 1.13 psia, and H_{VO} has been previously calculated as 1.57 ft (0.48 m). Therefore:

$$K_s = \frac{1}{1+0.053*1.13*1.57} = 0.9141\ (dimensionless)$$

C.2.1.4 Organic Standing Storage Losses

Standing storage losses are calculated through the following equation C16:

$$L_S = 365*W_V*V_v*K_E*K_s \qquad \text{(C16)}$$

Using the values calculated above:

W_V	$0.0128\frac{lb}{ft^3}$
V_v	$79.27\ ft^3$
K_E	0.033
K_s	0.9141

$$L_S = 365*0.0128*79.27*0.033*0.9141 = 11.2\frac{lb}{yr}\left(equates\ to\ 5.1\frac{kg}{yr}\right)$$

C.2.2 Organic Working Losses

The amount of VOCs emitted as a result of filling operations can be calculated from the following equation C17:

$$L_w = 0.0010*M_V*P_{VA}*Q*K_N*K_P \qquad \text{(C17)}$$

Where:

M_V 65 $\frac{lb}{lb-mole}$ as previously calculated

P_{VA} 1.13 psia as previously calculated

Q Annual net throughput 92.8 bbl (584 m^3/y or 1.6 m^3/day)

K_N Turnover factor, (dimensionless) K_N=1 for tank turnovers, N ≤36

N=number of turnovers per year (dimensionless)

N=5.61*Q/Vl_x

Where VL_x is the tank maximum liquid volume, 334 ft^3 for the filter press feed tank.
$N=5.61*Q/Vl_x=5.61*92.8/334=1.55$

K_P Product factor, (dimensionless) K_P = 1 for volatile organic liquids

$$L_w = 0.0010 * 65 * 1.13 * 92.8 * 1 * 1 = 6.8\frac{lb}{yr}(equates\ to\ 3.1\frac{kg}{yr})$$

C.2.3 Organic Total Losses

The total losses from a fixed roof tank is calculated through the following equation C18:

$$L_T = L_S + L_W \qquad \text{(C18)}$$

Where:

L_T Total losses, (lb/y)

L_S Standing storage losses (lb/y) as calculated above

L_W Working losses (lb/y) as calculated above

$$L_{T\ ORGANICS} = L_S + L_W = 11.2 + 6.8 = 18\frac{lb}{yr}(equates\ to\ 8.2\frac{kg}{yr})$$

So the total loss is 18 lb (8.2 kg) organics/y.

C.3 Water Phase Losses

C.3.1 Standing Losses

For the water component, the standing losses will be due to evaporation. An evaporation rate for undisturbed water pools of 0.002 lb/h.ft^2 is assumed from reference [C-2]. The standing storage loss over the course of a year can be calculated through the following equation C19:

$$L_S = 0.002\frac{lb}{hour.ft^2} * \left(365\frac{days}{year} * 24\frac{hours}{day}\right) * (\pi * R^2) \qquad \text{(C19)}$$

Where:

R Tank radius, (ft) which is 4.0 ft

Therefore:

$$L_S = 0.002\frac{lb}{hour.ft^2} * \left(365\frac{days}{year} * 24\frac{hours}{day}\right) * (\pi * 4^2) = 882\frac{lb}{yr}(equates\ to\ 400\frac{kg}{yr})$$

C.3.2 Water Working Losses

Assuming the same ratio of standing storage loss and working loss as for organics, where for organics:

$$\frac{L_w}{L_s} = \frac{18}{11.2} = 0.6$$

Then, for the water phase:

$$L_w = L_s * 1.43 = 882 * 0.6 = 536\frac{lb}{yr}\ (equates\ to\ 243\frac{kg}{yr})$$

C.3.3 Water Total Losses

As previously, the total losses from a fixed roof tank is calculated through the following equation C18:

$$L_T = L_S + L_W \qquad \text{(C18)}$$

Where:

L_T Total losses, (lb/y)

L_S Standing storage losses (lb/y) as calculated above

L_W Working losses (lb/y) as calculated above

$$L_{T\ WATER} = L_S + L_W = 882 + 536 = 1418\frac{lb}{yr}\ (which\ equates\ to\ 643\frac{kg}{yr})$$

C.3.4 Total Activity Losses

The total activity losses are: 8.2 kg/y organic phase and 643 kg/y water phase.

The total activity loss from organics per year is calculated using the equation below C20:

$$Q_{ORGANICS}\left(\frac{Bq}{yr}\right) = C\left(\frac{Bq}{l}\right) * 5.06E-5\ \left(\frac{l}{mg}\right) * 1E6\left(\frac{mg}{kg}\right) * L_{T\ organics}\left(\frac{kg}{yr}\right) \qquad \text{(C20)}$$

Where:

$Q_{ORGANICS}$ Radioactive material losses term from organic phase (Bq/y)

C Concentration of radionuclides within the waste stream (Bq/l)

$L_{T\ organics}$ Total organic losses (kg/y) as calculated above, 8.2 kg/y.

The total activity loss from the water phase material per year is calculated using the equation C21 below:

$$Q_{WATER}\left(\frac{Bq}{yr}\right) = C\left(\frac{Bq}{l}\right) * 1(\frac{l}{kg}) * L_{T\ WATER}\left(\frac{kg}{yr}\right) \qquad (C21)$$

Where:

Q_{WATER} Radioactive material losses from water phase (Bq/y)

C Concentration of radionuclides within the waste stream (Bq/l), ignoring the small quantity of organics.

$L_{T\ WATER}$ Total water losses (kg/y) as calculated above, 643 kg/y.

C.4 Conclusion

The total radioactive material losses for organics and water phases are shown in Table C-6. The organics phase is the main contributor to the radioactive releases, with the organic phase release being around two orders of magnitude higher than the water phase.

The comparison of the total radioactive material losses to the DRL for roof vents on the CRL site [C-9] are shown in Table C-7. Derived Release Limits represent release rates that correspond to critical groups at the public dose limits. If the gross alpha, gross beta and gross gamma values are compared to the most restrictive radionuclide DRL for that main emission type, (i.e. the lowest DRL, which for alpha is Ra-226, for beta is Cl-36 and for gamma is Co-60), total radioactive material loss is 0.004% of the DRL. From the individual radionuclide comparison with the DRLs, it is apparent that this is entirely from the Co-60 release.

In conclusion there are no appreciable airborne releases from the filter press feed tank vent.

Non-radioactive airborne effluent levels is accomplished through estimation and are typically calculated annually. Currently, the only non-radioactive airborne effluent levels are Regulatory Levels outlined in CRL's LCH, of which none have yet been set for NSDF [C-10]. The calculated value above of 8.2 kg of organic release per filter press feed tank is significantly below the VOC emission reporting threshold of the National Pollution Release Inventory, which is 10 tonnes [C-11].

Table C-6
Total Radioactive Material Losses per Year

Radionuclides	Concentration in Membrane Filter Residuals Non-organic Waste Stream (Bq/L)	Concentration in Membrane Filter Residuals Organic Waste Stream (Bq/mg)	Organic Phase Radioactive Material Losses (Bq/y)	Water Phase Radioactive Material Losses (Bq/y)	Total Radioactive Material Losses (Bq/y)
Gross alpha	3.15E-01	1.59E-05	1.31E+02	2.03E+02	3.33E+02
Gross beta	1.92E+02	9.72E-03	7.97E+04	1.23E+05	2.03E+05
Gross gamma	1.88E+04	9.51E-01	7.80E+06	1.21E+07	1.99E+07
Ag-108m	1.03E-03	5.21E-08	4.27E-01	6.62E-01	1.09E+00
Am-241	1.61E-02	8.15E-07	6.68E+00	1.04E+01	1.70E+01
Am-243	9.75E-06	4.93E-10	4.05E-03	6.27E-03	1.03E-02
C-14	3.03E+00	1.53E-04	1.26E+03	1.95E+03	3.21E+03
Cl-36	5.77E-02	2.92E-06	2.39E+01	3.71E+01	6.10E+01
Co-60	1.88E+04	9.51E-01	7.80E+06	1.21E+07	1.99E+07
Cs-135	4.01E-05	2.03E-09	1.66E-02	2.58E-02	4.24E-02
Cs-137	9.10E-01	4.61E-05	3.78E+02	5.85E+02	9.63E+02
H-3	1.37E+05	6.93E+00	5.69E+07	8.81E+07	1.45E+08
I-129	8.90E-02	4.50E-06	3.69E+01	5.72E+01	9.42E+01
Mo-93	4.01E-07	2.03E-11	1.66E-04	2.58E-04	4.24E-04
Nb-94	8.60E-02	4.35E-06	3.57E+01	5.53E+01	9.10E+01
Ni-59	3.04E-03	1.54E-07	1.26E+00	1.95E+00	3.22E+00
Ni-63	7.86E-01	3.98E-05	3.26E+02	5.05E+02	8.32E+02
Np-237	3.61E-06	1.83E-10	1.50E-03	2.32E-03	3.82E-03
Pu-239	2.52E-02	1.28E-06	1.05E+01	1.62E+01	2.67E+01
Pu-241	4.53E-01	2.29E-05	1.88E+02	2.91E+02	4.79E+02
Pu-242	1.89E-05	9.56E-10	7.84E-03	1.22E-02	2.00E-02
Ra-226	3.67E-03	1.86E-07	1.52E+00	2.36E+00	3.88E+00
Se-79	1.38E-04	6.98E-09	5.73E-02	8.87E-02	1.46E-01
Sn-126	4.13E-05	2.09E-09	1.71E-02	2.66E-02	4.37E-02
Sr-90	1.82E+02	9.21E-03	7.55E+04	1.17E+05	1.93E+05
Tc-99	5.57E+00	2.82E-04	2.31E+03	3.58E+03	5.89E+03
Th-230	1.26E-03	6.38E-08	5.23E-01	8.10E-01	1.33E+00
Th-232	5.50E-03	2.78E-07	2.28E+00	3.54E+00	5.82E+00
U-233	4.84E-04	2.45E-08	2.01E-01	3.11E-01	5.12E-01
U-234	1.30E-01	6.58E-06	5.39E+01	8.36E+01	1.38E+02
U-235	5.51E-03	2.79E-07	2.29E+00	3.54E+00	5.83E+00
U-238	1.27E-01	6.43E-06	5.27E+01	8.17E+01	1.34E+02
Zr-93	2.52E-01	1.28E-05	1.05E+02	1.62E+02	2.67E+02

Table C-7
Radioactive Releases as Percentage of Roof Vent DRL

Radionuclides	Radioactive Material Losses (Bq/wk)	Roof Vent DRL (Bq/wk)	Percentage of DRL
Gross alpha	6.41E+00	7.88E+08	0.0000%
Gross beta	3.91E+03	3.12E+09	0.0001%
Gross gamma	3.82E+05	1.03E+10	0.0037%
Ag-108m	2.10E-02	No calculated DRL	NV
Am-241	3.28E-01	1.48E+09	0.0000%
Am-243	1.98E-04	No calculated DRL	NV
C-14	6.16E+01	1.35E+13	0.0000%
Cl-36	1.17E+00	3.12E+09	0.0000%
Co-60	3.82E+05	1.03E+10	0.0037%
Cs-135	8.16E-04	No calculated DRL	NV
Cs-137	1.85E+01	1.00E+10	0.0000%
H-3	2.79E+06	3.98E+14	0.0000%
I-129	1.81E+00	4.32E+09	0.0000%
Mo-93	8.16E-06	No calculated DRL	NV
Nb-94	1.75E+00	No calculated DRL	NV
Ni-59	6.19E-02	No calculated DRL	NV
Ni-63	1.60E+01	No calculated DRL	NV
Np-237	7.34E-05	1.40E+09	0.0000%
Pu-239	5.13E-01	1.23E+09	0.0000%
Pu-241	9.22E+00	6.83E+10	0.0000%
Pu-242	3.85E-04	No calculated DRL	NV
Ra-226	7.47E-02	7.88E+08	0.0000%
Se-79	2.81E-03	No calculated DRL	NV
Sn-126	8.40E-04	No calculated DRL	NV
Sr-90	3.70E+03	1.01E+10	0.0000%
Tc-99	1.13E+02	1.40E+11	0.0000%
Th-230	2.56E-02	No calculated DRL	NV
Th-232	1.12E-01	8.97E+08	0.0000%
U-233	9.85E-03	1.06E+10	0.0000%
U-234	2.64E+00	1.09E+10	0.0000%
U-235	1.12E-01	7.99E+09	0.0000%
U-238	2.58E+00	9.25E+09	0.0000%
Zr-93	5.13E+00	No calculated DRL	NV

C.2 References

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[C-3] *Near Surface Disposal Facility Wastewater Treatment Plant Process – Filter Press Feed Tank Detail Layout TK-109*, B155-106400-515-01-GA-D, Revision 0, 2017 March.

[C-4] Memo from Barber, Brendan to Kingsbury, R and Birchall, R, *Near Surface Disposal Facility Wastewater Treatment Plant Process Tank Details*, 232-106470-230-00 (Atom ID: 48061952), 2019 April 15.

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[C-6] *Design Requirements*, 232-503212-DR-001, Revision 2, 2019 April.

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[C-8] NIST webbook https://webbook.nist.gov/cgi/cbook.cgi?ID=C123911&Mask=4&Type=ANTOINE&Plot=on

[C-9] *Derived Release Limits (DRL's) for CNL's Chalk River Laboratories*, CRL-509200-RRD-001, Revision 2, 2018 August.

[C-10] *Effluent Levels for CRL Air and Liquid Non-Radioactive Effluents*, 900-509200-STD-014, Revision 0, 2019 February.

[C-11] Letter from Murthy, K., to Dolinar, G., *CNSC Staff Review of CNL's Request for a Change of the Level for Volatile Organic Compound Emission in the Chalk River Licence Condition Handbook,* ENVP-NOCN-18-0002-L, ATOM ID: 42035678, 2018 December 21.

Appendix D

Dropped Load – Packaged Waste

D.1 Introduction

A drum and waste unloading platform is located within the ECM footprint in the TSWRPA. The drum unloading platform will be designed to facilitate the safe unloading and transfer of overpacked drummed waste and other packaged waste on-site. The platform is constructed at grade and consists of aggregate material provided to minimize dust generation. The platform incorporates the use of dedicated drum placement vehicles to transfer drummed wastes inside the NSDF cell waste placement area.

The TSWRPA, including the drum and waste handling area, is large enough to store waste materials including drums and boxes, for cold and inclement weather periods when placement within the active cell cannot take place. The TSWRPA is of a sufficient size to promote efficient unloading between the dedicated site vehicles and waste haulers, to minimize handling, to limit the potential of dust generation, and to contain spills. The TSWRPA is located within the ECM footprint, in an area where the floor composite base liner system has been installed, and will be moved as necessary for sequencing of the cells. The TSWRPA is shown in Figure D-1.

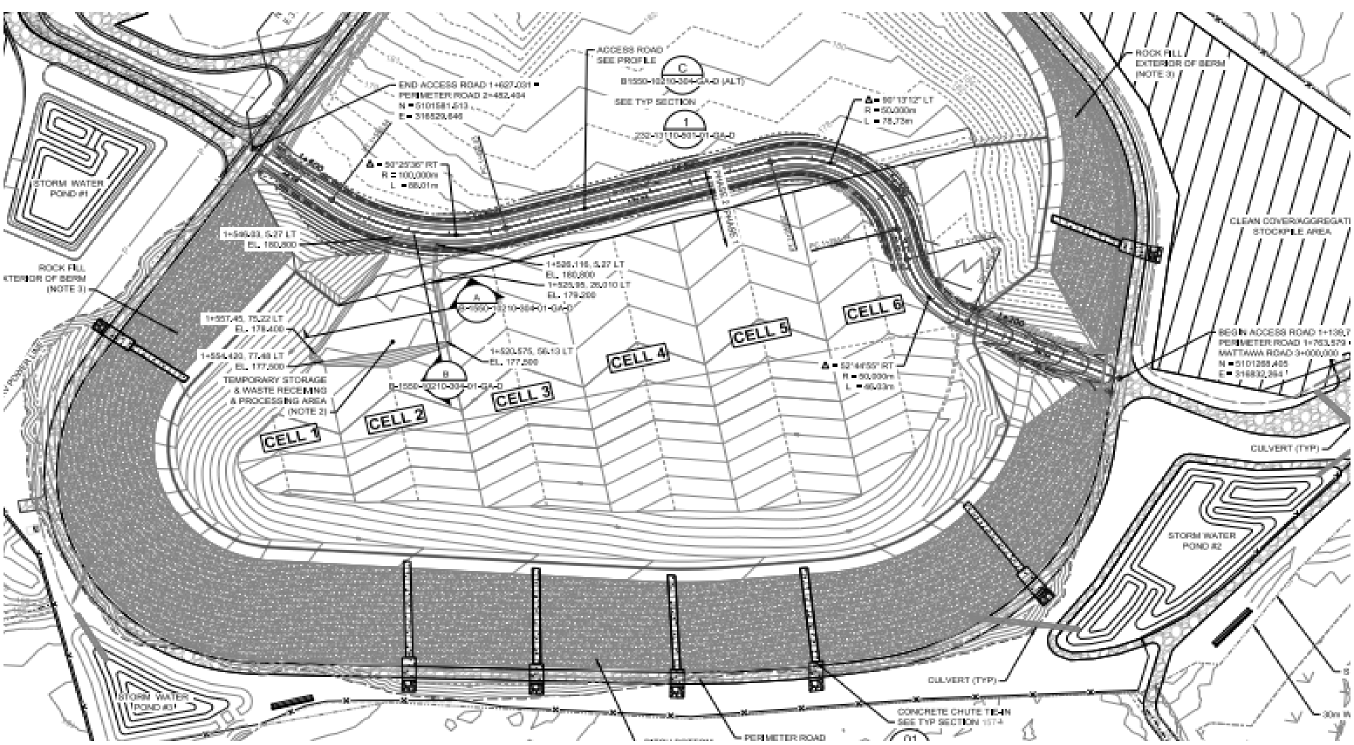


Figure D-1 Location of the Temporary Storage and Waste Receiving and Processing Area

D.2 Analysis Methodology

D.2.1 Event Scenario

This event assumes that a waste package is dropped on another waste package resulting in the solid waste content being spilled from both packages. The drop is due to either human error or mechanical failure of waste transferring equipment (e.g. crane). The drop results in a puff of radioactive material being released from both packages and inhaled by the worker.

The waste containers are assumed to be Type 5 packaged waste, and meets the external dose rate criteria for handling the waste by only mechanical means. The dose rates for handling the waste by mechanical means only are >0.5 mSv/h to ≤2 mSv/h near contact with any external surfaces of the package, and >0.001 mSv/h to ≤0.1 mSv/h at a distance of 1 m from the package [D-1].

As a result of the drop, there is a loss of containment and shielding of both waste packages, exposing the worker to contamination and radiation from the spilled waste.

D.2.1.1 Radionuclide Distribution (Source Term)

The respirable source term (*Q)* is determined by equation D1 [D-2]:

$$Q = MAR \times DR \times LPF \times ARF \times RF \qquad \text{(D1)}$$

Where:

MAR - Material at risk, the total activity in both waste containers (Bq), see Table D-1.

DR - Damage ratio, the fraction of MAR actually impacted by the accident, assumed to be 1.

LPF -Leak path factor, the fraction of the radionuclides passing through filtration systems, assumed to be 1.

ARF - Airborne release fraction, the fraction of radioactive material suspended in air as an aerosol, assumed to be 1E-03 based on bounding ARF for suspension of surface contamination from shock due to impact (Section 5.2.3.2 of Reference [D-3]).

RF - Respirable fraction, the fraction of airborne radionuclides inhaled, assumed to be 1, which applies for unpackaged material (i.e. the package is not credited for containment) [D-3]).

The activity concentration is based on the average radionuclide concentration in packaged waste that complies with the dose rate limits for waste packages handled by only mechanical means [D-1]. Due to a small volume of waste packages with significantly greater Co-60 concentrations, the average waste package inventory results in dose rates that exceed the dose rate limits defined in the WAC [D-1].

The total activity of all packaged waste is documented in [D-4]. To estimate the inventory of packaged waste, the Co-60 concentrations in the average radionuclide inventory of the Type 5 packaged waste, is scaled down, such that the resulting calculated dose rates correspond to 0.1 mSv/h at 1 m from the package surface. The scaling factor required to derive the waste package inventory meeting the dose rate limits is calculated using MicroShield (see Section D.4.1).

The calculated dose rates for a B-25 bin containing the averaged packaged waste activity with 0.266 cm of steel shielding, corresponding to thickness of the B-25 bin [D-5], are 571.2 mSv/h near contact and 108.6 mSv/h at 1 m. Therefore, the Co-60 concentration in the package inventory is scaled down by a factor of 1 086 to represent waste packages that meet the dose rate limits, handled by mechanical means only with the limiting the dose rate of 0.1 mSv/h at a distance of 1 m from the package.

The activity inside the average waste package is calculated as show in Table D-1. The averaged activity concentration of all packaged waste was calculated by dividing the total activity by the total volume of packaged waste (136 000 m^3) [D-4]. The activity in a single B-25 bin was calculated by multiplying the activity concentration by 2.55 m^3, which is the inner volume of the B-25 bin [D-5].

Table D-1
Radionuclide Activity in the Dropped Packages

Radionuclide	Total activity in packaged waste (Bq)	Activity concentration in packaged waste (Bq/m^3)	Activity in a single B25 box (Bq)	Activity in two B25 boxes (Bq)
Ag-108m	2.73E+10	2.01E+05	5.11E+05	1.02E+06
Am-241	4.80E+10	3.53E+05	8.99E+05	1.80E+06
Am-243	4.62E+07	3.40E+02	8.66E+02	1.73E+03
C-14	1.50E+12	1.10E+07	2.81E+07	5.62E+07
Cl-36	3.40E+09	2.50E+04	6.37E+04	1.27E+05
Co-60	9.06E+16	6.66E+11	1.56E+09	3.13E+09
Cs-135	5.10E+08	3.75E+03	9.55E+03	1.91E+04
Cs-137	4.91E+12	3.61E+07	9.20E+07	1.84E+08
H-3	7.94E+14	5.84E+09	1.49E+10	2.98E+10
I-129	3.01E+10	2.21E+05	5.64E+05	1.13E+06
Mo-93	1.31E+05	9.63E-01	2.45E+00	4.91E+00
Nb-94	2.09E+11*	1.54E+06	3.92E+06	7.83E+06
Ni-59	1.07E+09	7.87E+03	2.00E+04	4.01E+04
Ni-63	2.75E+11	2.02E+06	5.15E+06	1.03E+07
Np-237	1.53E+07	1.13E+02	2.87E+02	5.73E+02
Pu-239	7.74E+10	5.69E+05	1.45E+06	2.90E+06
Pu-241	1.46E+12	1.07E+07	2.74E+07	5.47E+07
Pu-242	5.55E+07	4.08E+02	1.04E+03	2.08E+03
Ra-226	3.63E+10	2.67E+05	6.80E+05	1.36E+06
Se-79	8.13E+07	5.98E+02	1.52E+03	3.05E+03
Sn-126	1.09E+08	8.01E+02	2.04E+03	4.08E+03
Sr-90	5.31E+12	3.90E+07	9.95E+07	1.99E+08
Tc-99	3.16E+11	2.32E+06	5.92E+06	1.18E+07
Th-230	4.50E+09	3.31E+04	8.43E+04	1.69E+05

Radionuclide	Total activity in packaged waste (Bq)	Activity concentration in packaged waste (Bq/m^3)	Activity in a single B25 box (Bq)	Activity in two B25 boxes (Bq)
Th-232	2.39E+10	1.76E+05	4.48E+05	8.96E+05
U-233	2.41E+08	1.77E+03	4.52E+03	9.03E+03
U-234	5.94E+10	4.37E+05	1.11E+06	2.23E+06
U-235	2.57E+09	1.89E+04	4.81E+04	9.63E+04
U-238	6.72E+10	4.94E+05	1.26E+06	2.52E+06
Zr-93	1.06E+12*	7.79E+06	1.99E+07	3.97E+07

*The values listed here, which served as the basis for design and licencing, are both conservatively higher than those in the NSDF Reference Inventory Report [D-6]. The NSDF Reference Inventory Report, Table 8, lists inventories of Nb-94 and Zr-93 as 2.09E+10 Bq and 4.35E+11 Bq, respectively [D-6].

D.2.2 Dose Receptor and Location

The on-site worker is assumed to be 1 m from the dropped waste packages. The worker is assumed to remain at that location for 10 minutes, and has a breathing rate of 1.2 m^3/h [D-7].

D.3 Assumptions and Inputs

The following assumptions were made to conservatively calculate the radiological consequences to a worker from the waste package dropped load event:

- The waste is assumed to be inside shielded B25 bins, 1.83 m long x 1.17 m wide x 1.19 m high, containing 2.55 m^3 of waste.
- The drop results in a loss of containment and shielding, and a puff release of radioactive material from both B25 boxes.
- The worker is not wearing any respiratory protection.
- The worker is assumed to be located 1 m away from the dropped packages, and remains at that location for 10 minutes. The dose rate was calculated at 1 m since that is the approximate width of the B25 lid, which is assumed to have fallen off, resulting in a loss of shielding between the B25 and the worker. Furthermore, shielding and containment provided by the package walls are not credited.
- The worker inhalation DCFs are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm AMAD (ICRP 119, Table A) [D-8].
- Tritium and C-14 are considered to be HTO and CO_2, respectively (inhalation DCFs from ICRP 119 Table B for workers) [D-8].
- A factor of 1.5 is applied to tritium inhalation DCF to account for skin absorption [D-9].

D.4 Calculations

As shown in Table D-2, radiological consequence to the on-site worker is assumed to be from external radiation and inhalation.

Table D-2
Exposure Pathways for the On-site Receptor

Exposure pathway	Included in dose calculation (yes/no)	Rationale
External	Yes	The worker will be exposed to radiation from a loss of shielding of the two B25 boxes.
Immersion	No	The immersion dose is assumed to be negligible compared to the inhalation dose for a puff dispersion.
Inhalation	Yes	A small portion of the radioactive particulate in the waste in both B25 boxes will re-suspend into the air and be inhaled by the worker. Skin absorption of tritium is accounted for by applying a factor of 1.5 to the tritium inhalation DCF [D-9].
Ingestion	No	The worker is assumed to not ingest radioactive particulate.

<u>Dose from external radiation</u>

The external dose to the worker (D_{ext}) is determined by equation D2:

$$D_{ext} = DR_{ext} \times t \qquad \text{(D2)}$$

Where:

DR_{ext} - effective dose rate from unshielded top of the container (mSv/h)
t - duration of exposure (h), assumed to be 10 min = 0.17 hr

The dose rate at 1 m from a dropped container was calculated using MicroShield. The inputs and results of MicroShield are shown in Section D.4.1. A rectangular volume was used to model the B25 bin in MicroShield. The dimensions are shown in Table D-3.

Table D-3
MicroShield B25 Bin Model Dimensions and Materials

Dimension	**Assumed value**
Length	1.83 m
Width	1.17 m
Height	1.19 m
Total volume	2.55 m^3
Density (waste material)	0.54 g/cm^3 (soil)

The dose rate at 1 m from the edge of one dropped waste package is 9.91E-02 mSv/h. With a loss of shielding of two waste packages and a 10 minute exposure time, the radiological consequence (dose) is 0.033 mSv.

<u>Dose from inhalation</u>

The committed effective dose (D_{inh}) from inhalation of radioactive material released from both containers is determined by equation D3 [D-10].

$$D_{inh} = Q \times DF_{ti} \times B \times DCF_{inh} \times \frac{1\,h}{3600\,s} \times \frac{1000\,mSv}{1\,Sv} \qquad \text{(D3)}$$

Where:

Q	- respirable source term from both containers (Bq)
DF_{ti}	- time-integrated dilution factor (s/m^3)
B	- worker breathing rate, assumed to be 1.2 m^3/h [D-7]
DCF_{inh}	- inhalation dose conversion factor (Sv/Bq) [D-8]

The dilution factors have been calculated based on the Doury puff model [D-11] and [D-12] using equation D4, since a Gaussian plume model is not applicable for this situation [D-13].

$$DF(x,y,z) = \frac{1}{(2\pi)^{3/2}\Sigma_x\Sigma_y\Sigma_z} \times e^{-\frac{(x-ut)^2}{2\Sigma_x^2}} \times e^{-\frac{y^2}{2\Sigma_y^2}} \times \left[e^{-\frac{(z-h)^2}{2\Sigma_z^2}} + e^{-\frac{(z+h)^2}{2\Sigma_z^2}}\right] \qquad \text{(D4)}$$

$$\Sigma_x = \Sigma_y = \left(A_y t\right)^{B_y}$$

$$\Sigma_z = (A_z t)^{B_z}$$

Where:

DF	- dilution factor (m^{-3})
x, y, z	- spatial coordinates of the receptor, with the source at the origin (m), assume $y = 0$ and $z = 1.5\,m$
u	- average wind speed (m/s), assumed to be zero
t	- time since the puff release (s)
h	- height of the release (m), assumed to be 0.5 m
A_y, A_z, B_y, B_z	- empirically derived dispersion parameters (see Table D-4)

Table D-4
Dispersion Parameters

Duration (min)	Normal dispersion (stability A-B-C-D)				Weak dispersion (stability E-F)			
	A_y	A_z	B_y	B_z	A_y	A_z	B_y	B_z
$t_r < 4$	0.405	0.42	0.859	0.814	0.405	0.2	0.859	0.50
$4 < t_r \leq 55$	0.135	1.00	1.13	0.685	0.135	0.2	1.13	0.50
$55 < t_r \leq 1\,617$	0.135	20.0	1.13	0.50	0.135	0.2	1.13	0.50

The dispersion parameters are time-dependent and the time-integrated concentration is obtained by numerical integration. Calculations have been performed for a short duration "puff release" in conditions of zero wind speed and weak vertical dispersion. The source is assumed to be at a height of 0.6 m (half the height of the B25 bin) and the receptor at a height of 1.5 m, although there is little sensitivity to source and receptor height close to the ground. The time-integrated dilution factors provide a reasonable conservative estimate of intakes under most conditions for an individual close to the source exposed to a puff release.

The time-integrated dilution factor at various distances from the release point is shown in Figure D-2. For a worker exposed at 1 m from the release point, the time-integrated dilution factor is DF_{ti} = 7.09×10^{-2} s/m^3. The committed effective dose to the worker is 7.3E-03 mSv. The details of the calculation are shown in Table D-5.

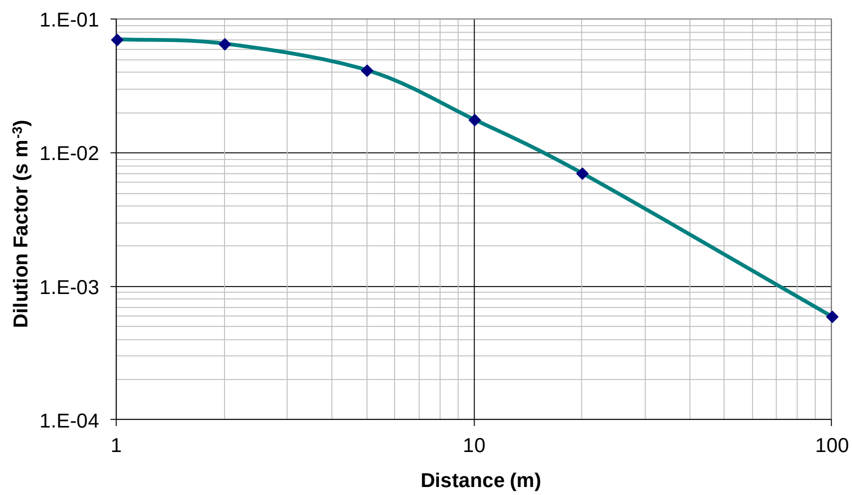


Figure D-2 Time-Integrated Dilution Factor at Various Distances (m) from the Source for a Puff Release at Ground Level (calm wind conditions, weak vertical dispersion)

Table D-5
Dropped Load Worker Estimated Inhalation Radiological Consequence

Radionuclide	Total activity in packaged waste (Bq)	Activity conc. in packaged waste (Bq/m^3)	Activity in a single B25 bin (Bq)	Activity in two B25 bins (Bq)	Inhalation DCF for workers (Sv/Bq)	Inhalation dose at 1 m from two damaged B25 bins (mSv)
Ag-108m	2.73E+10	2.01E+05	5.11E+05	1.02E+06	1.90E-08	4.59E-07
Am-241	4.80E+10	3.53E+05	8.99E+05	1.80E+06	2.70E-05	1.15E-03
Am-243	4.62E+07	3.40E+02	8.66E+02	1.73E+03	2.70E-05	1.10E-06
C-14	1.50E+12	1.10E+07	2.81E+07	5.62E+07	6.50E-12	8.63E-09
Cl-36	3.40E+09	2.50E+04	6.37E+04	1.27E+05	5.10E-09	1.54E-08
Co-60	9.06E+16	6.66E+11	1.56E+09	3.13E+09	1.70E-08	1.26E-03

Cs-135	5.10E+08	3.75E+03	9.55E+03	1.91E+04	9.90E-10	4.47E-10
Cs-137	4.91E+12	3.61E+07	9.20E+07	1.84E+08	6.70E-09	2.91E-05
H-3	7.94E+14	5.84E+09	1.49E+10	2.98E+10	2.70E-11	1.90E-05
I-129	3.01E+10	2.21E+05	5.64E+05	1.13E+06	5.10E-08	1.36E-06
Mo-93	1.31E+05	9.63E-01	2.45E+00	4.91E+00	1.40E-09	1.62E-13
Nb-94	2.09E+11	1.54E+06	3.92E+06	7.83E+06	2.50E-08	4.63E-06
Ni-59	1.07E+09	7.87E+03	2.00E+04	4.01E+04	2.20E-10	2.08E-10
Ni-63	2.75E+11	2.02E+06	5.15E+06	1.03E+07	5.20E-10	1.27E-07
Np-237	1.53E+07	1.13E+02	2.87E+02	5.73E+02	1.50E-05	2.03E-07
Pu-239	7.74E+10	5.69E+05	1.45E+06	2.90E+06	3.20E-05	2.19E-03
Pu-241	1.46E+12	1.07E+07	2.74E+07	5.47E+07	5.80E-07	7.50E-04
Pu-242	5.55E+07	4.08E+02	1.04E+03	2.08E+03	3.10E-05	1.52E-06
Ra-226	3.63E+10	2.67E+05	6.80E+05	1.36E+06	2.20E-06	7.07E-05
Se-79	8.13E+07	5.98E+02	1.52E+03	3.05E+03	3.10E-09	2.23E-10
Sn-126	1.09E+08	8.01E+02	2.04E+03	4.08E+03	1.80E-08	1.74E-09
Sr-90	5.31E+12	3.90E+07	9.95E+07	1.99E+08	7.70E-08	3.62E-04
Tc-99	3.16E+11	2.32E+06	5.92E+06	1.18E+07	3.20E-09	8.95E-07
Th-230	4.50E+09	3.31E+04	8.43E+04	1.69E+05	2.80E-05	1.12E-04
Th-232	2.39E+10	1.76E+05	4.48E+05	8.96E+05	2.90E-05	6.14E-04
U-233	2.41E+08	1.77E+03	4.52E+03	9.03E+03	6.90E-06	1.47E-06
U-234	5.94E+10	4.37E+05	1.11E+06	2.23E+06	6.80E-06	3.58E-04
U-235	2.57E+09	1.89E+04	4.81E+04	9.63E+04	6.10E-06	1.39E-05
U-238	6.72E+10	4.94E+05	1.26E+06	2.52E+06	5.70E-06	3.39E-04
Zr-93	1.06E+12	7.79E+06	1.99E+07	3.97E+07	2.90E-08	2.72E-05
					TOTAL	**47.30E-03**

D.4.1 MicroShield Calculations

The dose rates for averaged radionuclide activity concentrations packaged waste to derive the scaling factor for packaged wastes are shown in Figure D-3. Dose rates for averaged radionuclide activity concentrations packaged waste, with Co-60 scaled down to satisfy the waste dose rate criteria are shown in Figure D-4.

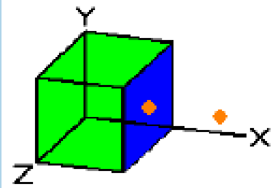
MicroShield 9.07
ISR (9.07-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Dropped package v0-2kp_ revised inventory.msd	November 5, 2018	1:15:52 PM	00:00:00

Project Info	
Case Title	Dropped package
Description	Dose rate outside unshielded B25 box
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	119.0 cm (3 ft 10.9 in)
Width	183.0 cm (6 ft 0.0 in)
Height	117.0 cm (3 ft 10.1 in)



Dose Points			
A	X	Y	Z
#1	219.266 cm (7 ft 2.3 in)	58.5 cm (1 ft 11.0 in)	91.5 cm (3 ft 0.0 in)
#2	120.266 cm (3 ft 11.3 in)	58.5 cm (1 ft 11.0 in)	91.5 cm (3 ft 0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	2.55e+06 cm³	Soil	0.54
Shield 1	.266 cm	Iron	7.86
Air Gap		Air	0.00122

Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	1.3820e-005	5.1134e+005	5.4241e-006	2.0069e-001
Am-241	2.4300e-005	8.9910e+005	9.5372e-006	3.5288e-001
Am-243	2.3390e-008	8.6543e+002	9.1801e-009	3.3966e-004
C-14	7.5950e-004	2.8102e+007	2.9809e-004	1.1029e+001
Cl-36	1.7220e-006	6.3714e+004	6.7585e-007	2.5006e-002
Co-60	4.5870e+001	1.6972e+012	1.8003e+001	6.6611e+005
Cs-135	2.5820e-007	9.5534e+003	1.0134e-007	3.7495e-003
Cs-137	2.4860e-003	9.1982e+007	9.7570e-004	3.6101e+001
H-3	4.0200e-001	1.4874e+010	1.5778e-001	5.8377e+003
I-129	1.5240e-005	5.6388e+005	5.9814e-006	2.2131e-001
Mo-93	6.6330e-011	2.4542e+000	2.6033e-011	9.6323e-007
Nb-94	1.0580e-004	3.9146e+006	4.1524e-005	1.5364e+000
Ni-59	5.4180e-007	2.0047e+004	2.1264e-007	7.8679e-003
Ni-63	1.3920e-004	5.1504e+006	5.4633e-005	2.0214e+000
Np-237	7.7470e-009	2.8664e+002	3.0405e-009	1.1250e-004
Pu-239	3.9190e-005	1.4500e+006	1.5381e-005	5.6911e-001
Pu-241	7.3930e-004	2.7354e+007	2.9016e-004	1.0736e+001
Pu-242	2.8100e-008	1.0397e+003	1.1029e-008	4.0806e-004
Ra-226	1.8380e-005	6.8006e+005	7.2138e-006	2.6691e-001

Se-79	4.1170e-008	1.5233e+003	1.6158e-008	5.9786e-004
Sn-126	5.5190e-008	2.0420e+003	2.1661e-008	8.0145e-004
Sr-90	2.6890e-003	9.9493e+007	1.0554e-003	3.9049e+001
Tc-99	1.6000e-004	5.9200e+006	6.2797e-005	2.3235e+000
Th-230	2.2790e-006	8.4323e+004	8.9446e-007	3.3095e-002
Th-232	1.2100e-005	4.4770e+005	4.7490e-006	1.7571e-001
U-233	1.2200e-007	4.5140e+003	4.7882e-008	1.7716e-003
U-234	3.0080e-005	1.1130e+006	1.1806e-005	4.3681e-001
U-235	1.3010e-006	4.8137e+004	5.1061e-007	1.8893e-002
U-238	3.4030e-005	1.2591e+006	1.3356e-005	4.9417e-001
Zr-93	5.3670e-004	1.9858e+007	2.1064e-004	7.7938e+000

Buildup: The material reference is Source Integration Parameters	
X Direction	10
Y Direction	20
Z Direction	20

Nominal Case	
Dose Point #2	**(120.266, 58.5, 91.5) cm**
Variable	**Not Applicable**

Nominal Case			
Dose Point #2	**(120.266, 58.5, 91.5) cm**		
Variable	**Not Applicable**		
Results (Summed over energies)	**Units**	**Without Buildup**	**With Buildup**
Effective Dose (ICRP 74 - 1997)			
Antero-posterior Geometry	mSv/hr	2.808e+002	5.712e+002
Postero-anterior Geometry	mSv/hr	2.495e+002	5.074e+002
Left Lateral Geometry	mSv/hr	2.007e+002	4.081e+002
Lateral Geometry	mSv/hr	0.000e+000	0.000e+000
Right Lateral Geometry	mSv/hr	1.902e+002	3.868e+002
Rotational Geometry	mSv/hr	2.374e+002	4.828e+002
Isotropic Geometry	mSv/hr	2.073e+002	4.216e+002

Nominal Case			
Dose Point #1	**(219.266, 58.5, 91.5) cm**		
Variable	**Not Applicable**		

Nominal Case			
Dose Point #1	**(219.266, 58.5, 91.5) cm**		
Variable	**Not Applicable**		
Results (Summed over energies)	**Units**	**Without Buildup**	**With Buildup**
Effective Dose (ICRP 74 - 1997)			
Antero-posterior Geometry	mSv/hr	6.089e+001	1.086e+002
Postero-anterior Geometry	mSv/hr	5.409e+001	9.647e+001
Left Lateral Geometry	mSv/hr	4.351e+001	7.760e+001
Lateral Geometry	mSv/hr	0.000e+000	0.000e+000
Right Lateral Geometry	mSv/hr	4.124e+001	7.355e+001
Rotational Geometry	mSv/hr	5.146e+001	9.179e+001
Isotropic Geometry	mSv/hr	4.494e+001	8.016e+001

Figure D-3 Deriving Scaling Factor for Packaged Wastes

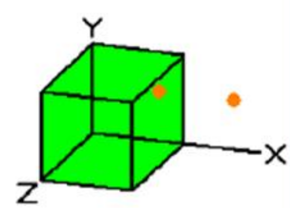
MicroShield 9.07
ISR (9.07-0000)

Date	By	Checked

Filename	Run Date	Run Time	Duration
Dropped package v0-2kp_ revised inventory.msd	November 5, 2018	1:26:05 PM	00:00:00

Project Info	
Case Title	Dropped package
Description	Dose rate outside unshielded B25 box
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	119.0 cm (3 ft 10.9 in)
Width	183.0 cm (6 ft 0.0 in)
Height	117.0 cm (3 ft 10.1 in)



Dose Points			
A	X	Y	Z
#1	219.0 cm (7 ft 2.2 in)	100.0 cm (3 ft 3.4 in)	91.5 cm (3 ft 0.0 in)
#2	120.0 cm (3 ft 11.2 in)	100.0 cm (3 ft 3.4 in)	91.5 cm (3 ft 0.0 in)

Shields			
Shield N	Dimension	Material	Density
Source	2.55e+06 cm³	Soil	0.54
Air Gap		Air	0.00122

Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ag-108m	1.3820e-005	5.1134e+005	5.4241e-006	2.0069e-001
Am-241	2.4300e-005	8.9910e+005	9.5372e-006	3.5288e-001
Am-243	2.3390e-008	8.6543e+002	9.1801e-009	3.3966e-004
Ba-137m	2.3518e-003	8.7015e+007	9.2301e-004	3.4152e+001
C-14	7.5950e-004	2.8102e+007	2.9809e-004	1.1029e+001
Cl-36	1.7220e-006	6.3714e+004	6.7585e-007	2.5006e-002
Co-60	4.2240e-002	1.5629e+009	1.6578e-002	6.1340e+002
Cs-135	2.5820e-007	9.5534e+003	1.0134e-007	3.7495e-003
Cs-137	2.4860e-003	9.1982e+007	9.7570e-004	3.6101e+001
H-3	4.0200e-001	1.4874e+010	1.5778e-001	5.8377e+003
I-129	1.5240e-005	5.6388e+005	5.9814e-006	2.2131e-001
Mo-93	6.6330e-011	2.4542e+000	2.6033e-011	9.6323e-007
Nb-94	1.0580e-004	3.9146e+006	4.1524e-005	1.5364e+000
Ni-59	5.4180e-007	2.0047e+004	2.1264e-007	7.8679e-003
Ni-63	1.3920e-004	5.1504e+006	5.4633e-005	2.0214e+000
Np-237	7.7470e-009	2.8664e+002	3.0405e-009	1.1250e-004
Pu-239	3.9190e-005	1.4500e+006	1.5381e-005	5.6911e-001
Pu-241	7.3930e-004	2.7354e+007	2.9016e-004	1.0736e+001
Pu-242	2.8100e-008	1.0397e+003	1.1029e-008	4.0806e-004
Ra-226	1.8380e-005	6.8006e+005	7.2138e-006	2.6691e-001

Se-79	4.1170e-008	1.5233e+003	1.6158e-008	5.9786e-004
Sn-126	5.5190e-008	2.0420e+003	2.1661e-008	8.0145e-004
Sr-90	2.6890e-003	9.9493e+007	1.0554e-003	3.9049e+001
Tc-99	1.6000e-004	5.9200e+006	6.2797e-005	2.3235e+000
Th-230	2.2790e-006	8.4323e+004	8.9446e-007	3.3095e-002
Th-232	1.2100e-005	4.4770e+005	4.7490e-006	1.7571e-001
U-233	1.2200e-007	4.5140e+003	4.7882e-008	1.7716e-003
U-234	3.0080e-005	1.1130e+006	1.1806e-005	4.3681e-001
U-235	1.3010e-006	4.8137e+004	5.1061e-007	1.8893e-002
U-238	3.4030e-005	1.2591e+006	1.3356e-005	4.9417e-001
Y-90	2.6890e-003	9.9493e+007	1.0554e-003	3.9049e+001
Zr-93	5.3670e-004	1.9858e+007	2.1064e-004	7.7938e+000

Buildup: The material reference is Source **Integration Parameters**	
X Direction	10
Y Direction	20
Z Direction	20

Nominal Case	
Dose Point #2	**(120, 100, 91.5) cm**
Variable	**Not Applicable**

Nominal Case			
Dose Point #2	**(120, 100, 91.5) cm**		
Variable	**Not Applicable**		
Results (Summed over energies)	**Units**	**Without Buildup**	**With Buildup**
Effective Dose (ICRP 74 - 1997)			
Antero-posterior Geometry	mSv/hr	3.098e-001	5.325e-001
Postero-anterior Geometry	mSv/hr	2.750e-001	4.728e-001
Left Lateral Geometry	mSv/hr	2.211e-001	3.799e-001
Lateral Geometry	mSv/hr	0.000e+000	0.000e+000
Right Lateral Geometry	mSv/hr	2.095e-001	3.600e-001
Rotational Geometry	mSv/hr	2.616e-001	4.497e-001
Isotropic Geometry	mSv/hr	2.284e-001	3.925e-001

Nominal Case			
Dose Point #1	**(219, 100, 91.5) cm**		
Variable	**Not Applicable**		
Nominal Case			
Dose Point #1	**(219, 100, 91.5) cm**		
Variable	**Not Applicable**		
Results (Summed over energies)	**Units**	**Without Buildup**	**With Buildup**
Effective Dose (ICRP 74 - 1997)			
Antero-posterior Geometry	mSv/hr	5.864e-002	9.911e-002
Postero-anterior Geometry	mSv/hr	5.206e-002	8.798e-002
Left Lateral Geometry	mSv/hr	4.185e-002	7.070e-002
Lateral Geometry	mSv/hr	0.000e+000	0.000e+000
Right Lateral Geometry	mSv/hr	3.966e-002	6.700e-002
Rotational Geometry	mSv/hr	4.953e-002	8.369e-002
Isotropic Geometry	mSv/hr	4.323e-002	7.305e-002

Figure D-4 Dropped Load Dose Rates

D.5 Results

As shown in Table D-6, the radiological consequence to the worker from a dropped packaged waste event for a 10 minute exposure time, is 4.0E-02 mSv.

Table D-6
Radiological Consequence to the Worker

Exposure Pathway	Radiological consequence from the dropped packaged waste event (mSv)
External radiation (at 1 m)	3.3E-02
Inhalation of re-suspended radionuclides	7.3E-03
TOTAL	**4.0E-02**

D.6 References

[D-1] *Near Surface Disposal Facility Waste Acceptance Criteria*, 232-508600-WAC-003, Revision 1, 2020 April.

[D-2] *Dose Calculations Pertaining to Respirable Radiation Sources,* 900-508770-FID-008, Revision 0, 2018 December.

[D-3] U.S. Department of Energy (DOE), *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, Volume I, DOE-HDBK-3010-94, Reaffirmed 2013.

[D-4] AECOM, *Waste Characterization*, 232-508600-REPT-002, Revision 4, 2020 February.

[D-5] W. E. Jones, T.-T. Wu and M. A. Phifer, *Structural Analysis for Subsidence of Stacked B-25 Boxes*, Savannah River Technology Center, 2003.

[D-6] *Near Surface Disposal Facility Reference Inventory Report*, 232-508600-REPT-003, Revision 3, 2020 April.

[D-7] *Standard Assumptions and Input Parameters for the Calculation of On-Site and Off-Site Doses Following Hypothetical Accidental Atmospheric Radioactive Releases from Facilities at CRL*, 145-508770-NSN-001, Revision 1, 2017 March.

[D-8] International Commission on Radiological Protection (ICRP), *Compendium of Dose Coefficients based on ICRP Publication 60*, ICRP Publication 119. Ann. ICRP 41(s), 2012.

[D-9] Canadian Nuclear Safety Commission, *Health Effects Dosimetry and Radiological Protection of Tritium*, INFO-0799, 2010.

[D-10] Canadian Standards Association (CSA), *Guidelines for Calculating Radiation Doses to the Public from a Release of Airborne Radioactive Material under Hypothetical Accident Conditions in Nuclear Reactor*s, CSA N288.2-M91, 1991.

[D-11] Ministere de l'Ecologie et du Developpement Durable, *Methods pour l'evaluation et la prevention des risques accidentels (DRA-006)*, INERIS-DRA-2002-25427, 2002.

[D-12] Atomic Energy Canada Limited (AECL), AERAD, *The Atmospheric Dispersion Model for Emergency Response at the Whiteshell Laboratories, Manitoba, Canada*, AECL-10817, 1993.

[D-13] Canadian Standards Association (CSA), *Guidelines for Calculating the Radiological Consequences to the Public of a Release of Airborne Radioactive Material for Nuclear Reactor Accidents*, CSA N288.2-14, 2014.

Appendix E

Waste Water Treatment Plant Splash Radiological Consequence

E.1 Introduction

A radiological consequence, skin dose, may occur from accidental splashes or spillage either onto exposed (bare) skin or clothing. Two situations have been considered to assess the dose from a spill of active liquid during WWTP operations. Firstly, a single droplet on exposed skin, secondly, a uniform deposit with the same activity concentration and depth as the droplet, but extending over a larger part of the body. These exposures are consistent with those expected from accidents during WWTP sampling operations. The skin equivalent doses calculated are applicable to an exposure on any part of the body, (e.g. extremity, limb, and trunk).

Two sampling locations are assessed, at the chemical precipitation tank and at the residual storage tank (filter press feed). Sampling of tanks later in the process would be less hazardous as the treatment reduces radionuclide activity, therefore, reducing the potential dose to the worker from an upset condition. Estimation of the equivalent skin dose due to a splash or spillage, while sampling the chemical precipitation tanks or the filter press feed tank is based on the following assumptions:

- The radionuclide concentrations within the waste are taken from the CRL NSDF Wastewater Treatment Material Balance Table, Column G “Precipitation Tanks” for the chemical precipitation tanks and Column N “Membrane Filter Residuals” for the filter press feed tank [E-1].
- Dose equivalents have been calculated for at a 70 µm basal layer depth, averaged over a skin area of 1 cm^2 in line with the Radiation Protection Regulations for non-uniform skin exposures [E-2]. The specific gravity for the liquids in the chemical precipitation tanks and the membrane filter feed tank are 1 g/ml and 1.05 g/ml respectively [E-1].
- The droplet is modelled as a cylinder with a density of 1 g/cm^3, a cross sectional area of 1 cm^2 (0.5642 cm radius) and a height of 0.5 mm. This droplet has a volume of 0.05 cm^3 or 5E-05 L.
- The uniform deposit is modelled as a cylinder with a density of 1 g/cm^3, a cross sectional area of 200 cm^2 (7.979 cm radius) and a height of 0.5 mm. This deposit has a volume of 10 cm^3 or 0.01 L.
- The radionuclide concentration is evenly distributed throughout the contents of the tank, and the liquid splashed or spilled on the skin. The splash or spillage therefore, results in an even distribution of contamination at the analysed radionuclide concentrations onto the skin.
- The United States Nuclear Regulatory Commission VARiable SKIN (VARSKIN) 6.2 code was used to calculate the equivalent dose. This code was subsequently updated to

VARSKIN 6.2.1, which is the computer code version that has been released [E-3]. VARSKIN 6.2.1 was used for verification [E-4].

- The effective atomic number of the source material was assumed to be 7.42, which represents a water deposit, when inputting the radionuclide library in VARSKIN.
- The ICRP 107 library was used in VARSKIN.
- Progeny were included in secular equilibrium, either by using the VARSKIN 107D library or by adding only the progeny that would be expected to reach secular equilibrium over periods of 1-10 years.

E.2 Dose Acceptance Criteria

The equivalent dose limit for the skin for a NEW is 500 mSv in an one-year dosimetry period, while for a non-NEW the equivalent dose limit is 50 mSv in one calendar year. When skin is unevenly irradiated, as is the case in this analysis, the equivalent dose received by the skin is the average equivalent dose over the 1 cm^2 that receives the highest equivalent dose [E-2].

The intent of equivalent dose limits is to prevent deterministic effects, such as skin injury.

E.3 Skin Equivalent Dose Source Term

The radionuclide concentrations within the waste are taken from the analysis results shown in the CRL NSDF Wastewater Treatment Material Balance Table, Column G “Precipitation Tanks” for the chemical precipitation tanks and Column N “Membrane Filter Residuals” for the residuals storage tank or filter press feed tank [E-1]. The progeny associated with some of these radionuclides were not included in the analysis results. To ensure that the calculated equivalent skin dose is accurate, progeny radionuclides were identified and included in the input source term.

These progeny radionuclides were identified by taking the analysis results shown in the CRL NSDF Wastewater Treatment Material Balance [E-6], and decaying these for a period of 1, 3, and 10 years using SCALE 6.2.1. From these decay periods, it was possible to identify those radioisotopes that reached equilibrium (particularly secular equilibrium) with all, or some, of their associated progeny.

For those radionuclides where all progeny was present in secular equilibrium the VARSKIN ICRP 107 decay library was used. The VARSKIN decay library assumes all progeny reach equilibrium. For those radioisotopes where only some progeny reached secular equilibrium, the radioisotopes that reached equilibrium were added separately to the VARSKIN input, this prevented unnecessary conservatism by inclusion of the entire decay chain, particularly in cases of transient or no equilibrium. This assessment is shown in Table E-1 for the chemical precipitation tanks and Table E-2 for the filter press feed tank, with progeny shown in italics.

Table E-1
Chemical Precipitation Tank Radionuclide Concentration and Progeny Assessment

Nuclide	Tank Activity (Bq/L)				Progeny Assessment
	0 years	1 year	3 years	10 years	
H-3	1.40E+05	1.32E+05	1.18E+05	7.98E+04	No progeny.
Co-60	1.30E+03	1.14E+03	8.76E+02	3.49E+02	No progeny.
Sr-90	9.60E+00	9.37E+00	8.93E+00	7.55E+00	Progeny not included in analysis results. Secular equilibrium, VARSKIN Sr-90D used.
Y-90*	-	9.37E+00	8.93E+00	7.55E+00	
Tc-99	5.70E+00	5.70E+00	5.70E+00	5.70E+00	No progeny.
C-14	3.10E+00	3.10E+00	3.10E+00	3.10E+00	No progeny.
Cs-137	9.30E-01	9.09E-01	8.68E-01	7.39E-01	Progeny not included in analysis results. Secular equilibrium, VARSKIN Cs-137D used.
Ba-137m*	-	8.61E-01	8.22E-01	6.99E-01	
I-129	9.10E-02	9.10E-02	9.10E-02	9.10E-02	No progeny.
Pu-241	7.90E-02	7.53E-02	6.83E-02	4.86E-02	No progeny.
Am-241*	-	1.23E-04	3.52E-04	9.94E-04	Progeny, Am-241, included in analysis results. Am-241 activity generated by Pu-241 decay are insignificant when compared to input source term analysis results.
Cl-36	5.90E-02	5.90E-02	5.90E-02	5.90E-02	No progeny.
Zr-93	4.40E-02	4.40E-02	4.40E-02	4.40E-02	Progeny, Nb-93m, not included in analysis results. Though secular equilibrium not reached in 10 years (100+ years required), VARSKIN Zr-93D used. This will be overly conservative.
Nb-93m*	Nb-93m	1.80E-03	5.19E-03	1.50E-02	
Ni-63	4.40E-02	4.37E-02	4.31E-02	4.11E-02	No progeny.
Nb-94	1.50E-02	1.50E-02	1.50E-02	1.50E-02	No progeny.
U-234	7.80E-03	7.80E-03	7.80E-03	7.80E-03	Progeny, Th-230, included in analysis results. Th-230 activity generated by U-234 decay is insignificant when compared to input source term analysis results.
Th-230*	-	7.17E-08	2.15E-07	7.17E-07	
U-238	7.60E-03	7.60E-03	7.60E-03	7.60E-03	Progeny, with the exception of U-234, not included in analysis results. Th-234 and Pa-234m added to input at secular equilibrium with U-238. Pa-234 activity generated by U-238 decay is not significant compared to other radionuclides. U-234 activity generated by U-238 decay is insignificant when compared to input source term analysis results.
Th-234*	-	7.60E-03	7.60E-03	7.60E-03	
Pa-234m*	-	7.60E-03	7.60E-03	7.60E-03	
U-234*	-	1.97E-08	6.23E-08	2.13E-07	
Pa-234*	-	1.22E-05	1.22E-05	1.22E-05	
Pu-239	4.40E-03	4.40E-03	4.40E-03	4.40E-03	Progeny, U-235m, not included in analysis results. U-235 is included. U-235m and U-235 activity generated by Pu-239 decay are insignificant.
U-235m*	-	Less than 1E-9.			
U-235*	-	Less than 1E-9.			
Am-241	2.80E-03	2.92E-03	3.14E-03	3.75E-03	Progeny, Np-237, included in analysis results.

Nuclide	Tank Activity (Bq/L)				Progeny Assessment
	0 years	1 year	3 years	10 years	
*Np-237**	-	9.05E-10	2.71E-09	8.98E-09	Np-237 activity generated by Am-241 decay is insignificant when compared to input source term analysis results.
Th-232	9.60E-04	9.60E-04	9.60E-04	9.60E-04	Progeny not included in analysis results. No secular equilibrium until 50-100 years. Th-232D used in VARSKIN, this will be overly conservative.
*Ra-228**	-	*1.09E-04*	*2.91E-04*	*6.72E-04*	
*Ac-228**	-	*1.09E-04*	*2.91E-04*	*6.72E-04*	
*Th-228**	-	*1.79E-05*	*1.19E-04*	*5.42E-04*	
*Ra-224**	-	*1.79E-05*	*1.19E-04*	*5.42E-04*	
*Rn-220**	-	*1.79E-05*	*1.19E-04*	*5.42E-04*	
*Po-216**	-	*1.79E-05*	*1.19E-04*	*5.42E-04*	
*Pb-212**	-	*1.79E-05*	*1.19E-04*	*5.42E-04*	
*Bi-212**	-	*1.79E-05*	*1.19E-04*	*5.42E-04*	
*Po-212**	-	*1.15E-05*	*7.65E-05*	*3.47E-04*	
Ra-226	6.40E-04	6.40E-04	6.39E-04	6.38E-04	Progeny not included in analysis results. Secular equilibrium, VARSKIN Ra-226D used.
*Rn-222**	-	*6.40E-04*	*6.39E-04*	*6.38E-04*	
*Po-218**	-	*6.40E-04*	*6.39E-04*	*6.38E-04*	
*Pb-214**	-	*6.40E-04*	*6.39E-04*	*6.38E-04*	
*Bi-214**	-	*6.40E-04*	*6.39E-04*	*6.38E-04*	
*Po-214**	-	*6.40E-04*	*6.39E-04*	*6.38E-04*	
*Pb-210**	-	*1.94E-05*	*5.69E-05*	*1.71E-04*	
*Bi-210**	-	*1.94E-05*	*5.69E-05*	*1.71E-04*	
*Po-210**	-	*1.03E-05*	*4.65E-05*	*1.71E-04*	
U-235	3.30E-04	3.30E-04	3.30E-04	3.30E-04	Progeny, Th-231, not included in analysis results. Added Th-231 in secular equilibrium, rest of progeny not included as their activities are insignificant.
*Th-231**	-	*3.30E-04*	*3.30E-04*	*3.30E-04*	
*Pa-231**	-	6.95E-09	2.09E-08	6.98E-08	
Th-230	2.20E-04	2.20E-04	2.20E-04	2.21E-04	Progeny, Ra-226, included in analysis results. Ra-226 activity generated by Th-230 decay is insignificant when compared to input source term analysis results.
*Ra-226**	-	*9.53E-08*	*2.86E-07*	*9.51E-07*	
Ag-108m	1.80E-04	1.80E-04	1.79E-04	1.77E-04	Progeny not included in analysis results. Secular equilibrium, VARSKIN Ag-108mD used.
*Ag-108**	-	*1.56E-05*	*1.56E-05*	*1.54E-05*	
Ni-59	1.70E-04	1.70E-04	1.70E-04	1.70E-04	No progeny.
Cs-135	4.10E-05	4.10E-05	4.10E-05	4.10E-05	No progeny.
U-233	2.90E-05	2.90E-05	2.90E-05	2.90E-05	Progeny, Th-229, not included in analysis results. Th-229 activity generated by U-233 is insignificant.
*Th-229**	-	*2.74E-09*	*8.22E-09*	*2.74E-08*	
Se-79	2.40E-05	2.40E-05	2.40E-05	2.40E-05	No progeny.
Sn-126	7.20E-06	7.20E-06	7.20E-06	7.20E-06	Progeny, Sb-126m and Sb-126, not included in analysis results. Secular equilibrium, VARSKIN Sn-126D used.
*Sb-126m**	-	*7.20E-06*	*7.20E-06*	*7.20E-06*	
*Sb-126**	-	*1.01E-06*	*1.01E-06*	*1.01E-06*	
Pu-242	3.30E-06	3.30E-06	3.30E-06	3.30E-06	Progeny, U-238, included in analysis results.

Nuclide	Tank Activity (Bq/L)				Progeny Assessment
	0 years	1 year	3 years	10 years	
*U-238**	-	*5.12E-16*	*1.54E-15*	*5.12E-15*	U-238 activity generated by Pu-242 decay insignificant when compared to input source term analysis results.
Am-243	1.70E-06	1.70E-06	1.70E-06	1.70E-06	Progeny, Np-239, not included in analysis results, Pu-239, is included. Added Np-239 in secular equilibrium, Pu-239 activity generated by Am-243 decay insignificant when compared to input source term analysis results.
*Np-239**	-	*1.70E-06*	*1.70E-06*	*1.70E-06*	
*Pu-239**	-	4.84E-11	1.46E-10	4.88E-10	
Np-237	6.30E-07	6.31E-07	6.33E-07	6.41E-07	Progeny, Pa-233, not included in analysis results, U-233 is included. Added Pa-233 in secular equilibrium. U-233 activity generated by Np-237 decay insignificant when compared to input source term analysis results.
*Pa-233**	-	*6.31E-07*	*6.33E-07*	*6.41E-07*	
*U-233**	-	*2.45E-12*	*7.94E-12*	*6.30E-07*	
Mo-93	4.10E-07	4.10E-07	4.10E-07	4.09E-07	Progeny, Nb-93m, not included in analysis results. Does not reach secular equilibrium. Nb-93m activity generated by Mo-93 decay as its activity is insignificant.
*Nb-93m**	-	1.52E-08	4.36E-08	1.26E-07	

* progeny.

Table E-2
Filter Press Feed Tank Radionuclide Concentration and Progeny Assessment

Nuclide	Tank Activity (Bq/L)				Progeny Assessment
	0 years	1 year	3 years	10 years	
H-3	1.37E+05	1.30E+05	1.16E+05	7.80E+04	No progeny.
Co-60	1.88E+04	1.65E+04	1.27E+04	5.05E+03	No progeny.
Sr-90	1.82E+02	1.78E+02	1.69E+02	1.43E+02	Progeny not included in analysis results. Secular equilibrium, VARSKIN Sr-90D used.
*Y-90**	-	*1.78e+02*	*1.69E+02*	*1.43E+02*	
Tc-99	5.57E+00	5.57E+00	5.57E+00	5.57E+00	No progeny.
C-14	3.03E+00	3.03E+00	3.03E+00	3.03E+00	No progeny.
Cs-137	9.10E-01	8.89E-01	8.49E-01	7.23E-01	Progeny not included in analysis results. Secular equilibrium, VARSKIN Cs-137D used.
*Ba-137m**	-	*8.42E-01*	*8.04E-01*	*6.84E-01*	
Ni-63	7.86E-01	7.81E-01	7.70E-01	7.34E-01	No progeny.
Pu-241	4.53E-01	4.32E-01	3.92E-01	2.79E-01	Progeny, Am-241, included in analysis results. Am-241 activity generated by Pu-241 decay are insignificant when compared to input source term analysis results.
*Am-241**	-	*7.08E-04*	*2.02E-03*	*5.70E-03*	
Zr-93	2.52E-01	2.52E-01	2.52E-01	2.52E-01	Progeny, Nb-93m, not included in analysis results. Though secular equilibrium not
*Nb-93m**	-	1.03E-02	2.97E-02	8.58E-02	

Nuclide	Tank Activity (Bq/L)				Progeny Assessment
	0 years	1 year	3 years	10 years	
					reached in 10 years (100+ years required), VARSKIN Zr-93D used. This will be overly conservative.
U-234	1.30E-01	1.30E-01	1.30E-01	1.30E-01	Progeny, Th-230, included in analysis results. Th-230 activity generated by U-234 decay is insignificant when compared to input source term analysis results.
*Th-230**	-	*1.20E-06*	*3.59E-06*	*1.20E-05*	
U-238	1.27E-01	1.27E-01	1.27E-01	1.27E-01	Progeny, with the exception of U-234, not included in analysis results. Th-234 and Pa-234m added to input at secular equilibrium with U-238. Pa-234 activity generated by U-238 decay is not significant compared to other radionuclides. U-234 activity generated by U-238 decay is insignificant when compared to input source term analysis results.
*Th-234**	-	*1.27E-01*	*1.27E-01*	*1.27E-01*	
*Pa-234m**	-	*1.27E-01*	*1.27E-01*	*1.27E-01*	
*U-234**	-	*3.24E-07*	*1.04E-06*	*3.55E-06*	
*Pa-234**	-	*2.03E-04*	*2.03E-04*	*2.03E-04*	
I-129	8.90E-02	8.90E-02	8.90E-02	8.90E-02	No progeny.
Nb-94	8.60E-02	8.60E-02	8.60E-02	8.60E-02	No progeny.
Cl-36	5.77E-02	5.77E-02	5.77E-02	5.77E-02	No progeny.
Pu-239	2.52E-02	2.52E-02	2.52E-02	2.52E-02	Progeny, U-235m, not included in analysis results. U-235 is included. U-235m and U-235 activity generated by Pu-239 decay are insignificant.
*U-235m**	-	*Less than 1E-9.*			
*U-235**	-	*Less than 1E-9.*			
Am-241	1.61E-02	1.61E-02	1.60E-02	1.58E-02	Progeny, Np-237, included in analysis results. Np-237 activity generated by Am-241 decay is insignificant when compared to input source term analysis results.
*Np-237**	-	5.20E-09	1.56E-08	5.1E-08	
U-235	5.51E-03	5.51E-03	5.51E-03	5.51E-03	Progeny, Th-231, not included in analysis results. Added Th-231 in secular equilibrium, rest of progeny not included as their activities are insignificant.
*Th-231**	-	*5.51E-03*	*5.51E-03*	*5.51E-03*	
*Pa-231**	-	*1.16E-07*	*3.49E-07*	*1.17E-06*	
Th-232	5.50E-03	5.50E-03	5.50E-03	5.50E-03	Progeny not included in analysis results. No secular equilibrium until 50-100 years. Th-232D used in VARSKIN, this will be overly conservative.
*Ra-228**	-	*6.25E-04*	*1.67E-03*	*3.85E-03*	
*Ac-228**	-	*6.25E-04*	*1.67E-03*	*3.85E-03*	
*Th-228**	-	*1.03E-04*	*6.84E-04*	*3.11E-03*	
*Ra-224**	-	*1.03E-04*	*6.84E-04*	*3.11E-03*	
*Rn-220**	-	*1.03E-04*	*6.84E-04*	*3.11E-03*	
*Po-216**	-	*1.03E-04*	*6.84E-04*	*3.11E-03*	
*Pb-212**	-	*1.03E-04*	*6.84E-04*	*3.11E-03*	
*Bi-212**	-	*1.03E-04*	*6.84E-04*	*3.11E-03*	
*Po-212**	-	*6.57E-05*	*4.38E-04*	*1.99E-03*	

Nuclide	Tank Activity (Bq/L)				Progeny Assessment
	0 years	1 year	3 years	10 years	
Ra-226	3.67E-03	3.67E-03	3.67E-03	3.65E-03	Progeny not included in analysis results. Ra-226D used in VARSKIN as in secular equilibrium.
*Rn-222**	-	*3.67E-04*	*3.67E-04*	*3.65E-03*	
*Po-218**	-	*3.67E-04*	*3.67E-04*	*3.65E-03*	
*Pb-214**	-	*3.67E-04*	*3.67E-04*	*3.65E-03*	
*Bi-214**	-	*3.67E-04*	*3.67E-04*	*3.65E-03*	
*Po-214**	-	*3.67E-04*	*3.67E-04*	*3.65E-03*	
*Pb-210**	-	*1.11E-04*	*3.26E-04*	*9.81E-04*	
*Bi-210**	-	*3.67E-04*	*3.67E-04*	*3.65E-03*	
*Po-210**	-	*5.92E-05*	*2.67E-04*	*9.81E-04*	
Ni-59	3.04E-03	3.04E-03	3.04E-03	3.04E-03	No progeny.
Th-230	1.26E-03	1.26E-03	1.26E-03	1.26E-03	Progeny, Ra-226, included in analysis results. Ra-226 activity generated by Th-230 decay is insignificant when compared to input source term analysis results.
*Ra-226**	-	*5.46E-06*	*1.64E-06*	*5.45E-06*	
Ag-108m	1.03E-03	1.03E-03	1.03E-03	1.01E-03	Progeny not included in analysis results. Secular equilibrium, VARSKIN Ag-108mD used.
*Ag-108**	-	*8.95E-05*	*8.92E-05*	*8.80E-05*	
U-233	4.84E-04	4.84E-04	4.84E-04	4.84E-04	Progeny, Th-229, not included in analysis results. Th-229 activity generated by U-233 is insignificant.
*Th-229**	-	*4.57E-08*	*1.37E-07*	*4.57E-07*	
Se-79	1.38E-04	1.38E-04	1.38E-04	1.38E-04	No progeny.
Sn-126	4.13E-05	4.13E-05	4.13E-05	4.13E-05	Progeny, Sb-126m and Sb-126, not included in analysis results. Secular equilibrium, VARSKIN Sn-126D used.
*Sb-126m**	-	*4.13E-05*	*4.13E-05*	*4.13E-05*	
*Sb-126**	-	*5.78E-06*	*5.78E-06*	*5.78E-06*	
Cs-135	4.01E-05	4.01E-05	4.01E-05	4.01E-05	No progeny.
Pu-242	1.89E-05	1.89E-05	1.89E-05	1.89E-05	Progeny, U-238, included in analysis results. U-238 activity generated by Pu-242 decay insignificant when compared to input source term analysis results.
*U-238**	-	*2.93E-15*	*8.80E-15*	*2.93E-14*	
Am-243	9.75E-06	9.75E-06	9.75E-06	9.75E-06	Progeny, Np-239, not included in analysis results, Pu-239, is included. Added Np-239 in secular equilibrium, Pu-239 activity generated by Am-243 decay insignificant when compared to input source term analysis results.
*Np-239**	-	*9.75E-06*	*9.75E-06*	*9.74E-06*	
*Pu-239**	-	2.78E-10	8.38E-10	2.80E-09	
Np-237	3.61E-06	3.61E-06	3.61E-06	3.61E-06	Progeny, Pa-233, not included in analysis results, U-233 is included. Added Pa-233 in secular equilibrium. U-233 activity generated by Np-237 decay insignificant when compared to input source term analysis results.
*Pa-233**	-	*3.61E-06*	*3.61E-06*	*3.61E-06*	
*U-233**	-	*1.40E-11*	*4.55E-11*	*1.56E-10*	

Nuclide	Tank Activity (Bq/L)				Progeny Assessment
	0 years	1 year	3 years	10 years	
Mo-93	4.01E-07	4.01E-07	4.01E-07	4.00E-07	Progeny, Nb-93m, not included in analysis results. Does not reach secular equilibrium. Nb-93m activity generated by Mo-93 decay as its activity is insignificant.
*Nb-93m**	-	*1.48E-08*	*4.27E-08*	*1.23E-07*	

* progeny.

E.4 Skin Equivalent Dose VARSKIN Model Description

A cylindrical source geometry was selected in VARSKIN. The parameters for the droplet model were: source diameter of 1.13 cm, source thickness of 0.5 mm, source density of 1 g/cm^3, and source volume of 0.05 cm^3 or 5E-05 L. The uniform deposit area modelled is representative of a spillage over the back of the hand as a 200 cm^2 cross-sectional area was used. The parameters for the uniform deposit were: source diameter of 16 cm, source thickness of 0.5 mm, source density of 1 g/cm^3, and source volume of 10 cm^3 or 0.01 L.

In both cases the skin thickness was taken to be 70 µm and the skin averaging area 1 cm^2, this is in line with the CNSC Radiation Protection Regulations [E-2] for unevenly irradiated skin, and the ICRP recommendations that all skin dose should be averaged over 1 cm^2 regardless of the area exposed [E-3]. With this averaging area, the calculated dose for a uniform deposit would also represent the dose from spillages over a larger surface area of the body, e.g. a spill that covers the hand and forearm, provided the activity per unit area (Bq/cm^2) remained constant. The radionuclide library selected was ICRP 107 as this is the most up to date radionuclide library, with the source material atomic number set to 7.42 to represent a water deposit.

The source term input was the analysis radionuclide at the 0 year decay values, plus the progeny identified for separate inclusion at secular equilibrium with the parent, and the progeny within the VARSKIN ICRP 107 decay libraries where those were identified for use. Details of the progeny inclusion are in Table E-1 and Table E-2.

The VARSKIN output files are combined as more than 20 radionuclides were required, the maximum for a single run, with just the individual source results shown in Section E.9.

E.5 Skin Equivalent Dose Rate

The radiation weighting factor for x-rays, gamma rays, beta particles and muons is 1. Therefore, the equivalent dose in mSv/h is the same as the absorbed dose in tissue in mGy/h. The unit's mGy/h are shown as these reflect the VARSKIN output.

E.6 Chemical Precipitation Tanks

The skin equivalent dose rates for the chemical precipitation tank droplet and the uniform deposit are shown in Table E-3 and Table E-4. The calculated dose rates are similar as both models fully cover the 1 cm^2 averaging area. As the uniform deposit is larger, there are additional contributions to the averaging area from the deposits close to, but just outside, the averaging area. This results in a slightly increased dose rate for the uniform deposit.

The calculated dose rates for both the chemical precipitation tank droplet and the uniform deposit are less than 2E-05 mGy/h (2E-05 mSv/h), so even with an 8 or 10 hour exposure time the skin dose would be insignificant, being orders of magnitude below the regulatory dose limit.

Table E-3
Equivalent Skin Dose Rate – Chemical Precipitation Tank Droplet

Radionuclides	Droplet (Bq)	Electron (mGy/h)	Photon (mGy/h)	Total (mGy/h)
H-3	7.00E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	6.50E-02	1.39E-05	1.38E-06	1.52E-05
Sr-90D	4.80E-04	7.41E-07	0.00E+00	7.41E-07
Tc-99	2.85E-04	6.63E-08	0.00E+00	6.63E-08
C-14	1.55E-04	3.61E-09	0.00E+00	3.61E-09
Cs-137D	4.65E-05	2.92E-08	4.23E-10	2.96E-08
I-129	4.55E-06	1.19E-10	2.22E-11	1.41E-10
Pu-241	3.95E-06	0.00E+00	0.00E+00	0.00E+00
Cl-36	2.95E-06	2.18E-09	0.00E+00	2.18E-09
Zr-93D	2.20E-06	0.00E+00	2.50E-12	2.50E-12
Ni-63	2.20E-06	0.00E+00	0.00E+00	0.00E+00
Nb-94	7.50E-07	3.65E-10	1.61E-11	3.81E-10
U-234	3.90E-07	9.39E-16	5.96E-13	5.97E-13
U-238	3.80E-07	1.48E-14	4.25E-13	4.40E-13
Th-234	3.80E-07	1.24E-11	6.04E-13	1.30E-11
Pa-234m	3.80E-07	3.72E-10	0.00E+00	3.72E-10
Pu-239	2.20E-07	0.00E+00	1.94E-13	1.94E-13
Am-241	1.40E-07	1.00E-14	1.02E-12	1.03E-12
Th-232D	4.80E-08	1.07E-10	1.68E-12	1.09E-10
Ra-226D	3.20E-08	8.14E-11	7.92E-13	8.22E-11
U-235	1.65E-08	3.42E-14	1.47E-13	1.81E-13
Th-231	1.65E-08	2.34E-12	2.22E-13	2.56E-12
Th-230	1.10E-08	5.05E-17	1.35E-14	1.36E-14
Ag-108mD	9.00E-09	8.90E-13	2.86E-13	1.18E-12
Ni-59	8.50E-09	0.00E+00	1.23E-13	1.23E-13
Cs-135	2.05E-09	3.72E-13	0.00E+00	3.72E-13
U-233	1.45E-09	0.00E+00	1.19E-15	1.19E-15
Se-79	1.20E-09	3.29E-14	0.00E+00	3.29E-14
Sn-126D	3.60E-10	4.14E-13	1.32E-14	4.27E-13
Pu-242	1.65E-10	1.90E-18	2.11E-16	2.13E-16
Am-243	8.50E-11	9.04E-18	3.59E-16	3.68E-16
Np-239	8.50E-11	4.53E-14	1.23E-15	4.65E-14
Np-237	3.15E-11	4.16E-17	3.26E-16	3.68E-16

Pa-233	3.15E-11	1.47E-14	4.31E-16	1.51E-14
Mo-93	2.05E-11	0.00E+00	1.44E-16	1.44E-16
Totals	**7.07E+00**	**1.47E-05**	**1.38E-06**	**1.60E-05**

Table E-4
Equivalent Skin Dose – Chemical Precipitation Tank Uniform Spill

Radionuclides	Uniform Spill (Bq)	Electron (mGy/h)	Photon (mGy/h)	Total (mGy/h)
H-3	1.40E+03	0.00E+00	0.00E+00	0.00E+00
Co-60	1.30E+01	1.42E-05	3.39E-06	1.75E-05
Sr-90D	9.60E-02	9.24E-07	0.00E+00	9.24E-07
Tc-99	5.70E-02	6.77E-08	0.00E+00	6.77E-08
C-14	3.10E-02	3.63E-09	0.00E+00	3.63E-09
Cs-137D	9.30E-03	3.17E-08	7.81E-10	3.25E-08
I-129	9.10E-04	1.19E-10	3.16E-11	1.51E-10
Pu-241	7.90E-04	0.00E+00	0.00E+00	0.00E+00
Cl-36	5.90E-04	2.37E-09	0.00E+00	2.37E-09
Zr-93D	4.40E-04	0.00E+00	4.06E-12	4.06E-12
Ni-63	4.40E-04	0.00E+00	0.00E+00	0.00E+00
Nb-94	1.50E-04	3.81E-10	3.17E-11	4.13E-10
U-234	7.80E-05	9.36E-16	8.22E-13	8.23E-13
Th-230	7.80E-05	1.80E-15	6.64E-13	6.66E-13
U-238	7.60E-05	1.48E-14	5.86E-13	6.01E-13
Th-234	7.60E-05	1.25E-11	8.33E-13	1.33E-11
Pa-234m	7.60E-05	4.80E-10	0.00E+00	4.80E-10
Pu-239	4.40E-05	0.00E+00	2.43E-13	2.43E-13
Am-241	2.80E-05	1.00E-14	1.46E-12	1.47E-12
Th-232D	9.60E-06	1.26E-10	3.17E-12	1.29E-10
Ra-226D	6.40E-06	9.52E-11	1.52E-12	9.67E-11
U-235	3.30E-06	3.42E-14	2.38E-13	2.72E-13
Th-231	3.30E-06	2.38E-12	3.11E-13	2.69E-12
Th-230	2.20E-06	5.07E-17	1.87E-14	1.88E-14
Ag-108mD	1.80E-06	1.07E-12	5.08E-13	1.58E-12
Ni-59	1.70E-06	0.00E+00	1.34E-13	1.34E-13
Cs-135	4.10E-07	3.79E-13	0.00E+00	3.79E-13
U-233	2.90E-07	0.00E+00	1.59E-15	1.59E-15
Se-79	2.40E-07	3.30E-14	0.00E+00	3.30E-14
Sn-126D	7.20E-08	4.97E-13	2.32E-14	5.20E-13
Pu-242	3.30E-08	1.90E-18	2.88E-16	2.90E-16
Am-243	1.70E-08	9.07E-18	5.46E-16	5.55E-16
Np-239	1.70E-08	4.65E-14	1.85E-15	4.83E-14
Np-237	6.30E-09	4.17E-17	4.65E-16	5.06E-16

Pa-233	6.30E-09	1.52E-14	6.32E-16	1.58E-14
Mo-93	4.10E-09	0.00E+00	2.38E-16	2.38E-16
Totals	**1.41E+03**	**1.52E-05**	**3.39E-06**	**1.85E-05**

E.6.1 Filter Press Feed Tank

The skin equivalent dose rates for the filter press feed tank droplet and the uniform deposit are shown in Table E-5 and Table E-6. As with chemical precipitation tanks, the calculated dose rates are similar due to both models fully covering the 1 cm^2 averaging area.

The calculated dose rates for both the filter press feed tank droplet and the uniform deposit are less than 3E-04 mGy/h (3E-04 mSv/h), even with an eight or 10 hour exposure time the skin dose would be insignificant, being orders of magnitude below the regulatory dose limit.

Table E-5
Equivalent Skin Dose Rate – Filter Press Feed Tank Droplet

Radionuclides	Droplet (Bq)	Electron (mGy/h)	Photon (mGy/h)	Total (mGy/h)
H-3	6.85E+00	0.00E+00	0.00E+00	0.00E+00
Co-60	9.40E-01	2.00E-04	2.00E-05	2.20E-04
Sr-90D	9.10E-03	1.41E-05	0.00E+00	1.41E-05
Tc-99	2.79E-04	6.49E-08	0.00E+00	6.49E-08
C-14	1.52E-04	3.54E-09	0.00E+00	3.54E-09
Cs-137D	4.55E-05	2.85E-08	4.14E-10	2.90E-08
Ni-63	3.93E-05	0.00E+00	0.00E+00	0.00E+00
Pu-241	2.27E-05	0.00E+00	0.00E+00	0.00E+00
Zr-93D	1.26E-05	0.00E+00	1.43E-11	1.43E-11
U-234	6.50E-06	1.56E-14	9.93E-12	9.94E-12
U-238	6.35E-06	2.48E-13	7.10E-12	7.35E-12
Th-234	6.35E-06	2.07E-10	1.01E-11	2.17E-10
Pa-234m	6.35E-06	6.22E-09	0.00E+00	6.22E-09
I-129	4.45E-06	1.16E-10	2.17E-11	1.38E-10
Nb-94	4.30E-06	2.09E-09	9.24E-11	2.19E-09
Cl-36	2.89E-06	2.14E-09	0.00E+00	2.14E-09
Pu-239	1.26E-06	0.00E+00	1.11E-12	1.11E-12
Am-241	8.05E-07	5.76E-14	5.89E-12	5.95E-12
U-235	2.76E-07	5.71E-13	2.46E-12	3.03E-12
Th-231	2.76E-07	3.92E-11	3.72E-12	4.29E-11
Th-232D	2.75E-07	6.14E-10	9.63E-12	6.24E-10
Ra-226D	1.84E-07	4.68E-10	4.55E-12	4.73E-10
Ni-59	1.52E-07	0.00E+00	2.20E-12	2.20E-12
Th-230	6.30E-08	2.89E-16	7.75E-14	7.78E-14

Ag-108mD	5.15E-08	5.09E-12	1.63E-12	6.73E-12
U-233	2.42E-08	0.00E+00	1.98E-14	1.98E-14
Se-79	6.90E-09	1.89E-13	0.00E+00	1.89E-13
Sn-126D	2.07E-09	2.38E-12	7.58E-14	2.45E-12
Cs-135	2.01E-09	3.65E-13	0.00E+00	3.65E-13
Pu-242	9.45E-10	1.09E-17	1.21E-15	1.22E-15
Am-243	4.88E-10	5.19E-17	2.06E-15	2.11E-15
Np-239	4.88E-10	2.60E-13	7.08E-15	2.67E-13
Np-237	1.81E-10	2.39E-16	1.87E-15	2.11E-15
Pa-233	1.81E-10	8.45E-14	2.48E-15	8.70E-14
Mo-93	2.005E-11	0.00E+00	1.41E-16	1.41E-16
Totals	**7.80E+00**	**2.14E-04**	**2.00E-05**	**2.34E-04**

Table E-6
Equivalent Skin Dose Rate – Filter Press Feed Tank Uniform Spill

Radionuclides	Uniform Spill (Bq)	Electron (mGy/h)	Photon (mGy/h)	Total (mGy/h)
H-3	1.37E+03	0.00E+00	0.00E+00	0.00E+00
Co-60	1.88E+02	2.05E-04	4.90E-05	2.54E-04
Sr-90D	1.82E+00	1.75E-05	0.00E+00	1.75E-05
Tc-99	5.57E-02	6.61E-08	0.00E+00	6.61E-08
C-14	3.03E-02	3.55E-09	0.00E+00	3.55E-09
Cs-137D	9.10E-03	3.11E-08	7.64E-10	3.18E-08
Ni-63	7.86E-03	0.00E+00	0.00E+00	0.00E+00
Pu-241	4.53E-03	0.00E+00	0.00E+00	0.00E+00
Zr-93D	2.52E-03	0.00E+00	0.00E+00	0.00E+00
U-234	1.30E-03	1.56E-14	1.37E-11	1.37E-11
U-238	1.27E-03	2.48E-13	9.80E-12	1.00E-11
Th-234	1.27E-03	2.08E-10	1.39E-11	2.22E-10
Pa-234m	1.27E-03	8.02E-09	0.00E+00	8.02E-09
I-129	8.90E-04	1.17E-10	3.09E-11	1.48E-10
Nb-94	8.60E-04	2.19E-09	1.82E-10	2.37E-09
Cl-36	5.77E-04	2.32E-09	0.00E+00	2.32E-09
Pu-239	2.52E-04	0.00E+00	1.39E-12	1.39E-12
Am-241	1.61E-04	5.76E-14	8.37E-12	8.43E-12
U-235	5.51E-05	5.71E-13	3.97E-12	4.54E-12
Th-231	5.51E-05	3.97E-11	5.19E-12	4.49E-11
Th-232D	5.50E-05	7.20E-10	1.81E-11	7.38E-10
Ra-226D	3.67E-05	5.46E-10	8.69E-12	5.55E-10
Ni-59	3.04E-05	0.00E+00	2.39E-12	2.39E-12
Th-230	1.26E-05	2.90E-16	1.07E-13	1.08E-13
Ag-108mD	1.03E-05	6.11E-12	2.91E-12	9.02E-12

U-233	4.84E-06	0.00E+00	2.66E-14	2.66E-14
Se-79	1.38E-06	1.90E-13	0.00E+00	1.90E-13
Sn-126D	4.13E-07	2.85E-12	1.33E-13	2.98E-12
Cs-135	4.01E-07	3.70E-13	0.00E+00	3.70E-13
Pu-242	1.89E-07	1.09E-17	1.65E-15	1.66E-15
Am-243	9.75E-08	5.20E-17	3.13E-15	3.18E-15
Np-239	9.75E-08	2.67E-13	1.06E-14	2.78E-13
Np-237	3.61E-08	2.39E-16	2.66E-15	2.90E-15
Pa-233	3.61E-08	8.69E-14	3.62E-15	9.05E-14
Mo-93	4.01E-09	0.00E+00	2.32E-16	2.32E-16
Totals	**1.56E+03**	**2.23E-04**	**4.90E-05**	**2.72E-04**

E.7 Conclusion

The total equivalent skin dose rate is less than 2.0E-05 mSv/h for the chemical precipitation tanks and 3.0E-04 mSv/h for the Filter Press Feed tanks. Any exposure due to skin contamination at these levels would be negligible when compared to the regulatory equivalent dose limit of 500 mSv [E-2]. To receive a 500 mSv equivalent skin dose, the contamination would need to be present on the skin for approximately 190 years.

E.8 References

[E-1] WWTP Process Design Report, B1551-508233-DRP-001, Revision 1, 2019 January.

[E-2] *Radiation Protection Regulations*, SOR-2000-203.

[E-3] International Commission on Radiological Protection (ICRP), *Annals of the ICRP*, ICRP Publication 103, Volume 37 Nos. 2-4, 2007.

[E-4] *Computer Program Release VARSKIN 6.2.1*, Revision 0, 120-118878-SRC-001, ATOM Id: 49731155, 2019 May.

[E-5] *Technical Calculation Dose Calculations for Skin Contamination for NSDF WWTP*, 232-508770-290-002, Revision 0, 2019. https://ytom.corp.cnl.ca/OTCS/llisapi.dll/link/49843503

[E-6] AECOM, *WWTP Material and Energy Balance Report,* B1551-503212-REPT-001, Revision 2, 2018 November.

E.9 Varskin Outputs

E.9.1 Varskin Chemical Precipitation Droplet Output

Varskin 6.2

Date: 21/05/2019 Combined Cases Results from Individual Sources
Cylinder Source Geometry

Source Diameter: 1.13E+00 cm
Source Thickness: 5.00E-01 mm
Source Density: 1.00E+00 g/cm^3
Irradiation Time: 6.00E+01 min
Irradiation Area: 1.00E+00 cm^2
Skin Density thickness: 7.00E+00 mg/cm^2
Air Gap Thickness: 0.00E+00 mm

RESULTS FROM INDIVIDUAL SOURCES

Nuclide: H-3 [7.42] 107
Half-Life: 107997 h
Average Electron Energy: 0.005684414 MeV
X-90 Distance: 0.0002344302 cm
Source Strength: 7.00E+00 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Co-60 [7.42] 107
Half-Life: 46208.2 h
Average Electron Energy: 0.09719985 MeV
X-90 Distance: 0.0335102 cm
Source Strength: 6.50E-02 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.39E-05 mGy/h	1.39E-05 mGy	1.39E-05 mGy
Photon	1.38E-06 mGy/h	1.38E-06 mGy	1.38E-06 mGy
Total	1.52E-05 mGy/h	1.52E-05 mGy	1.52E-05 mGy

Nuclide: Sr-90 [7.42] 107D

Half-Life: 252373 h
Average Electron Energy: 0.565269 MeV
X-90 Distance: 0.511423 cm
Source Strength: 4.80E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	7.41E-07 mGy/h	7.41E-07 mGy	7.41E-07 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	7.41E-07 mGy/h	7.41E-07 mGy	7.41E-07 mGy

Nuclide: Tc-99 [7.42] 107
Half-Life: 1850503000 h
Average Electron Energy: 0.101315 MeV
X-90 Distance: 0.03149679 cm
Source Strength: 2.85E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	6.63E-08 mGy/h	6.63E-08 mGy	6.63E-08 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	6.63E-08 mGy/h	6.63E-08 mGy	6.63E-08 mGy

Nuclide: C-14 [7.42] 107
Half-Life: 49966200 h
Average Electron Energy: 0.0494944 MeV
X-90 Distance: 0.01017324 cm
Source Strength: 1.55E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.61E-09 mGy/h	3.61E-09 mGy	3.61E-09 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.61E-09 mGy/h	3.61E-09 mGy	3.61E-09 mGy

Nuclide: Cs-137 [7.42] 107D
Half-Life: 264445 h
Average Electron Energy: 0.250268 MeV
X-90 Distance: 0.155388 cm
Source Strength: 4.65E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.92E-08 mGy/h	2.92E-08 mGy	2.92E-08 mGy
Photon	4.23E-10 mGy/h	4.23E-10 mGy	4.23E-10 mGy
Total	2.96E-08 mGy/h	2.96E-08 mGy	2.96E-08 mGy

Nuclide: I-129 [7.42] 107
Half-Life: 137626200000 h
Average Electron Energy: 0.06511037 MeV
X-90 Distance: 0.009658382 cm
Source Strength: 4.55E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.19E-10 mGy/h	1.19E-10 mGy	1.19E-10 mGy
Photon	2.22E-11 mGy/h	2.22E-11 mGy	2.22E-11 mGy
Total	1.41E-10 mGy/h	1.41E-10 mGy	1.41E-10 mGy

Nuclide: Pu-241 [7.42] 107
Half-Life: 125792 h
Average Electron Energy: 0.005242451 MeV
X-90 Distance: 0.0002593447 cm
Source Strength: 3.95E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Cl-36 [7.42] 107
Half-Life: 2638566000 h
Average Electron Energy: 0.278584 MeV
X-90 Distance: 0.122898 cm
Source Strength: 2.95E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.18E-09 mGy/h	2.18E-09 mGy	2.18E-09 mGy

Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	2.18E-09 mGy/h	2.18E-09 mGy	2.18E-09 mGy

Nuclide: Zr-93 [7.42] 107D
Half-Life: 13411980000 h
Average Electron Energy: 0.04814517 MeV
X-90 Distance: 0.001500853 cm
Source Strength: 2.20E-06 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	2.50E-12 mGy/h	2.50E-12 mGy	2.50E-12 mGy
Total	2.50E-12 mGy/h	2.50E-12 mGy	2.50E-12 mGy

Nuclide: Ni-63 [7.42] 107
Half-Life: 877477 h
Average Electron Energy: 0.01744128 MeV
X-90 Distance: 0.002131002 cm
Source Strength: 2.20E-06 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Nb-94 [7.42] 107
Half-Life: 177949800 h
Average Electron Energy: 0.168528 MeV
X-90 Distance: 0.06621521 cm
Source Strength: 7.50E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	3.65E-10 mGy/h	3.65E-10 mGy	3.65E-10 mGy
Photon	1.61E-11 mGy/h	1.61E-11 mGy	1.61E-11 mGy
Total	3.81E-10 mGy/h	3.81E-10 mGy	3.81E-10 mGy

Nuclide: U-234 [7.42] 107
Half-Life: 2152053000 h
Average Electron Energy: 0.01365477 MeV
X-90 Distance: 0.002455455 cm
Source Strength: 3.90E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	9.39E-16 mGy/h	9.39E-16 mGy	9.39E-16 mGy
Photon	5.96E-13 mGy/h	5.96E-13 mGy	5.96E-13 mGy
Total	5.97E-13 mGy/h	5.97E-13 mGy	5.97E-13 mGy

Nuclide: Th-230 [7.42] 107
Half-Life: 660781100 h
Average Electron Energy: 0.01459933 MeV
X-90 Distance: 0.00433568 cm
Source Strength: 3.90E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	1.79E-15 mGy/h	1.79E-15 mGy	1.79E-15 mGy
Photon	4.80E-13 mGy/h	4.80E-13 mGy	4.80E-13 mGy
Total	4.81E-13 mGy/h	4.81E-13 mGy	4.81E-13 mGy

Nuclide: U-238 [7.42] 107
Half-Life: 39166490000000 h
Average Electron Energy: 1.39899 MeV
X-90 Distance: 0.00296 cm
Source Strength: 3.80E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	1.48E-14 mGy/h	1.48E-14 mGy	1.48E-14 mGy
Photon	4.25E-13 mGy/h	4.25E-13 mGy	4.25E-13 mGy
Total	4.40E-13 mGy/h	4.40E-13 mGy	4.40E-13 mGy

Nuclide: Th-234 [7.42] 107
Half-Life: 578.4 h
Average Electron Energy: 0.06228527 MeV
X-90 Distance: 0.01096058 cm
Source Strength: 3.80E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.24E-11 mGy/h	1.24E-11 mGy	1.24E-11 mGy
Photon	6.04E-13 mGy/h	6.04E-13 mGy	6.03E-13 mGy
Total	1.30E-11 mGy/h	1.30E-11 mGy	1.30E-11 mGy

Nuclide: Pa-234m [7.42] 107
Half-Life: 0.0195 h
Average Electron Energy: 0.818873 MeV
X-90 Distance: 0.485459 cm
Source Strength: 3.80E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.72E-10 mGy/h	3.72E-10 mGy	1.06E-11 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.72E-10 mGy/h	3.72E-10 mGy	1.06E-11 mGy

Nuclide: Pu-239 [7.42] 107
Half-Life: 211348300 h
Average Electron Energy: 0.007454835 MeV
X-90 Distance: 0.001784425 cm
Source Strength: 2.20E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.94E-13 mGy/h	1.94E-13 mGy	1.94E-13 mGy
Total	1.94E-13 mGy/h	1.94E-13 mGy	1.94E-13 mGy

Nuclide: Am-241 [7.42] 107
Half-Life: 3788665 h
Average Electron Energy: 0.03730429 MeV
X-90 Distance: 0.002694058 cm
Source Strength: 1.40E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.00E-14 mGy/h	1.00E-14 mGy	1.00E-14 mGy

Photon	1.02E-12 mGy/h	1.02E-12 mGy	1.02E-12 mGy
Total	1.03E-12 mGy/h	1.03E-12 mGy	1.03E-12 mGy

Nuclide: Th-232 [7.42] 107D
Half-Life: 123162300000000 h
Average Electron Energy: 0.518376 MeV
X-90 Distance: 0.368003 cm
Source Strength: 4.80E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.07E-10 mGy/h	1.07E-10 mGy	1.07E-10 mGy
Photon	1.68E-12 mGy/h	1.68E-12 mGy	1.68E-12 mGy
Total	1.09E-10 mGy/h	1.09E-10 mGy	1.09E-10 mGy

Nuclide: Ra-226 [7.42] 107D
Half-Life: 14025600 h
Average Electron Energy: 0.461122 MeV
X-90 Distance: 0.359552 cm
Source Strength: 3.20E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	8.14E-11 mGy/h	8.14E-11 mGy	8.14E-11 mGy
Photon	7.92E-13 mGy/h	7.92E-13 mGy	7.92E-13 mGy
Total	8.22E-11 mGy/h	8.22E-11 mGy	8.22E-11 mGy

Nuclide: U-235 [7.42] 107
Half-Life: 6171264000000 h
Average Electron Energy: 0.05300679 MeV
X-90 Distance: 0.005031955 cm
Source Strength: 1.65E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.42E-14 mGy/h	3.42E-14 mGy	3.42E-14 mGy
Photon	1.47E-13 mGy/h	1.47E-13 mGy	1.47E-13 mGy
Total	1.81E-13 mGy/h	1.81E-13 mGy	1.81E-13 mGy

Nuclide: Th-231 [7.42] 107
Half-Life: 25.52 h
Average Electron Energy: 0.162286 MeV
X-90 Distance: 0.01889374 cm
Source Strength: 1.65E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.34E-12 mGy/h	2.34E-12 mGy	2.31E-12 mGy
Photon	2.22E-13 mGy/h	2.22E-13 mGy	2.19E-13 mGy
Total	2.56E-12 mGy/h	2.56E-12 mGy	2.53E-12 mGy

Nuclide: Th-230 [7.42] 107
Half-Life: 660781100 h
Average Electron Energy: 0.01459933 MeV
X-90 Distance: 0.00433568 cm
Source Strength: 1.10E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.05E-17 mGy/h	5.05E-17 mGy	5.05E-17 mGy
Photon	1.35E-14 mGy/h	1.35E-14 mGy	1.35E-14 mGy
Total	1.36E-14 mGy/h	1.36E-14 mGy	1.36E-14 mGy

Nuclide: Ag-108m [7.42] 107D
Half-Life: 3664188 h
Average Electron Energy: 0.639056 MeV
X-90 Distance: 0.32104 cm
Source Strength: 9.00E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	8.90E-13 mGy/h	8.90E-13 mGy	8.90E-13 mGy
Photon	2.86E-13 mGy/h	2.86E-13 mGy	2.86E-13 mGy
Total	1.18E-12 mGy/h	1.18E-12 mGy	1.18E-12 mGy

Nuclide: Ni-59 [7.42] 107
Half-Life: 885366000 h
Average Electron Energy: 0.03143022 MeV
X-90 Distance: 8.351027E-05 cm
Source Strength: 8.50E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.23E-13 mGy/h	1.23E-13 mGy	1.23E-13 mGy
Total	1.23E-13 mGy/h	1.23E-13 mGy	1.23E-13 mGy

Nuclide: Cs-135 [7.42] 107
Half-Life: 20161800000 h
Average Electron Energy: 0.08944196 MeV
X-90 Distance: 0.02696226 cm
Source Strength: 2.05E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.72E-13 mGy/h	3.72E-13 mGy	3.72E-13 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.72E-13 mGy/h	3.72E-13 mGy	3.72E-13 mGy

Nuclide: U-233 [7.42] 107
Half-Life: 1395547000 h
Average Electron Energy: 0.005905398 MeV
X-90 Distance: 0.001556473 cm
Source Strength: 1.45E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.19E-15 mGy/h	1.19E-15 mGy	1.19E-15 mGy
Total	1.19E-15 mGy/h	1.19E-15 mGy	1.19E-15 mGy

Nuclide: Se-79 [7.42] 107
Half-Life: 2585970000 h
Average Electron Energy: 0.05295027 MeV
X-90 Distance: 0.01049647 cm
Source Strength: 1.20E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.29E-14 mGy/h	3.29E-14 mGy	3.29E-14 mGy

Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.29E-14 mGy/h	3.29E-14 mGy	3.29E-14 mGy

Nuclide: Sn-126 [7.42] 107D
Half-Life: 2016180000 h
Average Electron Energy: 0.444015 MeV
X-90 Distance: 0.381969 cm
Source Strength: 3.60E-10 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	4.14E-13 mGy/h	4.14E-13 mGy	4.14E-13 mGy
Photon	1.32E-14 mGy/h	1.32E-14 mGy	1.32E-14 mGy
Total	4.27E-13 mGy/h	4.27E-13 mGy	4.27E-13 mGy

Nuclide: Pu-242 [7.42] 107
Half-Life: 3287250000 h
Average Electron Energy: 1.30817 MeV
X-90 Distance: 0.00296 cm
Source Strength: 1.65E-10 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.90E-18 mGy/h	1.90E-18 mGy	1.90E-18 mGy
Photon	2.11E-16 mGy/h	2.11E-16 mGy	2.11E-16 mGy
Total	2.13E-16 mGy/h	2.13E-16 mGy	2.13E-16 mGy

Nuclide: Am-243 [7.42] 107
Half-Life: 64605420 h
Average Electron Energy: 0.02337713 MeV
X-90 Distance: 0.004233347 cm
Source Strength: 8.50E-11 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	9.04E-18 mGy/h	9.04E-18 mGy	9.04E-18 mGy
Photon	3.59E-16 mGy/h	3.59E-16 mGy	3.59E-16 mGy
Total	3.68E-16 mGy/h	3.68E-16 mGy	3.68E-16 mGy

Nuclide: Np-239 [7.42] 107
Half-Life: 56.556 h
Average Electron Energy: 0.262474 MeV
X-90 Distance: 0.03928849 cm
Source Strength: 8.50E-11 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	4.53E-14 mGy/h	4.53E-14 mGy	4.50E-14 mGy
Photon	1.23E-15 mGy/h	1.23E-15 mGy	1.23E-15 mGy
Total	4.65E-14 mGy/h	4.65E-14 mGy	4.63E-14 mGy

Nuclide: Np-237 [7.42] 107
Half-Life: 18794300000 h
Average Electron Energy: 0.06810127 MeV
X-90 Distance: 0.004462322 cm
Source Strength: 3.15E-11 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	4.16E-17 mGy/h	4.16E-17 mGy	4.16E-17 mGy
Photon	3.26E-16 mGy/h	3.26E-16 mGy	3.26E-16 mGy
Total	3.68E-16 mGy/h	3.68E-16 mGy	3.68E-16 mGy

Nuclide: Pa-233 [7.42] 107
Half-Life: 647.208 h
Average Electron Energy: 0.215216 MeV
X-90 Distance: 0.04212751 cm
Source Strength: 3.15E-11 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.47E-14 mGy/h	1.47E-14 mGy	1.47E-14 mGy
Photon	4.31E-16 mGy/h	4.31E-16 mGy	4.31E-16 mGy
Total	1.51E-14 mGy/h	1.51E-14 mGy	1.51E-14 mGy

Nuclide: Mo-93 [7.42] 107
Half-Life: 35064000 h
Average Electron Energy: 0.005557584 MeV
X-90 Distance: 0.0003718758 cm
Source Strength: 2.05E-11 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.44E-16 mGy/h	1.44E-16 mGy	1.44E-16 mGy
Total	1.44E-16 mGy/h	1.44E-16 mGy	1.44E-16 mGy

E.9.2 VARSKIN Chemical Precipitation Uniform Deposit Output

Varskin 6.2

Date: 21/05/2019 Combined Cases Results from Individual Sources

Cylinder Source Geometry

Source Diameter: 1.60E+01 cm
Source Thickness: 5.00E-01 mm
Source Density: 1.00E+00 g/cm^3
Irradiation Time: 6.00E+01 min
Irradiation Area: 1.00E+00 cm^2
Skin Density thickness: 7.00E+00 mg/cm^2
Air Gap Thickness: 0.00E+00 mm

RESULTS FROM INDIVIDUAL SOURCES

Nuclide: H-3 [7.42] 107
Half-Life: 107997 h
Average Electron Energy: 0.005684414 MeV
X-90 Distance: 0.0002344302 cm
Source Strength: 1.40E+03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Co-60 [7.42] 107
Half-Life: 46208.2 h
Average Electron Energy: 0.09719985 MeV
X-90 Distance: 0.0335102 cm
Source Strength: 1.30E+01 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose

Electron	1.42E-05 mGy/h	1.42E-05 mGy	1.42E-05 mGy
Photon	3.39E-06 mGy/h	3.39E-06 mGy	3.39E-06 mGy
Total	1.75E-05 mGy/h	1.75E-05 mGy	1.75E-05 mGy

Nuclide: Sr-90 [7.42] 107D
Half-Life: 252373 h
Average Electron Energy: 0.565269 MeV
X-90 Distance: 0.511423 cm
Source Strength: 9.60E-02 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	9.24E-07 mGy/h	9.24E-07 mGy	9.24E-07 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	9.24E-07 mGy/h	9.24E-07 mGy	9.24E-07 mGy

Nuclide: Tc-99 [7.42] 107
Half-Life: 1850503000 h
Average Electron Energy: 0.101315 MeV
X-90 Distance: 0.03149679 cm
Source Strength: 5.70E-02 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	6.77E-08 mGy/h	6.77E-08 mGy	6.77E-08 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	6.77E-08 mGy/h	6.77E-08 mGy	6.77E-08 mGy

Nuclide: C-14 [7.42] 107
Half-Life: 49966200 h
Average Electron Energy: 0.0494944 MeV
X-90 Distance: 0.01017324 cm
Source Strength: 3.10E-02 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	3.63E-09 mGy/h	3.63E-09 mGy	3.63E-09 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Total	3.63E-09 mGy/h	3.63E-09 mGy	3.63E-09 mGy

Nuclide: Cs-137 [7.42] 107D
Half-Life: 264445 h
Average Electron Energy: 0.250268 MeV
X-90 Distance: 0.155388 cm
Source Strength: 9.30E-03 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	3.17E-08 mGy/h	3.17E-08 mGy	3.17E-08 mGy
Photon	7.81E-10 mGy/h	7.81E-10 mGy	7.81E-10 mGy
Total	3.25E-08 mGy/h	3.25E-08 mGy	3.25E-08 mGy

Nuclide: I-129 [7.42] 107
Half-Life: 137626200000 h
Average Electron Energy: 0.06511037 MeV
X-90 Distance: 0.009658382 cm
Source Strength: 9.10E-04 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	1.19E-10 mGy/h	1.19E-10 mGy	1.19E-10 mGy
Photon	3.16E-11 mGy/h	3.16E-11 mGy	3.16E-11 mGy
Total	1.51E-10 mGy/h	1.51E-10 mGy	1.51E-10 mGy

Nuclide: Pu-241 [7.42] 107
Half-Life: 125792 h
Average Electron Energy: 0.005242451 MeV
X-90 Distance: 0.0002593447 cm
Source Strength: 7.90E-04 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Cl-36 [7.42] 107
Half-Life: 2638566000 h

Average Electron Energy: 0.278584 MeV
X-90 Distance: 0.122898 cm
Source Strength: 5.90E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.37E-09 mGy/h	2.37E-09 mGy	2.37E-09 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	2.37E-09 mGy/h	2.37E-09 mGy	2.37E-09 mGy

Nuclide: Zr-93 [7.42] 107D
Half-Life: 13411980000 h
Average Electron Energy: 0.04814517 MeV
X-90 Distance: 0.001500853 cm
Source Strength: 4.44E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	4.06E-12 mGy/h	4.06E-12 mGy	4.06E-12 mGy
Total	4.06E-12 mGy/h	4.06E-12 mGy	4.06E-12 mGy

Nuclide: Ni-63 [7.42] 107
Half-Life: 877477 h
Average Electron Energy: 0.01744128 MeV
X-90 Distance: 0.002131002 cm
Source Strength: 4.40E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Nb-94 [7.42] 107
Half-Life: 177949800 h
Average Electron Energy: 0.168528 MeV
X-90 Distance: 0.06621521 cm
Source Strength: 1.50E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.81E-10 mGy/h	3.81E-10 mGy	3.81E-10 mGy
Photon	3.17E-11 mGy/h	3.17E-11 mGy	3.17E-11 mGy
Total	4.13E-10 mGy/h	4.13E-10 mGy	4.13E-10 mGy

Nuclide: U-234 [7.42] 107
Half-Life: 2152053000 h
Average Electron Energy: 0.01365477 MeV
X-90 Distance: 0.002455455 cm
Source Strength: 7.80E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	9.36E-16 mGy/h	9.36E-16 mGy	9.36E-16 mGy
Photon	8.22E-13 mGy/h	8.22E-13 mGy	8.22E-13 mGy
Total	8.23E-13 mGy/h	8.23E-13 mGy	8.23E-13 mGy

Nuclide: Pu-239 [7.42] 107
Half-Life: 211348300 h
Average Electron Energy: 0.007454835 MeV
X-90 Distance: 0.001784425 cm
Source Strength: 4.40E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	2.43E-13 mGy/h	2.43E-13 mGy	2.43E-13 mGy
Total	2.43E-13 mGy/h	2.43E-13 mGy	2.43E-13 mGy

Nuclide: Am-241 [7.42] 107
Half-Life: 3788665 h
Average Electron Energy: 0.03730429 MeV
X-90 Distance: 0.002694058 cm
Source Strength: 2.80E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.00E-14 mGy/h	1.00E-14 mGy	1.00E-14 mGy

Photon	1.46E-12 mGy/h	1.46E-12 mGy	1.46E-12 mGy
Total	1.47E-12 mGy/h	1.47E-12 mGy	1.47E-12 mGy

Nuclide: Ra-226 [7.42] 107D
Half-Life: 14025600 h
Average Electron Energy: 0.461122 MeV
X-90 Distance: 0.359552 cm
Source Strength: 6.40E-06 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	9.52E-11 mGy/h	9.52E-11 mGy	9.52E-11 mGy
Photon	1.52E-12 mGy/h	1.52E-12 mGy	1.52E-12 mGy
Total	9.67E-11 mGy/h	9.67E-11 mGy	9.67E-11 mGy

Nuclide: U-235 [7.42] 107
Half-Life: 6171264000000 h
Average Electron Energy: 0.05300679 MeV
X-90 Distance: 0.005031955 cm
Source Strength: 3.30E-06 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	3.42E-14 mGy/h	3.42E-14 mGy	3.42E-14 mGy
Photon	2.38E-13 mGy/h	2.38E-13 mGy	2.38E-13 mGy
Total	2.72E-13 mGy/h	2.72E-13 mGy	2.72E-13 mGy

Nuclide: Th-231 [7.42] 107
Half-Life: 25.52 h
Average Electron Energy: 0.162286 MeV
X-90 Distance: 0.01889374 cm
Source Strength: 3.30E-06 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	2.38E-12 mGy/h	2.38E-12 mGy	2.35E-12 mGy
Photon	3.11E-13 mGy/h	3.11E-13 mGy	3.07E-13 mGy
Total	2.69E-12 mGy/h	2.69E-12 mGy	2.65E-12 mGy

Nuclide: Th-230 [7.42] 107
Half-Life: 660781100 h
Average Electron Energy: 0.01459933 MeV
X-90 Distance: 0.00433568 cm
Source Strength: 2.20E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.07E-17 mGy/h	5.07E-17 mGy	5.07E-17 mGy
Photon	1.87E-14 mGy/h	1.87E-14 mGy	1.87E-14 mGy
Total	1.88E-14 mGy/h	1.88E-14 mGy	1.88E-14 mGy

Nuclide: Ag-108m [7.42] 107D
Half-Life: 3664188 h
Average Electron Energy: 0.639056 MeV
X-90 Distance: 0.32104 cm
Source Strength: 1.80E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.07E-12 mGy/h	1.07E-12 mGy	1.07E-12 mGy
Photon	5.08E-13 mGy/h	5.08E-13 mGy	5.08E-13 mGy
Total	1.58E-12 mGy/h	1.58E-12 mGy	1.58E-12 mGy

Nuclide: Ni-59 [7.42] 107
Half-Life: 885366000 h
Average Electron Energy: 0.03143022 MeV
X-90 Distance: 8.351027E-05 cm
Source Strength: 1.70E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.34E-13 mGy/h	1.34E-13 mGy	1.34E-13 mGy
Total	1.34E-13 mGy/h	1.34E-13 mGy	1.34E-13 mGy

Nuclide: Cs-135 [7.42] 107
Half-Life: 20161800000 h
Average Electron Energy: 0.08944196 MeV
X-90 Distance: 0.02696226 cm
Source Strength: 4.10E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.79E-13 mGy/h	3.79E-13 mGy	3.79E-13 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.79E-13 mGy/h	3.79E-13 mGy	3.79E-13 mGy

Nuclide: U-233 [7.42] 107
Half-Life: 1395547000 h
Average Electron Energy: 0.005905398 MeV
X-90 Distance: 0.001556473 cm
Source Strength: 2.90E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.59E-15 mGy/h	1.59E-15 mGy	1.59E-15 mGy
Total	1.59E-15 mGy/h	1.59E-15 mGy	1.59E-15 mGy

Nuclide: Se-79 [7.42] 107
Half-Life: 2585970000 h
Average Electron Energy: 0.05295027 MeV
X-90 Distance: 0.01049647 cm
Source Strength: 2.40E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.30E-14 mGy/h	3.30E-14 mGy	3.30E-14 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.30E-14 mGy/h	3.30E-14 mGy	3.30E-14 mGy

Nuclide: Sn-126 [7.42] 107D
Half-Life: 2016180000 h
Average Electron Energy: 0.444015 MeV
X-90 Distance: 0.381969 cm
Source Strength: 7.20E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	4.97E-13 mGy/h	4.97E-13 mGy	4.97E-13 mGy

Photon	2.32E-14 mGy/h	2.32E-14 mGy	2.32E-14 mGy
Total	5.20E-13 mGy/h	5.20E-13 mGy	5.20E-13 mGy

Nuclide: Pu-242 [7.42] 107
Half-Life: 3287250000 h
Average Electron Energy: 1.30817 MeV
X-90 Distance: 0.00296 cm
Source Strength: 3.30E-08 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	1.90E-18 mGy/h	1.90E-18 mGy	1.90E-18 mGy
Photon	2.88E-16 mGy/h	2.88E-16 mGy	2.88E-16 mGy
Total	2.90E-16 mGy/h	2.90E-16 mGy	2.90E-16 mGy

Nuclide: Am-243 [7.42] 107
Half-Life: 64605420 h
Average Electron Energy: 0.02337713 MeV
X-90 Distance: 0.004233347 cm
Source Strength: 1.70E-08 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	9.07E-18 mGy/h	9.07E-18 mGy	9.07E-18 mGy
Photon	5.46E-16 mGy/h	5.46E-16 mGy	5.46E-16 mGy
Total	5.55E-16 mGy/h	5.55E-16 mGy	5.55E-16 mGy

Nuclide: Np-239 [7.42] 107
Half-Life: 56.556 h
Average Electron Energy: 0.262474 MeV
X-90 Distance: 0.03928849 cm
Source Strength: 1.70E-08 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	4.65E-14 mGy/h	4.65E-14 mGy	4.62E-14 mGy
Photon	1.85E-15 mGy/h	1.85E-15 mGy	1.84E-15 mGy
Total	4.83E-14 mGy/h	4.83E-14 mGy	4.80E-14 mGy

Nuclide: Np-237 [7.42] 107
Half-Life: 18794300000 h
Average Electron Energy: 0.06810127 MeV
X-90 Distance: 0.004462322 cm
Source Strength: 6.30E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	4.17E-17 mGy/h	4.17E-17 mGy	4.17E-17 mGy
Photon	4.65E-16 mGy/h	4.65E-16 mGy	4.65E-16 mGy
Total	5.06E-16 mGy/h	5.06E-16 mGy	5.06E-16 mGy

Nuclide: Pa-233 [7.42] 107
Half-Life: 647.208 h
Average Electron Energy: 0.215216 MeV
X-90 Distance: 0.04212751 cm
Source Strength: 6.30E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.52E-14 mGy/h	1.52E-14 mGy	1.51E-14 mGy
Photon	6.32E-16 mGy/h	6.32E-16 mGy	6.32E-16 mGy
Total	1.58E-14 mGy/h	1.58E-14 mGy	1.58E-14 mGy

Nuclide: Mo-93 [7.42] 107
Half-Life: 35064000 h
Average Electron Energy: 0.005557584 MeV
X-90 Distance: 0.0003718758 cm
Source Strength: 4.10E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	2.38E-16 mGy/h	2.38E-16 mGy	2.38E-16 mGy
Total	2.38E-16 mGy/h	2.38E-16 mGy	2.38E-16 mGy

Nuclide: U-238 [7.42] 107
Half-Life: 39166490000000 h
Average Electron Energy: 1.39899 MeV
X-90 Distance: 0.00296 cm
Source Strength: 7.60E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.48E-14 mGy/h	1.48E-14 mGy	1.48E-14 mGy
Photon	5.86E-13 mGy/h	5.86E-13 mGy	5.86E-13 mGy
Total	6.01E-13 mGy/h	6.01E-13 mGy	6.01E-13 mGy

Nuclide: Pa-234m [7.42] 107
Half-Life: 0.0195 h
Average Electron Energy: 0.818873 MeV
X-90 Distance: 0.485459 cm
Source Strength: 7.60E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	4.80E-10 mGy/h	4.80E-10 mGy	1.37E-11 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	4.80E-10 mGy/h	4.80E-10 mGy	1.37E-11 mGy

Nuclide: Th-234 [7.42] 107
Half-Life: 578.4 h
Average Electron Energy: 0.06228527 MeV
X-90 Distance: 0.01096058 cm
Source Strength: 7.60E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.25E-11 mGy/h	1.25E-11 mGy	1.25E-11 mGy
Photon	8.33E-13 mGy/h	8.33E-13 mGy	8.33E-13 mGy
Total	1.33E-11 mGy/h	1.33E-11 mGy	1.33E-11 mGy

Nuclide: Th-232 [7.42] 107D
Half-Life: 123162300000000 h
Average Electron Energy: 0.518376 MeV
X-90 Distance: 0.368003 cm
Source Strength: 9.60E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose

Electron	1.26E-10 mGy/h	1.26E-10 mGy	1.26E-10 mGy
Photon	3.17E-12 mGy/h	3.17E-12 mGy	3.17E-12 mGy
Total	1.29E-10 mGy/h	1.29E-10 mGy	1.29E-10 mGy

Nuclide: Th-230 [7.42] 107
Half-Life: 660781100 h
Average Electron Energy: 0.01459933 MeV
X-90 Distance: 0.00433568 cm
Source Strength: 7.80E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.80E-15 mGy/h	1.80E-15 mGy	1.80E-15 mGy
Photon	6.64E-13 mGy/h	6.64E-13 mGy	6.64E-13 mGy
Total	6.66E-13 mGy/h	6.66E-13 mGy	6.66E-13 mGy

E.9.3 VARSKIN Filter Press Feed Tank Uniform Spill Output

Varskin 6.2
Date: 22/05/2019 Time2:51:08 PM
Cylinder Source Geometry
Source Diameter: 1.60E+01 cm
Source Thickness: 5.00E-01 mm
Source Density: 1.00E+00 g/cm^3
Irradiation Time: 6.00E+01 min
Irradiation Area: 1.00E+00 cm^2
Skin Density thickness: 7.00E+00 mg/cm^2
Air Gap Thickness: 0.00E+00 mm

RESULTS FROM INDIVIDUAL SOURCES
Nuclide: H-3 [7.42] 107
Half-Life: 107997 h
Average Electron Energy: 0.005684414 MeV
X-90 Distance: 0.0002344302 cm
Source Strength: 1.37E+03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose

Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Co-60 [7.42] 107
Half-Life: 46208.2 h
Average Electron Energy: 0.09719985 MeV
X-90 Distance: 0.0335102 cm
Source Strength: 1.88E+02 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.05E-04 mGy/h	2.05E-04 mGy	2.05E-04 mGy
Photon	4.90E-05 mGy/h	4.90E-05 mGy	4.90E-05 mGy
Total	2.54E-04 mGy/h	2.54E-04 mGy	2.54E-04 mGy

Nuclide: Sr-90 [7.42] 107D
Half-Life: 252373 h
Average Electron Energy: 0.565269 MeV
X-90 Distance: 0.511423 cm
Source Strength: 1.82E+00 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.75E-05 mGy/h	1.75E-05 mGy	1.75E-05 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	1.75E-05 mGy/h	1.75E-05 mGy	1.75E-05 mGy

Nuclide: Tc-99 [7.42] 107
Half-Life: 1850503000 h
Average Electron Energy: 0.101315 MeV
X-90 Distance: 0.03149679 cm
Source Strength: 5.57E-02 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	6.61E-08 mGy/h	6.61E-08 mGy	6.61E-08 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Total	6.61E-08 mGy/h	6.61E-08 mGy	6.61E-08 mGy

Nuclide: C-14 [7.42] 107
Half-Life: 49966200 h
Average Electron Energy: 0.0494944 MeV
X-90 Distance: 0.01017324 cm
Source Strength: 3.03E-02 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	3.55E-09 mGy/h	3.55E-09 mGy	3.55E-09 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.55E-09 mGy/h	3.55E-09 mGy	3.55E-09 mGy

Nuclide: Cs-137 [7.42] 107D
Half-Life: 264445 h
Average Electron Energy: 0.250268 MeV
X-90 Distance: 0.155388 cm
Source Strength: 9.10E-03 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	3.11E-08 mGy/h	3.11E-08 mGy	3.11E-08 mGy
Photon	7.64E-10 mGy/h	7.64E-10 mGy	7.64E-10 mGy
Total	3.18E-08 mGy/h	3.18E-08 mGy	3.18E-08 mGy

Nuclide: Ni-63 [7.42] 107
Half-Life: 877477 h
Average Electron Energy: 0.01744128 MeV
X-90 Distance: 0.002131002 cm
Source Strength: 7.86E-03 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Pu-241 [7.42] 107
Half-Life: 125792 h

Average Electron Energy: 0.005242451 MeV
X-90 Distance: 0.0002593447 cm
Source Strength: 4.53E-03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Zr-93 [7.42] 107D
Half-Life: 13411980000 h
Average Electron Energy: 0.04814517 MeV
X-90 Distance: 0.001500853 cm
Source Strength: 2.52E-03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	2.31E-11 mGy/h	2.31E-11 mGy	2.31E-11 mGy
Total	2.31E-11 mGy/h	2.31E-11 mGy	2.31E-11 mGy

Nuclide: U-234 [7.42] 107
Half-Life: 2152053000 h
Average Electron Energy: 0.01365477 MeV
X-90 Distance: 0.002455455 cm
Source Strength: 1.30E-03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.56E-14 mGy/h	1.56E-14 mGy	1.56E-14 mGy
Photon	1.37E-11 mGy/h	1.37E-11 mGy	1.37E-11 mGy
Total	1.37E-11 mGy/h	1.37E-11 mGy	1.37E-11 mGy

Nuclide: U-238 [7.42] 107
Half-Life: 39166490000000 h
Average Electron Energy: 1.39899 MeV
X-90 Distance: 0.00296 cm
Source Strength: 1.27E-03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.48E-13 mGy/h	2.48E-13 mGy	2.48E-13 mGy
Photon	9.80E-12 mGy/h	9.80E-12 mGy	9.80E-12 mGy
Total	1.00E-11 mGy/h	1.00E-11 mGy	1.00E-11 mGy

Nuclide: Th-234 [7.42] 107
Half-Life: 578.4 h
Average Electron Energy: 0.06228527 MeV
X-90 Distance: 0.01096058 cm
Source Strength: 1.27E-03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.08E-10 mGy/h	2.08E-10 mGy	2.08E-10 mGy
Photon	1.39E-11 mGy/h	1.39E-11 mGy	1.39E-11 mGy
Total	2.22E-10 mGy/h	2.22E-10 mGy	2.22E-10 mGy

Nuclide: Pa-234m [7.42] 107
Half-Life: 0.0195 h
Average Electron Energy: 0.818873 MeV
X-90 Distance: 0.485459 cm
Source Strength: 1.27E-03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	8.02E-09 mGy/h	8.02E-09 mGy	2.29E-10 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	8.02E-09 mGy/h	8.02E-09 mGy	2.29E-10 mGy

Nuclide: I-129 [7.42] 107
Half-Life: 137626200000 h
Average Electron Energy: 0.06511037 MeV
X-90 Distance: 0.009658382 cm
Source Strength: 8.90E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.17E-10 mGy/h	1.17E-10 mGy	1.17E-10 mGy

Photon	3.09E-11 mGy/h	3.09E-11 mGy	3.09E-11 mGy
Total	1.48E-10 mGy/h	1.48E-10 mGy	1.48E-10 mGy

Nuclide: Nb-94 [7.42] 107
Half-Life: 177949800 h
Average Electron Energy: 0.168528 MeV
X-90 Distance: 0.06621521 cm
Source Strength: 8.60E-04 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	2.19E-09 mGy/h	2.19E-09 mGy	2.19E-09 mGy
Photon	1.82E-10 mGy/h	1.82E-10 mGy	1.82E-10 mGy
Total	2.37E-09 mGy/h	2.37E-09 mGy	2.37E-09 mGy

Nuclide: Cl-36 [7.42] 107
Half-Life: 2638566000 h
Average Electron Energy: 0.278584 MeV
X-90 Distance: 0.122898 cm
Source Strength: 5.77E-04 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	2.32E-09 mGy/h	2.32E-09 mGy	2.32E-09 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	2.32E-09 mGy/h	2.32E-09 mGy	2.32E-09 mGy

Nuclide: Pu-239 [7.42] 107
Half-Life: 211348300 h
Average Electron Energy: 0.007454835 MeV
X-90 Distance: 0.001784425 cm
Source Strength: 2.52E-04 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.39E-12 mGy/h	1.39E-12 mGy	1.39E-12 mGy
Total	1.39E-12 mGy/h	1.39E-12 mGy	1.39E-12 mGy

Nuclide: Am-241 [7.42] 107
Half-Life: 3788665 h
Average Electron Energy: 0.03730429 MeV
X-90 Distance: 0.002694058 cm
Source Strength: 1.61E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.76E-14 mGy/h	5.76E-14 mGy	5.76E-14 mGy
Photon	8.37E-12 mGy/h	8.37E-12 mGy	8.37E-12 mGy
Total	8.43E-12 mGy/h	8.43E-12 mGy	8.43E-12 mGy

Nuclide: U-235 [7.42] 107
Half-Life: 6171264000000 h
Average Electron Energy: 0.05300679 MeV
X-90 Distance: 0.005031955 cm
Source Strength: 5.51E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.71E-13 mGy/h	5.71E-13 mGy	5.71E-13 mGy
Photon	3.97E-12 mGy/h	3.97E-12 mGy	3.97E-12 mGy
Total	4.54E-12 mGy/h	4.54E-12 mGy	4.54E-12 mGy

Nuclide: Th-231 [7.42] 107
Half-Life: 25.52 h
Average Electron Energy: 0.162286 MeV
X-90 Distance: 0.01889374 cm
Source Strength: 5.51E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.97E-11 mGy/h	3.97E-11 mGy	3.92E-11 mGy
Photon	5.19E-12 mGy/h	5.19E-12 mGy	5.12E-12 mGy
Total	4.49E-11 mGy/h	4.49E-11 mGy	4.43E-11 mGy

Nuclide: Th-232 [7.42] 107D
Half-Life: 123162300000000 h
Average Electron Energy: 0.518376 MeV
X-90 Distance: 0.368003 cm
Source Strength: 5.50E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	7.20E-10 mGy/h	7.20E-10 mGy	7.20E-10 mGy
Photon	1.81E-11 mGy/h	1.81E-11 mGy	1.81E-11 mGy
Total	7.38E-10 mGy/h	7.38E-10 mGy	7.38E-10 mGy

Nuclide: Ra-226 [7.42] 107D
Half-Life: 14025600 h
Average Electron Energy: 0.461122 MeV
X-90 Distance: 0.359552 cm
Source Strength: 3.67E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.46E-10 mGy/h	5.46E-10 mGy	5.46E-10 mGy
Photon	8.69E-12 mGy/h	8.69E-12 mGy	8.69E-12 mGy
Total	5.55E-10 mGy/h	5.55E-10 mGy	5.55E-10 mGy

Nuclide: Ni-59 [7.42] 107
Half-Life: 885366000 h
Average Electron Energy: 0.03143022 MeV
X-90 Distance: 8.351027E-05 cm
Source Strength: 3.04E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	2.39E-12 mGy/h	2.39E-12 mGy	2.39E-12 mGy
Total	2.39E-12 mGy/h	2.39E-12 mGy	2.39E-12 mGy

Nuclide: Th-230 [7.42] 107
Half-Life: 660781100 h
Average Electron Energy: 0.01459933 MeV
X-90 Distance: 0.00433568 cm
Source Strength: 1.26E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.90E-16 mGy/h	2.90E-16 mGy	2.90E-16 mGy

Photon	1.07E-13 mGy/h	1.07E-13 mGy	1.07E-13 mGy
Total	1.08E-13 mGy/h	1.08E-13 mGy	1.08E-13 mGy

Nuclide: Ag-108m [7.42] 107D
Half-Life: 3664188 h
Average Electron Energy: 0.639056 MeV
X-90 Distance: 0.32104 cm
Source Strength: 1.03E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	6.11E-12 mGy/h	6.11E-12 mGy	6.11E-12 mGy
Photon	2.91E-12 mGy/h	2.91E-12 mGy	2.91E-12 mGy
Total	9.02E-12 mGy/h	9.02E-12 mGy	9.02E-12 mGy

Nuclide: U-233 [7.42] 107
Half-Life: 1395547000 h
Average Electron Energy: 0.005905398 MeV
X-90 Distance: 0.001556473 cm
Source Strength: 4.84E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	2.66E-14 mGy/h	2.66E-14 mGy	2.66E-14 mGy
Total	2.66E-14 mGy/h	2.66E-14 mGy	2.66E-14 mGy

Nuclide: Se-79 [7.42] 107
Half-Life: 2585970000 h
Average Electron Energy: 0.05295027 MeV
X-90 Distance: 0.01049647 cm
Source Strength: 1.38E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.90E-13 mGy/h	1.90E-13 mGy	1.90E-13 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	1.90E-13 mGy/h	1.90E-13 mGy	1.90E-13 mGy

Nuclide: Sn-126 [7.42] 107D
Half-Life: 2016180000 h
Average Electron Energy: 0.444015 MeV
X-90 Distance: 0.381969 cm
Source Strength: 4.13E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	2.85E-12 mGy/h	2.85E-12 mGy	2.85E-12 mGy
Photon	1.33E-13 mGy/h	1.33E-13 mGy	1.33E-13 mGy
Total	2.98E-12 mGy/h	2.98E-12 mGy	2.98E-12 mGy

Nuclide: Cs-135 [7.42] 107
Half-Life: 20161800000 h
Average Electron Energy: 0.08944196 MeV
X-90 Distance: 0.02696226 cm
Source Strength: 4.01E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	3.70E-13 mGy/h	3.70E-13 mGy	3.70E-13 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.70E-13 mGy/h	3.70E-13 mGy	3.70E-13 mGy

Nuclide: Pu-242 [7.42] 107
Half-Life: 3287250000 h
Average Electron Energy: 1.30817 MeV
X-90 Distance: 0.00296 cm
Source Strength: 1.89E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	1.09E-17 mGy/h	1.09E-17 mGy	1.09E-17 mGy
Photon	1.65E-15 mGy/h	1.65E-15 mGy	1.65E-15 mGy
Total	1.66E-15 mGy/h	1.66E-15 mGy	1.66E-15 mGy

Nuclide: Am-243 [7.42] 107
Half-Life: 64605420 h
Average Electron Energy: 0.02337713 MeV
X-90 Distance: 0.004233347 cm
Source Strength: 9.75E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.20E-17 mGy/h	5.20E-17 mGy	5.20E-17 mGy
Photon	3.13E-15 mGy/h	3.13E-15 mGy	3.13E-15 mGy
Total	3.18E-15 mGy/h	3.18E-15 mGy	3.18E-15 mGy

Nuclide: Np-239 [7.42] 107
Half-Life: 56.556 h
Average Electron Energy: 0.262474 MeV
X-90 Distance: 0.03928849 cm
Source Strength: 9.75E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.67E-13 mGy/h	2.67E-13 mGy	2.65E-13 mGy
Photon	1.06E-14 mGy/h	1.06E-14 mGy	1.05E-14 mGy
Total	2.77E-13 mGy/h	2.77E-13 mGy	2.76E-13 mGy

Nuclide: Np-237 [7.42] 107
Half-Life: 18794300000 h
Average Electron Energy: 0.06810127 MeV
X-90 Distance: 0.004462322 cm
Source Strength: 3.61E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.39E-16 mGy/h	2.39E-16 mGy	2.39E-16 mGy
Photon	2.66E-15 mGy/h	2.66E-15 mGy	2.66E-15 mGy
Total	2.90E-15 mGy/h	2.90E-15 mGy	2.90E-15 mGy

Nuclide: Pa-233 [7.42] 107
Half-Life: 647.208 h
Average Electron Energy: 0.215216 MeV
X-90 Distance: 0.04212751 cm
Source Strength: 3.61E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	8.69E-14 mGy/h	8.69E-14 mGy	8.68E-14 mGy

Photon	3.62E-15 mGy/h	3.62E-15 mGy	3.62E-15 mGy
Total	9.05E-14 mGy/h	9.05E-14 mGy	9.04E-14 mGy

Nuclide: Mo-93 [7.42] 107
Half-Life: 35064000 h
Average Electron Energy: 0.005557584 MeV
X-90 Distance: 0.0003718758 cm
Source Strength: 4.01E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	2.32E-16 mGy/h	2.32E-16 mGy	2.32E-16 mGy
Total	2.32E-16 mGy/h	2.32E-16 mGy	2.32E-16 mGy

E.9.4 VARSKIN Filter Press Feed Tank Droplet Output

Varskin 6.2
Date22/05/2019 Time3:29:49 PM
Cylinder Source Geometry
Source Diameter: 1.13E+00 cm
Source Thickness: 5.00E-01 mm
Source Density: 1.00E+00 g/cm^3
Irradiation Time: 6.00E+01 min
Irradiation Area: 1.00E+00 cm^2
Skin Density thickness: 7.00E+00 mg/cm^2
Air Gap Thickness: 0.00E+00 mm

RESULTS FROM INDIVIDUAL SOURCES
Nuclide: H-3 [7.42] 107
Half-Life: 107997 h
Average Electron Energy: 0.005684414 MeV
X-90 Distance: 0.0002344302 cm
Source Strength: 6.85E+00 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Co-60 [7.42] 107
Half-Life: 46208.2 h
Average Electron Energy: 0.09719985 MeV
X-90 Distance: 0.0335102 cm
Source Strength: 9.40E-01 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.00E-04 mGy/h	2.00E-04 mGy	2.00E-04 mGy
Photon	2.00E-05 mGy/h	2.00E-05 mGy	2.00E-05 mGy
Total	2.20E-04 mGy/h	2.20E-04 mGy	2.20E-04 mGy

Nuclide: Sr-90 [7.42] 107D
Half-Life: 252373 h
Average Electron Energy: 0.565269 MeV
X-90 Distance: 0.511423 cm
Source Strength: 9.10E-03 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.41E-05 mGy/h	1.41E-05 mGy	1.41E-05 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	1.41E-05 mGy/h	1.41E-05 mGy	1.41E-05 mGy

Nuclide: Tc-99 [7.42] 107
Half-Life: 1850503000 h
Average Electron Energy: 0.101315 MeV
X-90 Distance: 0.03149679 cm
Source Strength: 2.79E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	6.49E-08 mGy/h	6.49E-08 mGy	6.49E-08 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	6.49E-08 mGy/h	6.49E-08 mGy	6.49E-08 mGy

Nuclide: C-14 [7.42] 107
Half-Life: 49966200 h

Average Electron Energy: 0.0494944 MeV
X-90 Distance: 0.01017324 cm
Source Strength: 1.52E-04 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.54E-09 mGy/h	3.54E-09 mGy	3.54E-09 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.54E-09 mGy/h	3.54E-09 mGy	3.54E-09 mGy

Nuclide: Cs-137 [7.42] 107D
Half-Life: 264445 h
Average Electron Energy: 0.250268 MeV
X-90 Distance: 0.155388 cm
Source Strength: 4.55E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.85E-08 mGy/h	2.85E-08 mGy	2.85E-08 mGy
Photon	4.14E-10 mGy/h	4.14E-10 mGy	4.14E-10 mGy
Total	2.90E-08 mGy/h	2.90E-08 mGy	2.90E-08 mGy

Nuclide: Ni-63 [7.42] 107
Half-Life: 877477 h
Average Electron Energy: 0.01744128 MeV
X-90 Distance: 0.002131002 cm
Source Strength: 3.93E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Pu-241 [7.42] 107
Half-Life: 125792 h
Average Electron Energy: 0.005242451 MeV
X-90 Distance: 0.0002593447 cm
Source Strength: 2.27E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy

Nuclide: Zr-93 [7.42] 107D
Half-Life: 13411980000 h
Average Electron Energy: 0.04814517 MeV
X-90 Distance: 0.001500853 cm
Source Strength: 1.26E-05 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.43E-11 mGy/h	1.43E-11 mGy	1.43E-11 mGy
Total	1.43E-11 mGy/h	1.43E-11 mGy	1.43E-11 mGy

Nuclide: U-234 [7.42] 107
Half-Life: 2152053000 h
Average Electron Energy: 0.01365477 MeV
X-90 Distance: 0.002455455 cm
Source Strength: 6.50E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.56E-14 mGy/h	1.56E-14 mGy	1.56E-14 mGy
Photon	9.93E-12 mGy/h	9.93E-12 mGy	9.93E-12 mGy
Total	9.94E-12 mGy/h	9.94E-12 mGy	9.94E-12 mGy

Nuclide: U-238 [7.42] 107
Half-Life: 39166490000000 h
Average Electron Energy: 1.39899 MeV
X-90 Distance: 0.00296 cm
Source Strength: 6.35E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.48E-13 mGy/h	2.48E-13 mGy	2.48E-13 mGy

Photon	7.10E-12 mGy/h	7.10E-12 mGy	7.10E-12 mGy
Total	7.35E-12 mGy/h	7.35E-12 mGy	7.35E-12 mGy

Nuclide: Th-234 [7.42] 107
Half-Life: 578.4 h
Average Electron Energy: 0.06228527 MeV
X-90 Distance: 0.01096058 cm
Source Strength: 6.35E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.07E-10 mGy/h	2.07E-10 mGy	2.07E-10 mGy
Photon	1.01E-11 mGy/h	1.01E-11 mGy	1.01E-11 mGy
Total	2.17E-10 mGy/h	2.17E-10 mGy	2.17E-10 mGy

Nuclide: Pa-234m [7.42] 107
Half-Life: 0.0195 h
Average Electron Energy: 0.818873 MeV
X-90 Distance: 0.485459 cm
Source Strength: 6.35E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	6.22E-09 mGy/h	6.22E-09 mGy	1.77E-10 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	6.22E-09 mGy/h	6.22E-09 mGy	1.77E-10 mGy

Nuclide: I-129 [7.42] 107
Half-Life: 137626200000 h
Average Electron Energy: 0.06511037 MeV
X-90 Distance: 0.009658382 cm
Source Strength: 4.45E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.16E-10 mGy/h	1.16E-10 mGy	1.16E-10 mGy
Photon	2.17E-11 mGy/h	2.17E-11 mGy	2.17E-11 mGy
Total	1.38E-10 mGy/h	1.38E-10 mGy	1.38E-10 mGy

Nuclide: Nb-94 [7.42] 107
Half-Life: 177949800 h
Average Electron Energy: 0.168528 MeV
X-90 Distance: 0.06621521 cm
Source Strength: 4.30E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.09E-09 mGy/h	2.09E-09 mGy	2.09E-09 mGy
Photon	9.24E-11 mGy/h	9.24E-11 mGy	9.24E-11 mGy
Total	2.19E-09 mGy/h	2.19E-09 mGy	2.19E-09 mGy

Nuclide: Cl-36 [7.42] 107
Half-Life: 2638566000 h
Average Electron Energy: 0.278584 MeV
X-90 Distance: 0.122898 cm
Source Strength: 2.89E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.14E-09 mGy/h	2.14E-09 mGy	2.14E-09 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	2.14E-09 mGy/h	2.14E-09 mGy	2.14E-09 mGy

Nuclide: Pu-239 [7.42] 107
Half-Life: 211348300 h
Average Electron Energy: 0.007454835 MeV
X-90 Distance: 0.001784425 cm
Source Strength: 1.26E-06 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.11E-12 mGy/h	1.11E-12 mGy	1.11E-12 mGy
Total	1.11E-12 mGy/h	1.11E-12 mGy	1.11E-12 mGy

Nuclide: Am-241 [7.42] 107
Half-Life: 3788665 h
Average Electron Energy: 0.03730429 MeV
X-90 Distance: 0.002694058 cm
Source Strength: 8.05E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.76E-14 mGy/h	5.76E-14 mGy	5.76E-14 mGy
Photon	5.89E-12 mGy/h	5.89E-12 mGy	5.89E-12 mGy
Total	5.95E-12 mGy/h	5.95E-12 mGy	5.95E-12 mGy

Nuclide: U-235 [7.42] 107
Half-Life: 6171264000000 h
Average Electron Energy: 0.05300679 MeV
X-90 Distance: 0.005031955 cm
Source Strength: 2.76E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.71E-13 mGy/h	5.71E-13 mGy	5.71E-13 mGy
Photon	2.46E-12 mGy/h	2.46E-12 mGy	2.46E-12 mGy
Total	3.03E-12 mGy/h	3.03E-12 mGy	3.03E-12 mGy

Nuclide: Th-231 [7.42] 107
Half-Life: 25.52 h
Average Electron Energy: 0.162286 MeV
X-90 Distance: 0.01889374 cm
Source Strength: 2.76E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.92E-11 mGy/h	3.92E-11 mGy	3.86E-11 mGy
Photon	3.72E-12 mGy/h	3.72E-12 mGy	3.67E-12 mGy
Total	4.29E-11 mGy/h	4.29E-11 mGy	4.23E-11 mGy

Nuclide: Th-232 [7.42] 107D
Half-Life: 123162300000000 h
Average Electron Energy: 0.518376 MeV
X-90 Distance: 0.368003 cm
Source Strength: 2.75E-07 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	6.14E-10 mGy/h	6.14E-10 mGy	6.14E-10 mGy

Photon	9.63E-12 mGy/h	9.63E-12 mGy	9.63E-12 mGy
Total	6.24E-10 mGy/h	6.24E-10 mGy	6.24E-10 mGy

Nuclide: Ra-226 [7.42] 107D
Half-Life: 14025600 h
Average Electron Energy: 0.461122 MeV
X-90 Distance: 0.359552 cm
Source Strength: 1.84E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	4.68E-10 mGy/h	4.68E-10 mGy	4.68E-10 mGy
Photon	4.55E-12 mGy/h	4.55E-12 mGy	4.55E-12 mGy
Total	4.73E-10 mGy/h	4.73E-10 mGy	4.73E-10 mGy

Nuclide: Ni-59 [7.42] 107
Half-Life: 885366000 h
Average Electron Energy: 0.03143022 MeV
X-90 Distance: 8.351027E-05 cm
Source Strength: 1.52E-07 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	2.20E-12 mGy/h	2.20E-12 mGy	2.20E-12 mGy
Total	2.20E-12 mGy/h	2.20E-12 mGy	2.20E-12 mGy

Nuclide: Th-230 [7.42] 107
Half-Life: 660781100 h
Average Electron Energy: 0.01459933 MeV
X-90 Distance: 0.00433568 cm
Source Strength: 6.30E-08 Bq

	Initial Dose Rate	**Dose (No Decay)**	**Decay-Corrected Dose**
Electron	2.89E-16 mGy/h	2.89E-16 mGy	2.89E-16 mGy
Photon	7.75E-14 mGy/h	7.75E-14 mGy	7.75E-14 mGy
Total	7.78E-14 mGy/h	7.78E-14 mGy	7.78E-14 mGy

Nuclide: Ag-108m [7.42] 107D
Half-Life: 3664188 h
Average Electron Energy: 0.639056 MeV
X-90 Distance: 0.32104 cm
Source Strength: 5.15E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.09E-12 mGy/h	5.09E-12 mGy	5.09E-12 mGy
Photon	1.63E-12 mGy/h	1.63E-12 mGy	1.63E-12 mGy
Total	6.73E-12 mGy/h	6.73E-12 mGy	6.73E-12 mGy

Nuclide: U-233 [7.42] 107
Half-Life: 1395547000 h
Average Electron Energy: 0.005905398 MeV
X-90 Distance: 0.001556473 cm
Source Strength: 2.42E-08 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.98E-14 mGy/h	1.98E-14 mGy	1.98E-14 mGy
Total	1.98E-14 mGy/h	1.98E-14 mGy	1.98E-14 mGy

Nuclide: Se-79 [7.42] 107
Half-Life: 2585970000 h
Average Electron Energy: 0.05295027 MeV
X-90 Distance: 0.01049647 cm
Source Strength: 6.90E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.89E-13 mGy/h	1.89E-13 mGy	1.89E-13 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	1.89E-13 mGy/h	1.89E-13 mGy	1.89E-13 mGy

Nuclide: Sn-126 [7.42] 107D
Half-Life: 2016180000 h
Average Electron Energy: 0.444015 MeV
X-90 Distance: 0.381969 cm
Source Strength: 2.07E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.38E-12 mGy/h	2.38E-12 mGy	2.38E-12 mGy
Photon	7.58E-14 mGy/h	7.58E-14 mGy	7.58E-14 mGy
Total	2.45E-12 mGy/h	2.45E-12 mGy	2.45E-12 mGy

Nuclide: Cs-135 [7.42] 107
Half-Life: 20161800000 h
Average Electron Energy: 0.08944196 MeV
X-90 Distance: 0.02696226 cm
Source Strength: 2.01E-09 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	3.65E-13 mGy/h	3.65E-13 mGy	3.65E-13 mGy
Photon	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Total	3.65E-13 mGy/h	3.65E-13 mGy	3.65E-13 mGy

Nuclide: Pu-242 [7.42] 107
Half-Life: 3287250000 h
Average Electron Energy: 1.30817 MeV
X-90 Distance: 0.00296 cm
Source Strength: 9.45E-10 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	1.09E-17 mGy/h	1.09E-17 mGy	1.09E-17 mGy
Photon	1.21E-15 mGy/h	1.21E-15 mGy	1.21E-15 mGy
Total	1.22E-15 mGy/h	1.22E-15 mGy	1.22E-15 mGy

Nuclide: Am-243 [7.42] 107
Half-Life: 64605420 h
Average Electron Energy: 0.02337713 MeV
X-90 Distance: 0.004233347 cm
Source Strength: 4.88E-10 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	5.19E-17 mGy/h	5.19E-17 mGy	5.19E-17 mGy

Photon	2.06E-15 mGy/h	2.06E-15 mGy	2.06E-15 mGy
Total	2.11E-15 mGy/h	2.11E-15 mGy	2.11E-15 mGy

Nuclide: Np-239 [7.42] 107
Half-Life: 56.556 h
Average Electron Energy: 0.262474 MeV
X-90 Distance: 0.03928849 cm
Source Strength: 4.88E-10 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.60E-13 mGy/h	2.60E-13 mGy	2.59E-13 mGy
Photon	7.08E-15 mGy/h	7.08E-15 mGy	7.04E-15 mGy
Total	2.67E-13 mGy/h	2.67E-13 mGy	2.66E-13 mGy

Nuclide: Np-237 [7.42] 107
Half-Life: 18794300000 h
Average Electron Energy: 0.06810127 MeV
X-90 Distance: 0.004462322 cm
Source Strength: 1.81E-10 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	2.39E-16 mGy/h	2.39E-16 mGy	2.39E-16 mGy
Photon	1.87E-15 mGy/h	1.87E-15 mGy	1.87E-15 mGy
Total	2.11E-15 mGy/h	2.11E-15 mGy	2.11E-15 mGy

Nuclide: Pa-233 [7.42] 107
Half-Life: 647.208 h
Average Electron Energy: 0.215216 MeV
X-90 Distance: 0.04212751 cm
Source Strength: 1.81E-10 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	8.45E-14 mGy/h	8.45E-14 mGy	8.44E-14 mGy
Photon	2.48E-15 mGy/h	2.48E-15 mGy	2.48E-15 mGy
Total	8.70E-14 mGy/h	8.70E-14 mGy	8.69E-14 mGy

Nuclide: Mo-93 [7.42] 107
Half-Life: 35064000 h
Average Electron Energy: 0.005557584 MeV
X-90 Distance: 0.0003718758 cm
Source Strength: 2.01E-11 Bq

	Initial Dose Rate	Dose (No Decay)	Decay-Corrected Dose
Electron	0.00E+00 mGy/h	0.00E+00 mGy	0.00E+00 mGy
Photon	1.41E-16 mGy/h	1.41E-16 mGy	1.41E-16 mGy
Total	1.41E-16 mGy/h	1.41E-16 mGy	1.41E-16 mGy

Appendix F

Calculation of Worker Exposure in the Vehicle Decontamination Facility

This analysis assesses the radiological consequence to a VDF worker from an exposure to a higher than the anticipated quantity of radioactive material entering the vehicle decontamination hall. The scenario assumes that a vehicle enters the VDF with a thick layer of bulk LLW surface contamination. During decontamination operations, the VDF worker is exposed to external gamma radiation from surface contamination, and inhales radionuclides that may be suspended in air from decontamination activities.

The direct radiation dose to the receptor, from contamination on the vehicle is analysed using MicroShield version 9.07 [F-1]. The inhalation dose is modelled using the instantaneous mixing with gradual removal model [F-2]. The immersion and ingestion dose from the suspended surface contamination is negligible compared to the associated inhalation dose and is excluded.

The surface contamination is conservatively modelled as an infinite slab of bulk LLW, 1 cm thick. The following inputs and assumptions are used for the radiation field calculation for residual contamination on the equipment:

- The source is modelled as an infinite slab 1 cm thick.
- The source term is modelled as bulk waste [F-3]. Y-90 is assumed to be in equilibrium with Sr-90 and Ba-137m in equilibrium with Cs-137.
- Dose point is 1 m from the source.
- Source term is modelled as soil with a density of 1.5 g/cm^3.
- Transition and air gap is modelled as air with a density of 0.00122 g/cm^3.
- Build-up occurs in the source.

The inhalation dose vehicle decontamination is estimated using the instantaneous mixing with gradual removal model as per [F-2]. The inhalation dose uses the following inputs and assumptions:

- The material at risk (MAR) is the volume of loose contamination conservatively assumed to be 0.5 m^3. The source term is modelled as bulk waste.
- The worker inhalations are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm AMAD (ICRP 119, Table A) [F-5]. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.
- Tritium and C-14 are considered to be HTO and CO_2, respectively (inhalation DCFs from ICRP 119 Table B for workers) [F-6].
- The damage ratio (DR) is conservatively assumed to be 1.
- The LPF is 1.
- The ARF is 0.8 for a shock effect to contaminated soil [F-4].

- The RF is 0.25 for a shock effect to contaminated soil [F-4].
- Worker breathing rate is 3.33E-04 m^3/s [F-2].
- A total of three air changes an hour occur in the room [F-6].
- The total volume of the VDF is 1 554.91 m^3 based on an area of 22.13 m^2 and ceiling height of 7 m [F-6].
- The exposure duration is one hour (3 600 seconds).
- Decay of radionuclides is excluded.
- PPE&C is excluded.
- Impact in reduction in airborne contamination by using wetting or dust suppression is excluded.

The respirable source term for each radionuclide is calculated using the following equation F-1 [F-2]:

$$Source\ Term_i\ (ST_i) = MAR_i * DR_i * LPF_i * ARF_i * RF_i \quad \text{(F1)}$$

Where:

MAR	- material at risk, the total activity in 0.5 m^3 of waste (Bq)
DR	- damage ratio, the fraction of MAR actually impacted by the accident, assumed to be 1
LPF	- leak path factor, assumed to be 1
ARF	- airborne release fraction, the fraction of radioactive material suspended in air as an aerosol, assumed to be 0.8.
RF	- respirable fraction, the fraction of airborne radionuclides inhaled, assumed to be 0.25

The committed effective dose is calculated using the instantaneous mixing with gradual removal using the following equation F2 [F-2]:

$$Committed\ Effective\ Dose = \sum_{All\ nuclides,i} \left[\frac{ST_i}{V} * \frac{\left[1 - e^{-\lambda_{eff} t}\right]}{\lambda_{eff}} \right] * BR * DCF_i \qquad \text{(F2)}$$

Where:

ST_i	Respirable Source term (Bq) for nuclide, i.
V	Volume of the room, m^3.
λ_{eff}	Effective removal constant of the radionuclide, s^{-1}.
BR	Breathing Rate, $m^3.s^{-1}$.
t	Residence time, s.
DCF_i	Dose conversion factor, $Sv.Bq^{-1}$for nuclide, i.

Where (equation F3):

$$\lambda_{eff} = \lambda + \frac{F}{V} \qquad \text{(F3)}$$

Note: The effective removal constant, λ_{eff}, is simplified in instances with negligible radioactive decay to just $\frac{F}{V}$.

$\boldsymbol{F}$, is the ventilation system flow rate, $\boldsymbol{m^3.h^{-1}}$, and $\boldsymbol{V}$ is the room volume, $\boldsymbol{m^3}$. If $\boldsymbol{N}$, the number of air changes per hour, is known, then $\boldsymbol{\frac{F}{V}}$ may be calculated using the equation F4:

$$N = \frac{F}{V} \qquad \text{(F4)}$$

Table F-1 shows the estimated inhalation dose to the worker for the decontamination activity. The MicroShield dose rate from the residuals bin is shown in Figure F-1. The dose rate from the contaminated vehicle is conservatively estimated as 1.02E-03 mSv/h. The inhalation dose from the decontamination activity is estimated in Table F-1 as 3.53E-02 mSv.

Therefore, assuming the VDF worker is exposed to the higher than anticipated levels of contamination for one hour, the radiological consequence to the VDF worker is 3.63E-02 mSv.

MicroShield 9.07
CNL (9.07-0000)

Date	By	Checked

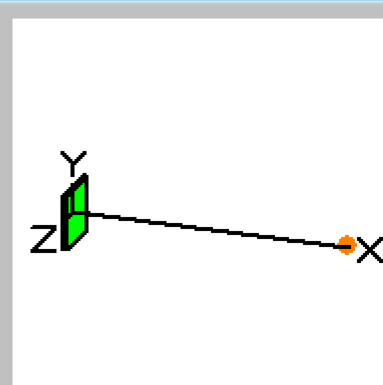
Filename	Run Date	Run Time	Duration
Infinite slab VDF.msd	June 3, 2019	2:28:02 PM	00:00:00

Project Info	
Case Title	VDF Contamination
Description	VDF Contamination
Geometry	16 - Infinite Slab

Source Dimensions	
Thickness	1.0 cm (0.4 in)

Dose Points			
A	X	Y	Z
#1	101.0 cm (3 ft 3.8 in)	0.0 cm (0 in)	0.0 cm (0 in)

Shields			
Shield N	Dimension	Material	Density
Source	Infinite	Soil	1.5
Air Gap		Air	0.00122



Source Input: Grouping Method - Standard Indices
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	μCi/cm³	Bq/cm³
Ag-108m	5.7027e-013	2.1100e-008
Am-241	3.8108e-007	1.4100e-002
Am-243	1.9405e-010	7.1800e-006
Ba-137m	1.9431e-005	7.1896e-001
C-14	6.2973e-006	2.3300e-001
Cl-36	1.7459e-008	6.4600e-004
Co-60	3.5946e-004	1.3300e+001
Cs-135	2.9189e-010	1.0800e-005
Cs-137	2.0541e-005	7.6000e-001
H-3	2.9730e-003	1.1000e+002
I-129	4.9189e-009	1.8200e-004
Mo-93	5.0811e-013	1.8800e-008
Nb-94	7.5946e-007	2.8100e-002
Ni-59	4.2432e-009	1.5700e-004
Ni-63	1.0757e-006	3.9800e-002
Np-237	6.4595e-011	2.3900e-006
Pu-239	3.1351e-007	1.1600e-002
Pu-241	6.1351e-006	2.2700e-001
Pu-242	2.3351e-010	8.6400e-006
Ra-226	5.8378e-009	2.1600e-004
Se-79	3.4595e-010	1.2800e-005
Sn-126	4.6216e-010	1.7100e-005
Sr-90	2.2405e-005	8.2900e-001
Tc-99	1.9541e-009	7.2300e-005
Th-230	2.4378e-008	9.0200e-004
Th-232	9.5676e-008	3.5400e-003
U-233	1.0027e-009	3.7100e-005
U-234	2.8378e-007	1.0500e-002
U-235	1.1892e-008	4.4000e-004
U-238	2.6000e-007	9.6200e-003
Y-90	2.2405e-005	8.2900e-001
Zr-93	4.2703e-006	1.5800e-001

Buildup: The material reference is Source
Integration Parameters

Results										
Energy (MeV)	**Activity (Photons/sec)**	**Fluence Rate MeV/cm²/sec No Buildup**	**Fluence Rate MeV/cm²/sec With Buildup**	**Exposure Rate mR/h No Buildup**	**Exposure Rate mR/h With Buildup**	**Absorbed Dose Rate mrad/h No Buildup**	**Absorbed Dose Rate mrad/h With Buildup**	**Absorbed Dose Rate mGy/h No Buildup**	**Absorbed Dose Rate mGy/h With Buildup**
0.015	1.657e-02	2.654e-06	2.693e-06	2.276e-07	2.310e-07	1.987e-07	2.016e-07	1.987e-09	2.016e-09
0.02	6.931e-06	4.194e-09	4.306e-09	1.453e-10	1.492e-10	1.268e-10	1.302e-10	1.268e-12	1.302e-12
0.03	4.283e-02	1.390e-04	1.553e-04	1.378e-06	1.539e-06	1.203e-06	1.344e-06	1.203e-08	1.344e-08
0.04	1.001e-02	9.307e-05	1.209e-04	4.116e-07	5.346e-07	3.593e-07	4.667e-07	3.593e-09	4.667e-09
0.05	1.241e-05	2.287e-07	3.302e-07	6.091e-10	8.797e-10	5.318e-10	7.679e-10	5.318e-12	7.679e-12
0.06	5.108e-03	1.498e-04	2.345e-04	2.975e-07	4.659e-07	2.598e-07	4.067e-07	2.598e-09	4.067e-09
0.08	2.645e-05	1.398e-06	2.492e-06	2.213e-09	3.943e-09	1.932e-09	3.443e-09	1.932e-11	3.443e-11
0.1	4.623e-05	3.533e-06	6.536e-06	5.405e-09	1.000e-08	4.718e-09	8.730e-09	4.718e-11	8.730e-11
0.15	7.001e-05	9.354e-06	1.973e-05	1.540e-08	3.249e-08	1.345e-08	2.837e-08	1.345e-10	2.837e-10
0.2	2.786e-04	5.315e-05	1.177e-04	9.381e-08	2.078e-07	8.189e-08	1.814e-07	8.189e-10	1.814e-09
0.3	1.441e-08	4.456e-09	9.513e-09	8.452e-12	1.804e-11	7.379e-12	1.575e-11	7.379e-14	1.575e-13
0.4	1.896e-08	8.232e-09	1.657e-08	1.604e-11	3.228e-11	1.400e-11	2.818e-11	1.400e-13	2.818e-13
0.6	6.491e-01	4.540e-01	8.230e-01	8.862e-04	1.606e-03	7.736e-04	1.402e-03	7.736e-06	1.402e-05
0.8	5.620e-02	5.517e-02	9.081e-02	1.049e-04	1.727e-04	9.162e-05	1.508e-04	9.162e-07	1.508e-06
1.0	1.330e+01	1.699e+01	2.635e+01	3.133e-02	4.857e-02	2.735e-02	4.241e-02	2.735e-04	4.241e-04
1.5	1.330e+01	2.744e+01	3.794e+01	4.617e-02	6.384e-02	4.030e-02	5.573e-02	4.030e-04	5.573e-04
Totals	**2.738e+01**	**4.494e+01**	**6.521e+01**	**7.849e-02**	**1.142e-01**	**6.852e-02**	**9.969e-02**	**6.852e-04**	**9.969e-04**

Effective Dose Equivalent Rate (ICRP 51 - 1987)			
Results (Summed over energies)	**Units**	**Without Buildup**	**With Buildup**
Anterior/Posterior Geometry	**mSv/h**	**7.015e-004**	**1.021e-003**

Figure F-1 Dose Rate from Surface Contamination in VDF

Table F-1
Inhalation Radiological Consequence From VDF Decontamination Activity

Radionuclide	Inhalation DCF (Sv/Bq)	Concentration in Bulk Waste (Bq/cm³)	MAR of 0.5 m³ (Bq)	Respirable Source term (Bq)	Inhalation Dose (mSv)
Ag-108m	1.90E-08	2.11E-08	1.06E-02	2.11E-03	9.79E-12
Am-241	2.70E-05	1.41E-02	7.05E+03	1.41E+03	9.30E-03
Am-243	2.70E-05	7.18E-06	3.59E+00	7.18E-01	4.73E-06
C-14	6.50E-12	2.33E-01	1.17E+05	2.33E+04	3.70E-08

Radionuclide	Inhalation DCF (Sv/Bq)	Concentration in Bulk Waste (Bq/cm³)	MAR of 0.5 m³ (Bq)	Respirable Source term (Bq)	Inhalation Dose (mSv)
Cl-36	5.10E-09	6.46E-04	3.23E+02	6.46E+01	8.05E-08
Co-60	1.70E-08	1.33E+01	6.65E+06	1.33E+06	5.52E-03
Cs-135	9.90E-10	1.08E-05	5.40E+00	1.08E+00	2.61E-10
Cs-137	6.70E-09	7.60E-01	3.80E+05	7.60E+04	1.24E-04
H-3	2.70E-11	1.10E+02	5.50E+07	1.10E+07	7.25E-05
I-129	5.10E-08	1.82E-04	9.10E+01	1.82E+01	2.27E-07
Mo-93	1.40E-09	1.88E-08	9.40E-03	1.88E-03	6.43E-13
Nb-94	2.50E-08	2.81E-02	1.41E+04	2.81E+03	1.72E-05
Ni-59	2.20E-10	1.57E-04	7.85E+01	1.57E+01	8.43E-10
Ni-63	5.20E-10	3.98E-02	1.99E+04	3.98E+03	5.05E-07
Np-237	1.50E-05	2.39E-06	1.20E+00	2.39E-01	8.75E-07
Pu-239	3.20E-05	1.16E-02	5.80E+03	1.16E+03	9.06E-03
Pu-241	5.80E-07	2.27E-01	1.14E+05	2.27E+04	3.22E-03
Pu-242	3.10E-05	8.64E-06	4.32E+00	8.64E-01	6.54E-06
Ra-226	2.20E-06	2.16E-04	1.08E+02	2.16E+01	1.16E-05
Se-79	3.10E-09	1.28E-05	6.40E+00	1.28E+00	9.69E-10
Sn-126	1.80E-08	1.71E-05	8.55E+00	1.71E+00	7.52E-09
Sr-90	7.70E-08	8.29E-01	4.15E+05	8.29E+04	1.56E-03
Tc-99	3.20E-09	7.23E-05	3.62E+01	7.23E+00	5.65E-09
Th-230	2.80E-05	9.02E-04	4.51E+02	9.02E+01	6.17E-04
Th-232	2.90E-05	3.54E-03	1.77E+03	3.54E+02	2.51E-03
U-233	6.90E-06	3.71E-05	1.86E+01	3.71E+00	6.25E-06
U-234	6.80E-06	1.05E-02	5.25E+03	1.05E+03	1.74E-03
U-235	6.10E-06	4.40E-04	2.20E+02	4.40E+01	6.55E-05
U-238	5.70E-06	9.62E-03	4.81E+03	9.62E+02	1.34E-03
Y-90	1.70E-09	8.29E-01	4.15E+05	8.29E+04	3.44E-05
Zr-93	2.90E-08	1.58E-01	7.90E+04	1.58E+04	1.12E-04
Total Dose (mSv)					**3.53E-02**

F.1 References

[F-1] Grove Software, *MicroShield User Manual*, 2012.

[F-2] *Dose Calculations Pertaining to Respirable Radiation Sources*, 900-505770-FID-008, Revision 0, 2018 December.

[F-3] *Waste Characterization*, 232-508600-REPT-002, Revision 4, 2020 February.

[F-4] *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, December 1994.

[F-5] ICRP, *Compendium of Dose Coefficients based on ICRP 60*, ICRP Publication 119, Volume 41 Supplement 1, 2012.

[F-6] AECOM, *NSDF Design Description*, 232-503212-DD-001, Revision 1, 2019 May.

Appendix G

Fire of Combustible Waste in the Engineered Containment Mound

G.1 Introduction

A drum and waste unloading platform, is located within the ECM footprint in the TSWRPA. The drum unloading platform facilitates the safe unloading and transfer of overpacked drummed waste and other packaged waste. The platform constructed at grade, consists of aggregate material provided to minimize dust generation. The platform incorporates the use of dedicated drum placement vehicles to transfer drummed wastes inside the NSDF cell waste placement area.

The TSWRPA, including the drum and waste handling area, is large enough to store bulk and packaged wastes, for cold and inclement weather periods when placement within the active cell cannot take place. The TSWRPA is located within the ECM footprint in an area where the floor composite base liner system has been installed and will be moved as necessary for sequencing of the cells. The TSWRPA is shown in Figure G-1.

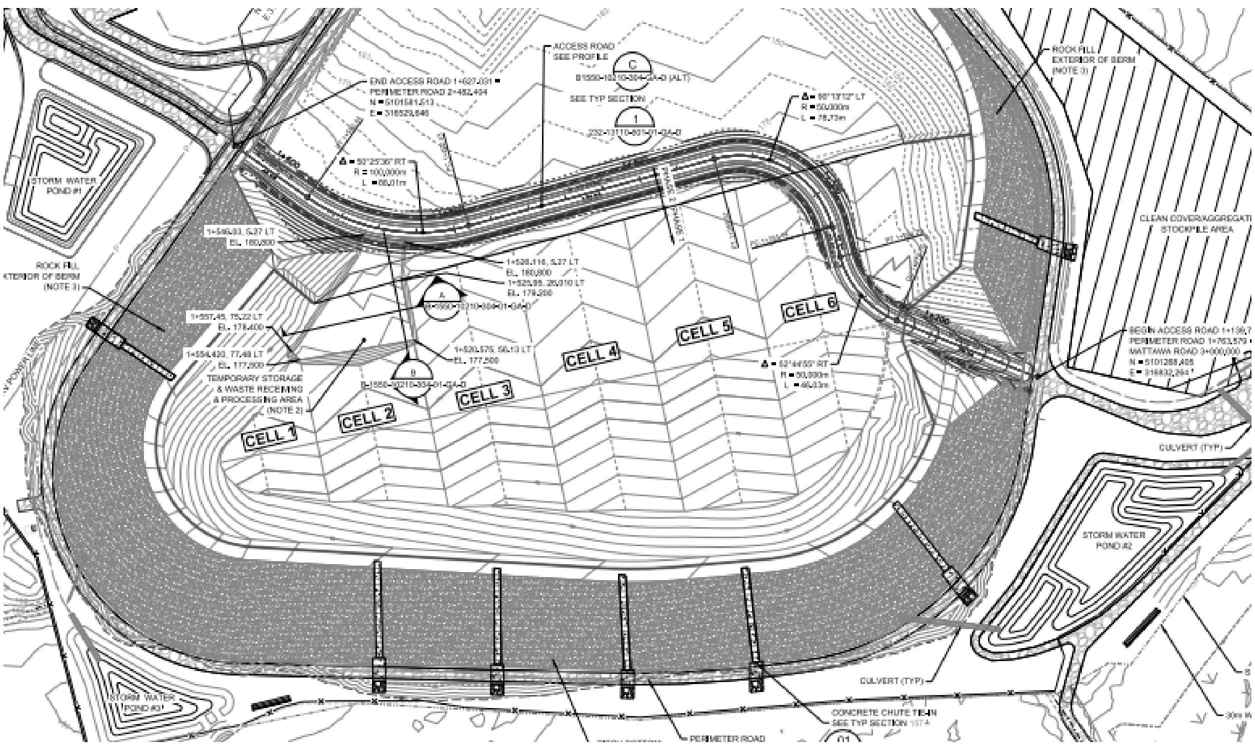


Figure G-1 ECM and Temporary Storage and Waste Receiving and Processing Area

G.2 Analysis Methodology

G.2.1 Event Scenario

The bounding scenario considers that the waste being staged in the TSWRPA catches fire due to a lightning strike or another source of ignition. The consequences of this scenario are bounding to a fire on a transport vehicle, since the volume of waste affected is larger than the volume that can be transported by a transport vehicle.

G.2.2 Radionuclide Distribution (Source Term)

Bulk waste and packaged waste temporarily staged in the TSWRPA, may be combustible and are affected by the fire. The total waste staged is 800 m^3, the limit for staged waste in the TSWRPA [G-1].

The total volumes of bulk waste and packaged waste are 866 000 m^3 and 136 000 m^3 respectively [G-2], a ratio of 6.4 to 1. With a total of 800 m^3 of waste, this ratio approximately corresponds to 692 m^3 and 108 m^3 of bulk and packaged waste respectively. With this volume of waste, the radionuclide activity affected by the fire at the ECM is approximately 0.08% (0.0798%) of the total inventory of bulk and packaged waste, and is shown in Table G-1.

The fire is assumed to last for one hour, at which point the fire is extinguished by CRL or off-site emergency responders.

Table G-1
Radionuclide Activity in Waste Affected by a Fire in the Engineered Containment Mound

Radionuclide	Total activity in bulk waste (Bq)	Total activity in packaged waste (Bq)	Activity in bulk waste on fire (Bq)	Activity in packaged waste on fire (Bq)
Ag-108m	1.87E+04	2.73E+10	1.49E+01	2.18E+07
Am-241	1.25E+10	4.80E+10	9.98E+06	3.83E+07
Am-243	6.38E+06	4.62E+07	5.09E+03	3.69E+04
C-14	2.07E+11	1.50E+12	1.65E+08	1.20E+09
Cl-36	5.74E+08	3.40E+09	4.58E+05	2.71E+06
Co-60	1.18E+13	9.06E+16	9.42E+09	7.23E+13
Cs-135	9.59E+06	5.10E+08	7.66E+03	4.07E+05
Cs-137	6.75E+11	4.91E+12	5.39E+08	3.92E+09
H-3	9.75E+13	7.94E+14	7.78E+10	6.34E+11
I-129	1.62E+08	3.01E+10	1.29E+05	2.40E+07
Mo-93	1.67E+04	1.31E+05	1.33E+01	1.05E+02
Nb-94	2.50E+10*	2.09E+11	2.00E+07	1.67E+08
Ni-59	1.39E+08	1.07E+09	1.11E+05	8.54E+05
Ni-63	3.54E+10	2.75E+11	2.83E+07	2.20E+08

Np-237	2.12E+06	1.53E+07	1.69E+03	1.22E+04
Pu-239	1.03E+10	7.74E+10	8.22E+06	6.18E+07
Pu-241	2.02E+11	1.46E+12	1.61E+08	1.17E+09
Pu-242	7.68E+06	5.55E+07	6.13E+03	4.43E+04
Ra-226	1.92E+08	3.63E+10	1.53E+05	2.90E+07
Se-79	1.13E+07	8.13E+07	9.02E+03	6.49E+04
Sn-126	1.52E+07	1.09E+08	1.21E+04	8.70E+04
Sr-90	7.36E+11	5.31E+12	5.88E+08	4.24E+09
Tc-99	6.42E+07	3.16E+11	5.13E+04	2.52E+08
Th-230	8.01E+08	4.50E+09	6.40E+05	3.59E+06
Th-232	3.15E+09	2.39E+10	2.51E+06	1.91E+07
U-233	3.29E+07	2.41E+08	2.63E+04	1.92E+05
U-234	9.34E+09	5.94E+10	7.46E+06	4.74E+07
U-235	3.91E+08	2.57E+09	3.12E+05	2.05E+06
U-238	8.54E+09	6.72E+10	6.82E+06	5.37E+07
Zr-93	1.41E+11*	1.06E+12	1.13E+08	8.46E+08

*The values listed here, which served as the basis for design and licencing, are both conservatively higher than those in the NSDF Reference Inventory Report [G-3]. The NSDF Reference Inventory Report, Table 8, lists inventories of Nb-94 and Zr-93 as 2.09E+10 Bq and 4.35E+11 Bq, respectively [G-3].

Dose to Workers and Members of the Public

The dose to workers and members of the public is calculated based on the air concentration of radionuclides, which is determined using a Gaussian plume dispersion model and airborne release fractions.

If the fire burns hot, the heat from the fire will loft the plume upward, and the main exposure will occur some distance away from the fire, when the plume vertically reaches the ground. The heat of combustion for wood is about 10 MJ/kg at 70% efficiency [G-4]. Nevertheless, for conservatism it is assumed that the fire spreads at ground level in the least dispersive conditions (stability Category F, wind speed 2 m/s).

Therefore, as a bounding scenario for workers and members of the public, it is assumed that the radionuclide airborne fraction of the waste on fire is dispersed from the NSDF site in a plume that disperses in the atmosphere.

The respirable source term (Q) is determined by equation G1:

$$Q = MAR \times DR \times LPF \times ARF \times RF \qquad \text{(G1)}$$

Where:

MAR - material at risk, the total activity in the staged waste (Bq), see Table G-1.

DR - damage ratio, the fraction of MAR actually impacted by the accident, assumed to be 1

LPF - leak path factor, the fraction of the radionuclides passing through filtration systems, assumed to be 1

ARF - airborne release fraction, the fraction of radioactive material suspended in air as an aerosol. For bulk waste, these are based on Fire Release Fractions (FRFs) shown in Table G-2 [G-5]. For packaged waste, the ARF s assumed to be 5E-04, which is the bounding ARF for contaminated combustible materials heated or burned in packages [G-6].

RF - respirable fraction, the fraction of airborne radionuclides inhaled, assumed to be 1

The Fire Release Fractions for bulk waste are shown in Table G-2. These release fractions for a fire scenario were chosen since they are radionuclide-specific; therefore the risk is more accurate, specifically for alpha emitters such as americium and plutonium.

Table G-2
Fire Release Fractions for a Fire Involving Bulk Waste

Radionuclide	Fire Release Fraction for Bulk Waste
Ag-108m	1E-02
Am-241	1E-03
Am-243	1E-03
C-14	1E-02
Cl-36	5E-01
Co-60	1E-03
Cs-135	1E-02
Cs-137	1E-02
H-3	5E-01
I-129	5E-01
Mo-93	1E-02
Nb-94	1E-02
Ni-59	1E-02
Ni-63	1E-02
Np-237	1E-03
Pu-239	1E-03
Pu-241	1E-03
Pu-242	1E-03
Ra-226	1E-03
Se-79	1E-02
Sn-126	1E-02
Sr-90	1E-02
Tc-99	1E-02
Th-230	1E-03
Th-232	1E-03
U-233	1E-03
U-234	1E-03
U-235	1E-03
U-238	1E-03
Zr-93	1E-02

G.2.3 Dose Receptor and Location

The on-site worker is assumed to be inside the ECM, adjacent to the TSWRPA at a distance of 100 m from the fire. The worker is assumed to remain at that location for one hour and has a breathing rate of 1.2 m^3/h [G-7]. Another on-site worker is assumed to be at Building 700, at about 1 km from the fire.

For exposure to airborne contaminants, the member of the public is assumed to be a cottager approximately 3 km away from the NSDF site (see Figure G-2). This is considered to be bounding of all potential public locations (e.g. Chalk River), based on calculated atmospheric dilution factors [G-7]. Dose is calculated for both an infant (1-year old child) and adult receptor at this location.

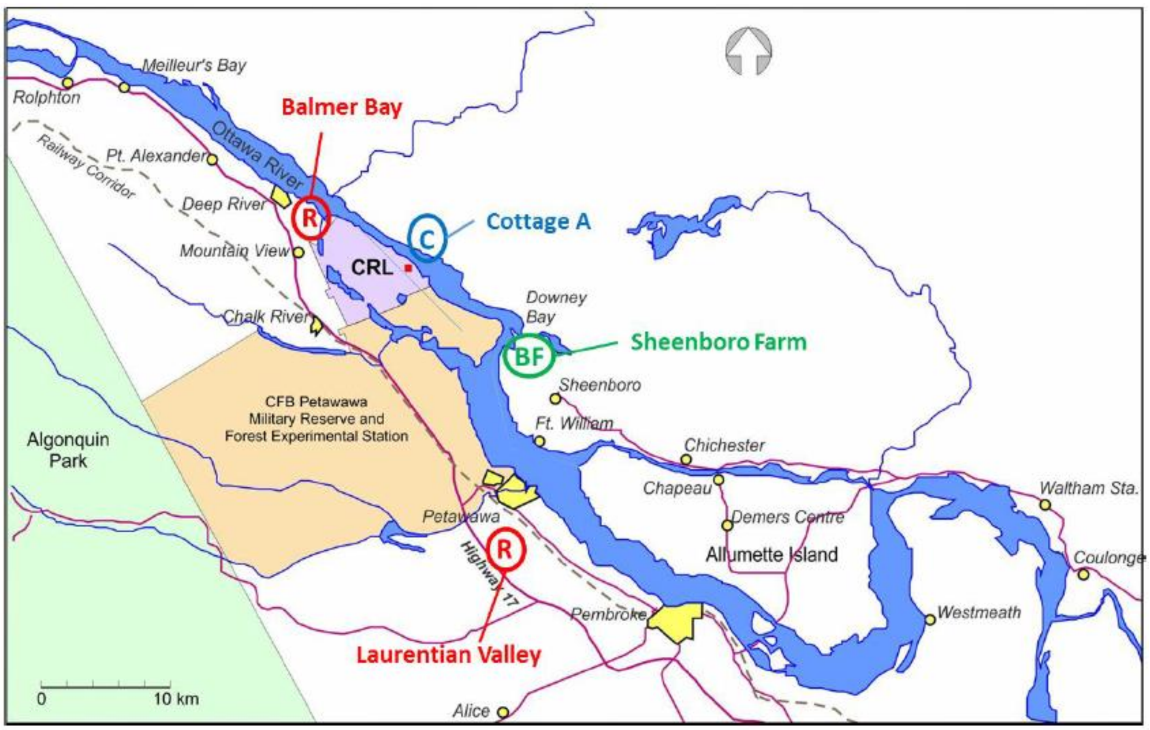


Figure G-2 Off-site Member of the Public Location for Airborne Emissions [G-8]

G.3 Assumptions and Inputs

Assumptions that apply to the calculation of dose to both the worker and member of the public are:

- Approximately 0.08% of the total bulk and packaged waste destined for the NSDF is staged in the TSWRPA and is affected by the fire (corresponds to 800 m^3 of staged waste).
- Emergency response crews extinguish the fire after 1 hour.

- A ground-level release is assumed. Given the elevation of the NSDF site relative to Building 700, this is a conservative assumption that maximizes the exposure at the receptor location.
- There is no depletion of contaminants from the plume.
- The plume is not considered to be affected by nearby buildings.
- Wind speed is assumed to be 2 m/s [G-7] and is assumed to be constant therefore, there are no meteorological time averaging effects.
- Tritium and C-14 are assumed to be in the form of HTO and CO_2 respectively (inhalation DCFs from ICRP 119 Table B for workers, Table H for public) [G-9].
- Air immersion (i.e. cloudshine) DCFs are based on Health Canada's Recommendations of Dose Coefficients for Assessing Doses from Accidental Radionuclide Releases to the Environment [G-10].
- A factor of 1.5 is applied to tritium inhalation DCF to account for skin absorption [G-11].

Assumptions specifically related to the calculation of dose to the workers are:

- There is a worker at the NSDF, adjacent to the TSWRPA and 100 m from the fire, and another worker at Building 700 and 1 000 m from the fire; both remain there for 1 hour.
- The fire rises immediately and is atmospherically dispersed.
- Workers are not wearing any respiratory protection.
- The wind is in the direction of the worker.
- The worker breathing rate of 1.2 m^3/h [G-12].
- The worker inhalation DCFs are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm AMAD (ICRP 119, Table A) [G-9].

Assumptions specifically related to the calculation of dose to the member of the public are:

- The member of the public is a cottager located on the Quebec side of the Ottawa River [G-12], approximately 3 km away from the NSDF site; they are assumed to be outdoors in the centerline of the plume and remain there during the full plume exposure duration.
- The wind is in the direction of the cottage (to the East).
- The public inhalation DCFs are based on the most restrictive dosimetric form (slow, moderate, or fast) and 1 µm AMAD (ICRP 119, Table G) [G-9].
- A factor of 1.5 is applied to adult immersion DCFs to represent infant immersion DCFs [G-10].
- The adult member of the public breathing rate is 0.925 m^3/h, and the infant breathing rate is 0.215 m^3/h [G-12].

G.4 Calculations

Dose to Worker at NSDF and Building 700

The total dose to the worker (D_{TOT}) is determined by equation G2:

$$D_{TOT} = D_{inh} + D_{imm} \qquad \text{(G2)}$$

Where:

D_{inh} - inhalation dose to the worker (mSv)
D_{imm} - immersion dose to the worker (mSv)

The inhalation dose to the worker for a 1-hour exposure is determined by equation G3:

$$D_{inh} = Q \times ADF \times B \times DCF_{inh} \times \frac{1000\ mSv}{1\ Sv} \times \frac{1\ h}{3600\ s} \qquad \text{(G3)}$$

Where:

Q - respirable source term (Bq)
ADF - atmospheric dilution factor for the on-site receptor location (s m^{-3}), 1.12E-02 for a worker at 100 m and 2.47E-04 for a worker at 1 km, for a wind speed of 2 m/s, short-term (10 min) ground-level release, Stability Class F [G-7]
B - breathing rate, assumed to be 1.2 m^3/h for the worker [G-12].
DCF_{inh} - inhalation dose conversion factor (Sv/Bq) [G-9]

The immersion dose to the worker for a 1 hour exposure is determined by equation G4:

$$D_{imm} = Q \times ADF \times DCF_{imm} \times \frac{1000\ mSv}{1\ Sv} \qquad \text{(G4)}$$

Where:

Q - respirable source term (Bq)
ADF - atmospheric dilution factor for the on-site receptor location (s m^{-3}), 1.12E-02 for a worker at 100 m and 2.47E-04 for a worker at 1 km, for a wind speed of 2 m/s, short-term (10 min) ground-level release, Stability Class F [G-7]
DCF_{imm} - immersion dose conversion factor (Sv/s per Bq/m^3) [G-10].

Dose to Member of the Public

The total dose to the member of the public (D_{TOT}) is determined by equation G2:

$$D_{TOT} = D_{inh} + D_{imm} \qquad \text{(G2)}$$

Where:

D_{inh} - inhalation dose (mSv)
D_{imm} - immersion dose (mSv)

The inhalation dose for a 1 hour exposure is determined by equation G3:

$$D_{inh} = Q \times ADF \times B \times DCF_{inh} \times \frac{1000\ mSv}{1\ Sv} \times \frac{1\ h}{3600\ s} \qquad \text{(G3)}$$

Where:

Q	- respirable source term (Bq)
ADF	- atmospheric dilution factor for the off-site receptor location (s m^{-3}), 7.21E-05 s m^{-3} for the member of the public at cottage locations 3 km away, for a wind speed of 2 m/s, short-term (10 minutes) ground-level release, Stability Class F [G-7]
B	- breathing rate, assumed to be 0.925 m^3/h for the adult member of the public and 0.215 m^3/h for the infant [G-12]
DCF_{inh}	- inhalation dose conversion factor (Sv/Bq) [G-9]

The immersion dose for a 1-hour exposure is determined by equation G4:

$$D_{imm} = Q \times ADF \times DCF_{imm} \times \frac{1000\ mSv}{1\ Sv} \qquad (G4)$$

Where:

Q	- respirable source term (Bq)
ADF	- atmospheric dilution factor for the off-site receptor location (s m^{-3}), 7.21E-05 s m^{-3} for the member of the public at cottage locations 3 km away, for a wind speed of 2 m/s, short-term (10 minutes) ground-level release, Stability Class F [G-7].
DCF_{imm}	- immersion dose conversion factor (Sv/s per Bq/m^3) [G-10]. A factor of 1.5 is applied to adult immersion DCFs to represent infant immersion DCFs [G-10].

G.5 Results

Table G-3 shows the estimated radiological consequence to the on-site receptors for a fire in the TSWRPA. Table G-4 shows the estimated radiological consequence to the off-site receptors for a fire in the TSWRPA.

The radiological consequence to the worker at the NSDF, due to inhalation and immersion, is approximately 2.4 mSv. The radiological consequence to the on-site receptor at Building 700, 1 km from the accident, due to inhalation and immersion is 5.2E-02 mSv. The primary radionuclide contributing to the on-site receptor radiological consequence is Co-60.

The inhalation radiological consequence to the adult member of the public is 2.1E-02 mSv and the immersion radiological consequence is 3.1E-04 mSv. The total inhalation radiological consequence to the infant, 1 year old child member of the public is 1.4E-02 mSv and the total immersion radiological consequence is 4.7E-04 mSv. The radiological consequence to the closest member of the public, located 3 km from the accident, due to inhalation and immersion is approximately 2.1E-02 mSv for the adult, and 1.4E-02 mSv for the infant, 1 year old child. The primary radionuclide contributing to the off-site receptor radiological consequence is Co-60.

There is uncertainty associated with the amount of bulk and packaged waste involved in the fire respectively. As a sensitivity calculation, a fire involving 800 m^3 of packaged waste is considered here instead of the 108 m^3 considered in the reference calculation. Given the total respirable source term is predominantly attributable to packaged waste, the overall respirable source term is approximately 7.4 times greater for the sensitivity calculation, and therefore the doses to the worker and the closest member of the public are also approximately 7.4 times greater. In this case, the radiological consequences are approximately 17.5 mSv for the worker at the TSWRPA, 3.9E-01 mSv to the worker at Building 700, 1.6E-01 mSv to the adult member of the public, and 1.0E-01 mSv to the infant, 1 year old child, member of the public.

Table G-3
Radiological Consequence to the On-site Receptor for a TSWRPA Fire

1	2	3	4	5	6	7	8	9	10	11	12
Radionuclide	**Total activity in bulk waste (Bq)**	**Total activity in packaged waste (Bq)**	**Activity in bulk waste on fire (Bq)**	**Activity in packaged waste on fire (Bq)**	**Fire Release Fractions for bulk waste**	**Inhalation DCF for workers (Sv/Bq)**	**Immersion DCF (Sv/s per Bq/m^3)**	**Inhalation dose to worker at 100 m (mSv)**	**Immersion dose to worker at 100 m (mSv)**	**Inhalation dose to worker at 1 km (mSv)**	**Immersion dose to worker at 1 km (mSv)**
Ag-108m	1.87E+04	2.73E+10	1.49E+01	2.18E+07	1E-02	1.90E-08	7.24E-14	7.73E-07	8.84E-09	1.70E-08	1.95E-10
Am-241	1.25E+10	4.80E+10	9.98E+06	3.83E+07	1E-03	2.70E-05	6.74E-16	2.94E-03	2.20E-10	6.48E-05	4.85E-12
Am-243	6.38E+06	4.62E+07	5.09E+03	3.69E+04	1E-03	2.70E-05	1.85E-15	2.37E-06	4.88E-13	5.23E-08	1.08E-14
C-14	2.07E+11	1.50E+12	1.65E+08	1.20E+09	1E-02	6.50E-12	2.60E-18	5.46E-08	6.56E-11	1.20E-09	1.45E-12
Cl-36	5.74E+08	3.40E+09	4.58E+05	2.71E+06	5E-01	5.10E-09	1.66E-16	4.39E-06	4.29E-10	9.68E-08	9.45E-12
Co-60	1.18E+13	9.06E+16	9.42E+09	7.23E+13	1E-03	1.70E-08	1.19E-13	2.30E+00	4.82E-02	5.06E-02	1.06E-03
Cs-135	9.59E+06	5.10E+08	7.66E+03	4.07E+05	1E-02	9.90E-10	9.50E-18	1.04E-09	2.98E-14	2.28E-11	6.57E-16
Cs-137	6.75E+11	4.91E+12	5.39E+08	3.92E+09	1E-02	6.70E-09	2.55E-14	1.84E-04	2.10E-06	4.05E-06	4.63E-08
H-3	9.75E+13	7.94E+14	7.78E+10	6.34E+11	5E-01	2.70E-11	0.00E+00	3.96E-03	0.00E+00	8.72E-05	0.00E+00
I-129	1.62E+08	3.01E+10	1.29E+05	2.40E+07	5E-01	5.10E-08	2.81E-16	1.46E-05	2.41E-10	3.22E-07	5.32E-12
Mo-93	1.67E+04	1.31E+05	1.33E+01	1.05E+02	1E-02	1.40E-09	1.73E-17	9.70E-13	3.60E-17	2.14E-14	7.93E-19
Nb-94	2.50E+10	2.09E+11	2.00E+07	1.67E+08	1E-02	2.50E-08	7.20E-14	2.64E-05	2.28E-07	5.83E-07	5.03E-09
Ni-59	1.39E+08	1.07E+09	1.11E+05	8.54E+05	1E-02	2.20E-10	0.00E+00	1.26E-09	0.00E+00	2.78E-11	0.00E+00
Ni-63	3.54E+10	2.75E+11	2.83E+07	2.20E+08	1E-02	5.20E-10	0.00E+00	7.62E-07	0.00E+00	1.68E-08	0.00E+00
Np-237	2.12E+06*	1.53E+07*	1.69E+03	1.22E+04	1E-03	1.50E-05	8.87E-16	4.37E-07	7.75E-14	9.63E-09	1.71E-15
Pu-239	1.03E+10	7.74E+10	8.22E+06	6.18E+07	1E-03	3.20E-05	3.48E-18	4.67E-03	1.52E-12	1.03E-04	3.36E-14
Pu-241	2.02E+11	1.46E+12	1.61E+08	1.17E+09	1E-03	5.80E-07	6.33E-20	1.61E-03	5.28E-13	3.55E-05	1.16E-14
Pu-242	7.68E+06	5.55E+07	6.13E+03	4.43E+04	1E-03	3.10E-05	2.90E-18	3.27E-06	9.19E-16	7.22E-08	2.03E-17
Ra-226	1.92E+08	3.63E+10	1.53E+05	2.90E+07	1E-03	2.20E-06	2.84E-16	1.20E-04	4.66E-11	2.65E-06	1.03E-12
Se-79	1.13E+07	8.13E+07	9.02E+03	6.49E+04	1E-02	3.10E-09	3.94E-18	1.42E-09	5.41E-15	3.13E-11	1.19E-16
Sn-126	1.52E+07	1.09E+08	1.21E+04	8.70E+04	1E-02	1.80E-08	1.84E-15	1.11E-08	3.40E-12	2.44E-10	7.49E-14
Sr-90	7.36E+11	5.31E+12	5.88E+08	4.24E+09	1E-02	7.70E-08	9.83E-17	2.30E-03	8.80E-09	5.07E-05	1.94E-10
Tc-99	6.42E+07	3.16E+11	5.13E+04	2.52E+08	1E-02	3.20E-09	2.87E-17	1.51E-06	4.07E-11	3.34E-08	8.98E-13
Th-230	8.01E+08	4.50E+09	6.40E+05	3.59E+06	1E-03	2.80E-05	1.48E-17	2.55E-04	4.04E-13	5.62E-06	8.90E-15
Th-232	3.15E+09	2.39E+10	2.51E+06	1.91E+07	1E-03	2.90E-05	7.24E-18	1.31E-03	9.78E-13	2.88E-05	2.16E-14

1	2	3	4	5	6	7	8	9	10	11	12
Radionuclide	**Total activity in bulk waste (Bq)**	**Total activity in packaged waste (Bq)**	**Activity in bulk waste on fire (Bq)**	**Activity in packaged waste on fire (Bq)**	**Fire Release Fractions for bulk waste**	**Inhalation DCF for workers (Sv/Bq)**	**Immersion DCF (Sv/s per Bq/m³)**	**Inhalation dose to worker at 100 m (mSv)**	**Immersion dose to worker at 100 m (mSv)**	**Inhalation dose to worker at 1 km (mSv)**	**Immersion dose to worker at 1 km (mSv)**
U-233	3.29E+07	2.41E+08	2.63E+04	1.92E+05	1E-03	6.90E-06	1.42E-17	3.15E-06	1.95E-14	6.96E-08	4.30E-16
U-234	9.34E+09	5.94E+10	7.46E+06	4.74E+07	1E-03	6.80E-06	6.11E-18	7.91E-04	2.13E-12	1.75E-05	4.70E-14
U-235	3.91E+08	2.57E+09	3.12E+05	2.05E+06	1E-03	6.10E-06	6.46E-15	3.05E-05	9.68E-11	6.72E-07	2.14E-12
U-238	8.54E+09	6.72E+10	6.82E+06	5.37E+07	1E-03	5.70E-06	2.50E-18	7.16E-04	9.42E-13	1.58E-05	2.08E-14
Zr-93	1.41E+11*	1.06E+12*	1.13E+08	8.46E+08	1E-02	2.90E-08	0.00E+00	1.68E-04	0.00E+00	3.70E-06	0.00E+00
							TOTAL	**2.32E+00**	**4.82E-02**	**5.11E-02**	**1.06E-03**

*The values listed here, which served as the basis for design and licencing, are both conservatively higher than those in the NSDF Reference Inventory Report [G-3]. The NSDF Reference Inventory Report, Table 8, lists inventories of Nb-94 and Zr-93 as 2.09E+10 Bq and 4.35E+11 Bq, respectively [G-3].

Notes for each column	
1	The list of radionuclides in NSDF waste [G-2].
2	Total activity in bulk waste to be emplaced in the ECM [G-2].
3	Total activity in packaged waste to be emplaced in the ECM [G-2].
4	Activity in bulk waste on fire, Column 2 x 0.0798%.
5	Activity in packaged waste on fire, Column 3 x 0.0798%.
6	Airborne release fraction for bulk waste on fire (IAEA-TECDOC-1162) [G-5].
7	Adult values from ICRP 119, Table G, 1 µm particulate size. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.
8	1-year old values from ICRP 119, Table G, 1 µm particulate size. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.
9	Taken from Health Canada's Recommendations of Dose Coefficients for Assessing Doses from Accidental Radionuclide Releases to the Environment [G-10].
10	Inhalation dose to public – adult at cottager location $D_{inh} = Q \times ADF \times B \times DCF_{inh} \times \frac{1000\ mSv}{1\ Sv} \times \frac{1\ hr}{3600\ s}$, Q = (Column 4 x Column 6 + Column 5 x 5E-04), ADF = 7.21E-05 s/m³, B = breathing rate of 0.925 m³/h, DCF_{inh} = Column 7
11	Immersion dose to public – adult at cottager location: $D_{imm} = Q \times ADF \times DCF_{imm} \times \frac{1000\ mSv}{1\ Sv}$, Q = (Column 4 x Column 6 + Column 5 x 5E-04), ADF = 7.21E-05 s/m³, DCF_{imm} = Column 9
12	Inhalation dose to public – infant at cottager location $D_{inh} = Q \times ADF \times B \times DCF_{inh} \times \frac{1000\ mSv}{1\ Sv} \times \frac{1\ hr}{3600\ s}$, Q = (Column 4 x Column 6 + Column 5 x 5E-04), ADF = 7.21E-05 s/m³, B = breathing rate of 0.215 m³/h, DCF_{inh} = Column 8
13	Immersion dose to public – infant at cottager location: $D_{imm} = Q \times ADF \times DCF_{imm} \times 1.5 \times \frac{1000\ mSv}{1\ Sv}$, Q = (Column 4 x Column 6 + Column 5 x 5E-04), ADF = 7.21E-05 s/m³, DCF_{imm} = Column 9

Table G-4
Radiological Consequence to the Off-Site Receptor (Public) for a TSWRPA Fire

1	2	3	4	5	6	7	8	99	10	11	12	13
Radionuclide	**Total activity in bulk waste (Bq)**	**Total activity in packaged waste (Bq)**	**Activity in bulk waste on fire (Bq)**	**Activity in packaged waste on fire (Bq)**	**Fire Release Fractions for bulk waste**	**Inhalation DCF for public adult (Sv/Bq)**	**Inhalation DCF for public infant (Sv/Bq)**	**Immersion DCF (Sv/s per Bq/m^3)**	**Inhalation dose to public adult at 3 km (mSv)**	**Immersion dose to public adult at 3 km (mSv)**	**Inhalation dose to public infant at 3 km (mSv)**	**Immersion dose to public infant at 3 km (mSv)**
Ag-108m	1.87E+04	2.73E+10	1.49E+01	2.18E+07	1E-02	3.70E-08	8.70E-08	7.24E-14	7.47E-09	5.69E-11	4.08E-09	8.53E-11
Am-241	1.25E+10	4.80E+10	9.98E+06	3.83E+07	1E-03	9.60E-05	1.80E-04	6.74E-16	5.18E-05	1.42E-12	2.26E-05	2.12E-12
Am-243	6.38E+06	4.62E+07	5.09E+03	3.69E+04	1E-03	9.60E-05	1.70E-04	1.85E-15	4.19E-08	3.14E-15	1.72E-08	4.71E-15
C-14	2.07E+11	1.50E+12	1.65E+08	1.20E+09	1E-02	6.20E-12	1.90E-11	2.60E-18	2.59E-10	4.22E-13	1.84E-10	6.33E-13
Cl-36	5.74E+08	3.40E+09	4.58E+05	2.71E+06	5E-01	7.30E-09	2.60E-08	1.66E-16	3.12E-08	2.76E-12	2.58E-08	4.14E-12
Co-60	1.18E+13	9.06E+16	9.42E+09	7.23E+13	1E-03	3.10E-08	8.60E-08	1.19E-13	2.08E-02	3.10E-04	1.34E-02	4.66E-04
Cs-135	9.59E+06	5.10E+08	7.66E+03	4.07E+05	1E-02	8.60E-09	2.40E-08	9.50E-18	4.46E-11	1.92E-16	2.90E-11	2.88E-16
Cs-137	6.75E+11	4.91E+12	5.39E+08	3.92E+09	1E-02	3.90E-08	1.10E-07	2.55E-14	5.31E-06	1.35E-08	3.48E-06	2.03E-08
H-3	9.75E+13	7.94E+14	7.78E+10	6.34E+11	5E-01	2.70E-11	7.20E-11	0.00E+00	1.96E-05	0.00E+00	1.22E-05	0.00E+00
I-129	1.62E+08	3.01E+10	1.29E+05	2.40E+07	5E-01	3.60E-08	8.60E-08	2.81E-16	5.11E-08	1.55E-12	2.84E-08	2.33E-12
Mo-93	1.67E+04	1.31E+05	1.33E+01	1.05E+02	1E-02	2.30E-09	4.80E-09	1.73E-17	7.91E-15	2.32E-19	3.84E-15	3.47E-19
Nb-94	2.50E+10*	2.09E+11*	2.00E+07	1.67E+08	1E-02	4.90E-08	1.20E-07	7.20E-14	2.57E-07	1.47E-09	1.46E-07	2.20E-09
Ni-59	1.39E+08	1.07E+09	1.11E+05	8.54E+05	1E-02	4.40E-10	1.50E-09	0.00E+00	1.25E-11	0.00E+00	9.93E-12	0.00E+00
Ni-63	3.54E+10	2.75E+11	2.83E+07	2.20E+08	1E-02	1.30E-09	4.30E-09	0.00E+00	9.45E-09	0.00E+00	7.27E-09	0.00E+00
Np-237	2.12E+06	1.53E+07	1.69E+03	1.22E+04	1E-03	5.00E-05	9.30E-05	8.87E-16	7.23E-09	4.99E-16	3.12E-09	7.48E-16
Pu-239	1.03E+10	7.74E+10	8.22E+06	6.18E+07	1E-03	1.20E-04	2.00E-04	3.48E-18	8.70E-05	9.82E-15	3.37E-05	1.47E-14
Pu-241	2.02E+11	1.46E+12	1.61E+08	1.17E+09	1E-03	2.30E-06	2.90E-06	6.33E-20	3.17E-05	3.40E-15	9.29E-06	5.09E-15
Pu-242	7.68E+06	5.55E+07	6.13E+03	4.43E+04	1E-03	1.10E-04	1.90E-04	2.90E-18	5.76E-08	5.91E-18	2.31E-08	8.87E-18
Ra-226	1.92E+08	3.63E+10	1.53E+05	2.90E+07	1E-03	9.50E-06	2.90E-05	2.84E-16	2.58E-06	3.00E-13	1.83E-06	4.50E-13
Se-79	1.13E+07	8.13E+07	9.02E+03	6.49E+04	1E-02	6.80E-09	2.00E-08	3.94E-18	1.55E-11	3.48E-17	1.06E-11	5.23E-17
Sn-126	1.52E+07	1.09E+08	1.21E+04	8.70E+04	1E-02	2.80E-08	1.00E-07	1.84E-15	8.55E-11	2.19E-14	7.10E-11	3.28E-14
Sr-90	7.36E+11	5.31E+12	5.88E+08	4.24E+09	1E-02	1.60E-07	4.00E-07	9.83E-17	2.37E-05	5.67E-11	1.38E-05	8.50E-11
Tc-99	6.42E+07	3.16E+11	5.13E+04	2.52E+08	1E-02	1.30E-08	3.70E-08	2.87E-17	3.05E-08	2.62E-13	2.02E-08	3.93E-13
Th-230	8.01E+08	4.50E+09	6.40E+05	3.59E+06	1E-03	1.00E-04	2.00E-04	1.48E-17	4.51E-06	2.60E-15	2.10E-06	3.90E-15
Th-232	3.15E+09	2.39E+10	2.51E+06	1.91E+07	1E-03	1.10E-04	2.20E-04	7.24E-18	2.46E-05	6.29E-15	1.14E-05	9.44E-15
U-233	3.29E+07	2.41E+08	2.63E+04	1.92E+05	1E-03	9.60E-06	3.00E-05	1.42E-17	2.18E-08	1.25E-16	1.58E-08	1.88E-16
U-234	9.34E+09	5.94E+10	7.46E+06	4.74E+07	1E-03	9.40E-06	2.90E-05	6.11E-18	5.43E-06	1.37E-14	3.89E-06	2.06E-14

1	2	3	4	5	6	7	8	99	10	11	12	13
Radionuclide	**Total activity in bulk waste (Bq)**	**Total activity in packaged waste (Bq)**	**Activity in bulk waste on fire (Bq)**	**Activity in packaged waste on fire (Bq)**	**Fire Release Fractions for bulk waste**	**Inhalation DCF for public adult (Sv/Bq)**	**Inhalation DCF for public infant (Sv/Bq)**	**Immersion DCF (Sv/s per Bq/m³)**	**Inhalation dose to public adult at 3 km (mSv)**	**Immersion dose to public adult at 3 km (mSv)**	**Inhalation dose to public infant at 3 km (mSv)**	**Immersion dose to public infant at 3 km (mSv)**
U-235	3.91E+08	2.57E+09	3.12E+05	2.05E+06	1E-03	8.50E-06	2.60E-05	6.46E-15	2.11E-07	6.23E-13	1.50E-07	9.35E-13
U-238	8.54E+09	6.72E+10	6.82E+06	5.37E+07	1E-03	8.00E-06	2.50E-05	2.50E-18	4.99E-06	6.06E-15	3.62E-06	9.10E-15
Zr-93	1.41E+11*	1.06E+12*	1.13E+08	8.46E+08	1E-02	2.50E-08	6.40E-09	0.00E+00	7.17E-07	0.00E+00	4.27E-08	0.00E+00
								TOTAL	**2.10E-02**	**3.10E-04**	**1.35E-02**	**4.66E-04**

*The values listed here, which served as the basis for design and licencing, are both conservatively higher than those in the NSDF Reference Inventory Report [G-3]. The NSDF Reference Inventory Report, Table 8, lists inventories of Nb-94 and Zr-93 as 2.09E+10 Bq and 4.35E+11 Bq, respectively [G-3].

Notes for each column

1 The list of radionuclides in NSDF waste [G-2].

2 Total activity in bulk waste to be emplaced in the ECM [G-2].

3 Total activity in packaged waste to be emplaced in the ECM [G-2].

4 Activity in bulk waste on fire, Column 2 x 0.0798%

5 Activity in packaged waste on fire, Column 3 x 0.0798%

6 Airborne release fraction for bulk waste on fire (IAEA-TECDOC-1162) [G-5].

7 Adult values from ICRP 119, Table G, 1 µm particulate size. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.

8 1-year old values from ICRP 119, Table G, 1 µm particulate size. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.

9 Taken from Health Canada, Recommendations of Dose Coefficients for Assessing Doses from Accidental Radionuclide Releases to the Environment [G-10].

10 Inhalation dose to public – adult at cottager location: $D_{inh} = Q \times ADF \times B \times DCF_{inh} \times \frac{1000\ mSv}{1\ Sv} \times \frac{1\ hr}{3600\ s}$, Q = (Column 4 x Column 6 + Column 5 x 5E-04), ADF = 7.21E-05 s/m³, B = breathing rate of 0.925 m³/h, DCF_{inh} = Column 7.

11 Immersion dose to public – adult at cottager location: $D_{imm} = Q \times ADF \times DCF_{imm} \times \frac{1000\ mSv}{1\ Sv}$, Q = (Column 4 x Column 6 + Column 5 x 5E-04), ADF = 7.21E-05 s/m³, DCF_{imm} = Column 9.

12 Inhalation dose to public – infant at cottager location: $D_{inh} = Q \times ADF \times B \times DCF_{inh} \times \frac{1000\ mSv}{1\ Sv} \times \frac{1\ hr}{3600\ s}$, Q = (Column 4 x Column 6 + Column 5 x 5E-04), ADF = 7.21E-05 s/m³, B = breathing rate of 0.215 m³/h, DCF_{inh} = Column 8.

13 Immersion dose to public – infant at cottager location: $D_{imm} = Q \times ADF \times DCF_{imm} \times 1.5 \times \frac{1000\ mSv}{1\ Sv}$, Q = (Column 4 x Column 6 + Column 5 x 5E-04), ADF = 7.21E-05 s/m³, DCF_{imm} = Column 9.

G.6 References

[G-1] AECOM, *Design Requirements*, 232-503212-DR-001, Revision 2, 2019 April.

[G-2] AECOM, *Waste Characterization*, 232-508600-REPT-002, Revision 4, 2020 February.

[G-3] *Near Surface Disposal Facility Reference Inventory*, 232-508600-REPT-003, Revision 3, 2020 April.

[G-4] University of Nebraska Lincoln, Institute of Agriculture and Natural Resources, "*Heating with wood*," March 2005. [Online]. Available (accessed 2016 November 07): https://my.extension.illinois.edu/documents/1722110809110911/Nebraska%20producing,%20harvesting%20and%20processing%20firewood.pdf.

[G-5] International Atomic Energy Agency (IAEA), *Generic Procedures for Assessment and Response During a Radiological Emergency*, IAEA-TECDOC-1162, 2000.

[G-6] U.S. Department of Energy (DOE), *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, Reaffirmed 2013.

[G-7] *Dose Calculations for Ground Level Releases from Facilities at CRL*, 900-508770-FID-016, Revision 0, 2019 August.

[G-8] *Derived Release Limits for AECL's Chalk River Laboratories*, CRL-509200-RRD-001, Revision 2, 2018 August.

[G-9] International Commission on Radiological Protection (ICRP), *Compendium of Dose Coefficients based on ICRP Publication 60*, ICRP Publication 119. Ann. ICRP 41(s), 2012.

[G-10] Health Canada, *Recommendations on Dose Coefficients for Assessing Doses from Accidental Radionuclide Releases to the Environment*, H46-1-33-1999, 1999.

[G-11] Canadian Nuclear Safety Commission, "*Health Effects Dosimetry and Radiological Protection of Tritium,*" INFO-0799, 2010.

[G-12] *Standard Assumptions and Input Parameters for the Calculation of On-Site and Off-Site Doses Following Hypothetical Accidental Atmospheric Radioactive Releases from Facilities at CRL,* 145-508770-NSN-001, Revision 1, 2017 March.

Appendix H

Pressure Boundary Failure in the Waste Water Treatment Plant

H.1 Introduction

Pressure boundary, tank and or piping failure in the WWTP is a DBA.

H.2 Analysis Methodology

H.2.1 Event Scenario

The scenario involves a failure of piping preceding a failure of tanks on the ground floor of the WWTP that results in a complete loss of wastewater. This is considered to be a bounding scenario, as the majority of water is within the pre-treatment area on the ground floor. The event is assumed to affect the membrane filter feed tanks and membrane filter process tanks in a single treatment train, as well as the associated piping. A severe pipe rupture results in a spill of a large amount of wastewater, with a small amount of water becoming suspended following the free-fall spill.

All of the spilled wastewater is assumed to be confined to the main treatment area of the WWTP (i.e. drainage within the WWTP fails and no water drains away through the drainage system). The worker remains in the area for 10 minutes, in an attempt to mitigate the spill. The event occurs just prior to the final cell being closed, when the maximum amount of leachate is generated from the ECM. Therefore, Cells 1 to 9 are closed with the final cover and Cell 10 is open. The effects of this event to the worker, bounds all other pipe rupture events, including outdoor wastewater transfer pipes from the ECM to the Equalization Tanks, since there is a large amount of untreated wastewater and airborne contamination that remains confined for the duration of exposure.

H.2.2 Radionuclide Distribution (Source Term)

The radionuclide concentration in the wastewater near the end of the operations phase is calculated in the Leachate and Wastewater Characterization [H-1], and is shown in Table H-1. The total activity in the membrane filter feed tank and membrane filter process tank is calculated by multiplying the wastewater concentration by the combined wastewater capacity: $91\ m^3 + 5\ m^3 = 96\ m^3$ [H-2].

Table H-1
Radionuclide Concentration and Activity in Membrane Filter Feed and Process Tanks Near the End of the Operations Period

Radionuclide	Wastewater Activity Concentration (Bq/L)	Wastewater Activity (Bq)
Ag-108m	1.80E-04	1.73E+01
Am-241	2.80E-03	2.69E+02
Am-243	1.70E-06	1.63E-01
C-14	3.10E+00	2.98E+05
Cl-36	5.90E-02	5.66E+03
Co-60	1.30E+03	1.25E+08
Cs-135	4.10E-05	3.94E+00
Cs-137	9.30E-01	8.93E+04
H-3	1.40E+05	1.34E+10
I-129	9.10E-02	8.74E+03
Mo-93	4.10E-07	3.94E-02
Nb-94	1.50E-02	1.44E+03
Ni-59	1.70E-04	1.63E+01
Ni-63	4.40E-02	4.22E+03
Np-237	6.30E-07	6.05E-02
Pu-239	4.40E-03	4.22E+02
Pu-241	7.90E-02	7.58E+03
Pu-242	3.30E-06	3.17E-01
Ra-226	6.40E-04	6.14E+01
Se-79	2.40E-05	2.30E+00
Sn-126	7.20E-06	6.91E-01
Sr-90	9.60E+00	9.22E+05
Tc-99	5.70E+00	5.47E+05
Th-230	2.20E-04	2.11E+01
Th-232	9.60E-04	9.22E+01
U-233	2.90E-05	2.78E+00
U-234	7.80E-03	7.49E+02
U-235	3.30E-04	3.17E+01
U-238	7.60E-03	7.30E+02
Zr-93	4.40E-02	4.22E+03

H.2.3 On-site Receptor and Location

As shown in Figure H-1, the on-site worker is assumed to be in the area of membrane filtration tanks for 10 minutes. The worker breathing rate is 1.2 m^3/h [H-3].

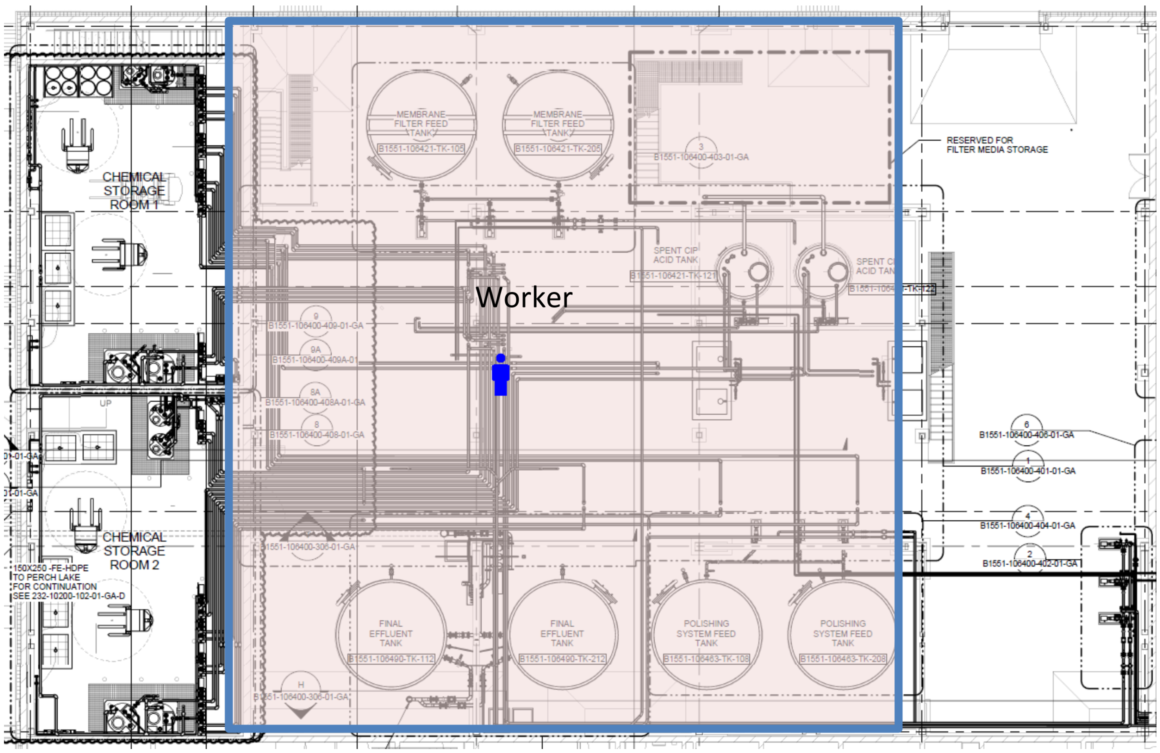


Figure H-1 Area of the Spill in the WWTP and the Worker Location

H.3 Assumptions and Inputs

The following assumptions were made to conservatively calculate the radiological consequences to a worker in the event of a severe failure of tanks and piping in the WWTP:

- The event is assumed to occur near the end of the 50 year operations phase. At this time, packaging for the packaged waste will have degraded by 1%/year in addition to the initial 5% degradation – resulting in the highest wastewater concentrations during the operations phase.
- The total spill of wastewater in the WWTP is assumed to be 96 000 L, the volume of wastewater in membrane filter feed and process tanks.
- The spilled wastewater is assumed to be untreated.
- There is no ventilation in the area.
- The worker remains in the affected area for 10 minutes in an attempt to mitigate the spill.
- The worker inhalation DCFs are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm AMAD (ICRP 119, Table A) [H-4].
- Tritium and C-14 are considered to be HTO and CO_2, respectively (inhalation DCFs from ICRP 119 Table B for workers) [H-4].

- A factor of 1.5 is applied to tritium inhalation DCFs to account for skin absorption [H-5].

H.4 Calculations

H.4.1 Tritium Concentration in the Waste Water Treatment Plant Water

The concentration of leachate (C_L) is estimated based on Equation H1, in CSA Standard N288.1-14: [H-6].

$$C_L = \left(\frac{A_b + f_p \times A_p}{V_b + f_p \times V_p}\right) \frac{1}{\theta_v + \rho_w K_d} \times 1000 \frac{ml}{L} \qquad \text{(H1)}$$

Where:

A	- activity in bulk and packaged waste in the ECM (Bq), see NSDF Waste Characterization [H-7]
V	- volume of bulk and packaged waste in the ECM (cm^3), see NSDF Waste Characterization [H-7]
f_p	- percentage package degradation for packaged waste, assumed to be 100% for bounding calculation of tritium concentration.
ρ_w	- density of waste in the ECM (assumed to be soil-like, 1.5 g/cm^3)
θ_v	- water moisture content by volume, 0.2181 [H-1]
K_d	- Soil solid/liquid partition coefficient (ml/g), zero for tritium as HTO [H-8]

To assess a bounding, worst-case scenario, if all of the packaging for packaged waste has degraded, and all of the tritium in the waste inventory (8.91E+14 Bq) [H-7] is available for leachate, the concentration of leachate from 1 M m^3 (1E+12 cm^3) of waste is:

$$C_L = \left(\frac{8.91 \times 10^{14}\ Bq}{1 \times 10^{12}\ cm^3}\right) \times \frac{1}{0.2181\ ml/cm^3} \times 1000 \frac{ml}{L} = 4.1 \times 10^6 \frac{Bq}{L}$$

The maximum possible concentration of tritium in leachate from the ECM is 0.005% of the threshold value of 74 GBq/kg. The actual concentration of tritium in the WWTP during the pressure boundary failure event would be even lower due to the dilution in wastewater.

Therefore, the concentration of tritium is not a factor in the pressure boundary classification of systems. The potential impact of a system failure involving all other radionuclides in wastewater is examined in the following section.

H.4.2 Effective Dose from all Radionuclides

This section details the calculation of radiation dose to the worker resulting from all radionuclides.

Table H-2
Exposure Pathways for the On-site Receptor (Worker)

Exposure pathway	Included in dose calculation (Yes/No)	Rationale
External	Yes	The worker will be exposed to radiation from the spilled wastewater.
Immersion	No	The worker is splashed with wastewater when the pipe ruptures; however the small amount of radioactivity remaining on the worker's clothes is expected to result in a dose much lower than that from inhalation.
Inhalation	Yes	Following the free-fall spill of wastewater, a fraction will become airborne and inhaled by the worker. Skin absorption of tritium is accounted for by applying a factor of 1.5 to the tritium inhalation DCF [H-5].
Ingestion	No	It is assumed that the worker will not ingest wastewater during the event.

The external dose to the worker (D_{ext}) is determined by equation H2.

$$D_{ext} = DR_{ext} \times t \qquad \text{(H2)}$$

Where:

DR_{ext} - effective dose rate from the spilled wastewater (mSv/h)
t - duration of exposure (h), assumed to be 10 min

The dose rate at 1 m above the ground [H-9] over the spilled wastewater was calculated using MicroShield.

A rectangular volume was used to model the spilled wastewater in MicroShield. The dimensions of the rectangular volume were 36 m x 28.5 m (surface area of the pre-treatment area) x 0.094 m, for a total volume of approximately 96 m^3 (or 96 000 L of wastewater).

The inhalation dose to the worker (D_{inh}) is determined by equation H3.

$$D_{inh} = \frac{Q \times B \times DCF_{inh} \times t}{V} \times \frac{1000\ mSv}{1\ Sv} \qquad \text{(H3)}$$

Where:

Q - respirable source term (Bq)
V - volume in which the respirable source term is airborne, assumed to be half of the total pre-treatment area volume = ½ (36 m x 28.5 m x 13.5 m) = 6 900 m^3 to account for volume of process systems
B - worker breathing rate, assumed to be 1.2 m^3/h [H-3].
t - exposure time (h), assumed to be 10 min = 0.17 h
DCF_{inh} - inhalation dose conversion factor (Sv/Bq) [H-4]

The respirable source term (Q) is determined by equation H4 [H-10]:

$$Q = MAR \times DR \times LPF \times ARF \times RF \qquad \text{(H4)}$$

Where:

MAR	- material at risk, the total activity in the tanks and piping (Bq), see Table H-1
DR	- damage ratio, the fraction of MAR actually impacted by the accident, assumed to be 1
LPF	- leakpath factor, the fraction of the radionuclides passing through filtration systems, assumed to be 1
ARF	- airborne release fraction, the fraction of radioactive material suspended in air as an aerosol, assumed to be 2E-04, which is bounding for free-fall spill of aqueous solutions from a height of 3 m or less [H-11]
RF	- respirable fraction, the fraction of airborne radionuclides inhaled, assumed to be 0.5, which is bounding for free-fall spill of aqueous solutions from a height of 3 m or less [H-11]

The total effective dose to the worker (D_{worker}) is determined by equation H5:

$$D_{worker} = D_{ext} + D_{inh} \qquad \text{(H5)}$$

H.4.3 MicroShield Output

MicroShield 9.07 ISR (9.07-0000)

Date	By	Checked

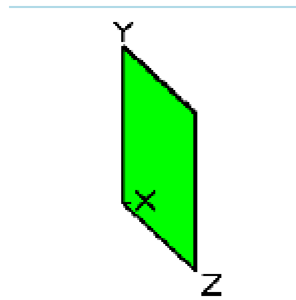
Filename	Run Date	Run Time	Duration
Pressure Boundary _ Jan 2019 rounded inventory.msd	January 23, 2019	9:52:00 AM	00:00:00

Project Info	
Case Title	Pressure Boundary
Description	External dose to worker at 1 m above spill
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	9.4 cm (3.7 in)
Width	3.6e+3 cm (118 ft 1.3 in)
Height	2.9e+3 cm (93 ft 6.0 in)

Dose Points			
A	X	Y	Z
#1	100.0 cm (3 ft 3.4 in)	1.4e+3 cm (46 ft 9.0 in)	1.8e+3 cm (59 ft 0.7 in)

Shields			
Shield N	Dimension	Material	Density
Source	9.64e+07 cm³	Water	1
Air Gap		Air	0.00122



Source Input: Grouping Method - Linear Energy
Number of Groups: 25
Lower Energy Cutoff: 0.015
Photons < 0.015: Included
Library: Grove

Nuclide	Ci	Bq	µCi/cm³	Bq/cm³
Ag-108m	4.6703e-010	1.7280e+001	4.8425e-012	1.7917e-007
Am-241	7.2649e-009	2.6880e+002	7.5328e-011	2.7871e-006
Am-243	4.4108e-012	1.6320e-001	4.5734e-014	1.6922e-009
Ba-137m	2.2827e-006	8.4460e+004	2.3669e-008	8.7574e-004
C-14	8.0432e-006	2.9760e+005	8.3398e-008	3.0857e-003
Cl-36	1.5308e-007	5.6640e+003	1.5872e-009	5.8728e-005
Co-60	3.3730e-003	1.2480e+008	3.4974e-005	1.2940e+000
Cs-135	1.0638e-010	3.9361e+000	1.1030e-012	4.0812e-008
Cs-137	2.4130e-006	8.9281e+004	2.5020e-008	9.2573e-004
H-3	3.6324e-001	1.3440e+010	3.7663e-003	1.3935e+002
I-129	2.3611e-007	8.7361e+003	2.4482e-009	9.0582e-005
Mo-93	1.0638e-012	3.9361e-002	1.1030e-014	4.0812e-010
Nb-94	3.8919e-008	1.4400e+003	4.0354e-010	1.4931e-005
Ni-59	4.4108e-010	1.6320e+001	4.5734e-012	1.6922e-007
Ni-63	1.1416e-007	4.2239e+003	1.1837e-009	4.3797e-005
Np-237	1.6346e-012	6.0480e-002	1.6949e-014	6.2710e-010
Pu-239	1.1416e-008	4.2239e+002	1.1837e-010	4.3797e-006
Pu-241	2.0497e-007	7.5839e+003	2.1253e-009	7.8635e-005
Pu-242	8.5622e-012	3.1680e-001	8.8779e-014	3.2848e-009
Ra-226	1.6605e-009	6.1439e+001	1.7217e-011	6.3704e-007

Se-79	6.2270e-011	2.3040e+000	6.4566e-013	2.3889e-008
Sn-126	1.8681e-011	6.9120e-001	1.9370e-013	7.1668e-009
Sr-90	2.4908e-005	9.2160e+005	2.5826e-007	9.5558e-003
Tc-99	1.4789e-005	5.4719e+005	1.5334e-007	5.6737e-003
Th-230	5.7081e-010	2.1120e+001	5.9186e-012	2.1899e-007
Th-232	2.4908e-009	9.2160e+001	2.5826e-011	9.5558e-007
U-233	7.5243e-011	2.7840e+000	7.8017e-013	2.8866e-008
U-234	2.0238e-008	7.4881e+002	2.0984e-010	7.7642e-006
U-235	8.5622e-010	3.1680e+001	8.8779e-012	3.2848e-007
U-238	1.9719e-008	7.2960e+002	2.0446e-010	7.5650e-006
Y-90	2.4908e-005	9.2160e+005	2.5826e-007	9.5558e-003
Zr-93	1.1416e-007	4.2239e+003	1.1837e-009	4.3797e-005

Buildup: The material reference is Source Integration Parameters	
X Direction	10
Y Direction	20
Z Direction	20

Nominal Case	
Dose Point #1	**(100, 1425, 1800) cm**
Variable	**Not Applicable**

Nominal Case			
Dose Point #1	**(100, 1425, 1800) cm**		
Variable	**Not Applicable**		
Results (Summed over energies)	**Units**	**Without Buildup**	**With Buildup**
Effective Dose (ICRP 74 - 1997)			
Antero-posterior Geometry	mSv/hr	2.569e-004	4.129e-004
Postero-anterior Geometry	mSv/hr	2.282e-004	3.668e-004
Left Lateral Geometry	mSv/hr	1.836e-004	2.950e-004
Lateral Geometry	mSv/hr	0.000e+000	0.000e+000
Right Lateral Geometry	mSv/hr	1.740e-004	2.796e-004
Rotational Geometry	mSv/hr	2.172e-004	3.490e-004
Isotropic Geometry	mSv/hr	1.896e-004	3.047e-004

H.5 Results

Table H-3 shows the estimated radiological consequence to the WWTP worker for a WWTP pressure boundary failure. The effective dose rate to a worker 1 m above the spill is 4.1E-04 mSv/h. With an exposure time of 10 minutes, this corresponds to a radiological consequence of 6.9E-05 mSv. The radiological consequence to the worker is 7.6E-05 mSv due to inhalation and external radiation exposure pathways. The primary radionuclides contributing to the inhalation dose are Co-60 and tritium.

Table H-3
Worker Radiological Consequence due to WWTP Pressure Boundary Failure

1	2	3	4	5	6
Radionuclide	**Wastewater concentration (Bq/L)**	**Activity in wastewater (Bq)**	**Respirable source term (Bq)**	**Inhalation DCF (Sv/Bq)**	**Inhalation dose (mSv)**
Ag-108m	1.80E-04	1.73E+01	1.73E-03	1.90E-08	9.48E-13
Am-241	2.80E-03	2.69E+02	2.69E-02	2.70E-05	2.10E-08
Am-243	1.70E-06	1.63E-01	1.63E-05	2.70E-05	1.27E-11
C-14	3.10E+00	2.98E+05	2.98E+01	6.50E-12	5.59E-12
Cl-36	5.90E-02	5.66E+03	5.66E-01	5.10E-09	8.34E-11
Co-60	1.30E+03	1.25E+08	1.25E+04	1.70E-08	6.13E-06
Cs-135	4.10E-05	3.94E+00	3.94E-04	9.90E-10	1.13E-14
Cs-137	9.30E-01	8.93E+04	8.93E+00	6.70E-09	1.73E-09
H-3	1.40E+05	1.34E+10	1.34E+06	2.70E-11	1.05E-06
I-129	9.10E-02	8.74E+03	8.74E-01	5.10E-08	1.29E-09
Mo-93	4.10E-07	3.94E-02	3.94E-06	1.40E-09	1.59E-16
Nb-94	1.50E-02	1.44E+03	1.44E-01	2.50E-08	1.04E-10
Ni-59	1.70E-04	1.63E+01	1.63E-03	2.20E-10	1.04E-14
Ni-63	4.40E-02	4.22E+03	4.22E-01	5.20E-10	6.34E-12
Np-237	6.30E-07	6.05E-02	6.05E-06	1.50E-05	2.62E-12
Pu-239	4.40E-03	4.22E+02	4.22E-02	3.20E-05	3.90E-08
Pu-241	7.90E-02	7.58E+03	7.58E-01	5.80E-07	1.27E-08
Pu-242	3.30E-06	3.17E-01	3.17E-05	3.10E-05	2.84E-11
Ra-226	6.40E-04	6.14E+01	6.14E-03	2.20E-06	3.90E-10
Se-79	2.40E-05	2.30E+00	2.30E-04	3.10E-09	2.06E-14
Sn-126	7.20E-06	6.91E-01	6.91E-05	1.80E-08	3.59E-14
Sr-90	9.60E+00	9.22E+05	9.22E+01	7.70E-08	2.05E-07
Tc-99	5.70E+00	5.47E+05	5.47E+01	3.20E-09	5.06E-09
Th-230	2.20E-04	2.11E+01	2.11E-03	2.80E-05	1.71E-09
Th-232	9.60E-04	9.22E+01	9.22E-03	2.90E-05	7.72E-09
U-233	2.90E-05	2.78E+00	2.78E-04	6.90E-06	5.55E-11
U-234	7.80E-03	7.49E+02	7.49E-02	6.80E-06	1.47E-08
U-235	3.30E-04	3.17E+01	3.17E-03	6.10E-06	5.58E-10
U-238	7.60E-03	7.30E+02	7.30E-02	5.70E-06	1.20E-08
Zr-93	4.40E-02	4.22E+03	4.22E-01	2.90E-08	3.54E-10
				TOTAL	**7.50E-06**

Notes for each column

1 The list of radionuclides in NSDF waste [H-7]

2 Radionuclide concentration in wastewater near the end of the Operations phase [H-1]

3 The total activity in the membrane filter feed and process tanks, Column 3 x 96 000 L

4 $Q = MAR \times DR \times LPF \times ARF \times RF$, where MAR = Column 3, DR=1, LPF=1, ARF=2E-04, RF=0.5

5 Taken from ICRP 119, Table A, 5 µm particulate size [H-4]. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.

6 $D_{inh} = \frac{Q \times B \times DCF_{inh} \times t}{V} \times \frac{1000\ mSv}{1\ Sv}$, where Q=Column 4, V=6925 m^3, B=1.2 m^3/h, t=0.17 h, DCF_{inh} = Column 5

H.6 References

[H-1] AECOM, *Leachate and Wastewater Characterization (Quantity and Quality)*, B1551-508600-REPT-001, Revision 3, 2019 May.

[H-2] AECOM, *Equipment List*, B1551-508234-EL-001, Revision 0, 2017 March.

[H-3] *Standard Assumptions and Input Parameters for the Calculation of On-Site and Off-Site Doses Following Hypothetical Accidental Atmospheric Radioactive Releases from Facilities at CRL*, 145-508770-NSN-001, Revision 1, 2017 March.

[H-4] International Commission on Radiological Protection (ICRP), *Compendium of Dose Coefficients based on ICRP Publication 60,* ICRP Publication 119. Ann. ICRP 41(s), 2012.

[H-5] Canadian Nuclear Safety Commission, *Health Effects Dosimetry and Radiological Protection of Tritium*, INFO-0799, 2010.

[H-6] Canadian Standards Association (CSA), *Guidelines for Calculating Derived Release Limits for Radioactive Material in Airborne and Liquid Effluents for Normal Operation of Nuclear Facilities*, CSA N288.1-14, 2014.

[H-7] AECOM, *Waste Characterization*, 232-508600-REPT-002, Revision 4, 2020 February.

[H-8] *Reference Distribution Coefficient and Calculation of the Effective Distribution Coefficient for the NSDF Engineered Containment Mound (Kd)*, 232-508600-TN-008, Revision 1, 2018 February.

[H-9] International Atomic Energy Agency (IAEA), *Generic Procedures for Assessment and Response During a Radiological Emergency*, IAEA-TECDOC-1162, 2000.

[H-10] *Dose Calculations Pertaining to Respirable Radiation Sources*, 900-508770-FID-008, Revision 0, 2018 December.

[H-11] U.S. Department of Energy (DOE), *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, Reaffirmed 2013.

Appendix I

Failure of the Ion Exchange System

The IX system is used to remove low concentrations of metals and radionuclides from the wastewater, after the chemical precipitation, membrane filtration, and GAC adsorptions steps in the WWTP treatment process.

Feed and pH adjustment tanks, as well as associated pumping equipment, are situated on the inlet to the GAC and IX system, to transfer wastewater into the system and optimize the effectiveness of the IX system. The pH adjustment tank will be sized to provide 20 minutes of hydraulic detention time at a design flow rate of 11.36 m^3/h, while the IX feed tank will accommodate eight hours of wastewater flow at this rate.

Each IX vessel will contain resin specific to the containment to be removed from the wastewater. The design includes two vessels in a lead-lag arrangement for Zeolite (cesium) and SAC resin (for heavy metals and cationic radionuclides).

I.1 Analysis Methodology

I.1.1 Event Scenario

The event involves a pressure build-up in the IX vessel containing SAC resin, with a simultaneous failure of pressure relief components. It is further assumed that the feed pump continues to operate without deadhead. Consequently, a pipe fails, leading to the release of wastewater and spent SAC resin to the floor of the WWTP. The SAC resin is assumed to have reached exhaustion; this equates to 712 bed volumes to exhaustion (approximately 59 days of wastewater treatment) [I-1]. This ensures the scenario and calculations are conservative and bounding.

The assumption that the IX tank involved in the scenario contains SAC resin is bounding, since spent SAC resin contains significantly greater total radioactivity than spent Zeolite resin and GAC, including greater concentrations of radionuclides significant to inhalation and external dose. Particularly, spent SAC resin contains more than two orders of magnitude greater Co-60 activity than the total gross gamma activity in spent Zeolite resin or GAC. Furthermore, spent SAC resin contains approximately three orders of magnitude greater concentration of gross alpha than spent Zeolite resin, including greater concentrations of the alpha emitters with the highest inhalation dose coefficients (e.g. Np, Pu, and Th).

The worker is assumed to remain in the area for 10 minutes during an attempt to mitigate the situation. Given the uncertainty of the exposure duration, the analysis will include a sensitivity calculation for an exposure duration of one hour.

I.1.2 Radionuclide Distribution (Source Term)

The concentration of radionuclides in the SAC resin is calculated in the WWTP Material and Energy Balance Report [I-1] and is shown in Table I-1. The radionuclide concentrations are based on wastewater characteristics that are considered to be maximum during the operations phase (i.e. during the last five years of the operations phase), and includes the anticipated failure of normal waste packages [I-2].

The total activity for a given radionuclide in the SAC resin is calculated by multiplying the concentration by the volume of the SAC resin, which is 2.55 m^3 or 2 550 L [I-1]. This activity is a result of the accumulation of cationic radionuclides in the SAC resin as well as the activity of all other radionuclides in wastewater contained in the resin at this stage of the treatment process. The height of the spilled resin on the floor is assumed to be 0.2 m with a surface area of 12.75 m^2.

For the spill of wastewater from the IX vessel, the concentration of radionuclides is shown in Table I-1. The total volume of the wastewater inside the vessel is assumed to equal the total volume of the vessel, 3.68 m^3 (diameter of 1.37 m and a height of 2.49 m) [I-3], and conservatively does not consider the volume of wet resin. The height of the spilled wastewater is assumed to be 0.02 m and the surface area of the spill is 184 m^2.

Table I-1
Concentration and Activity of Radionuclides in the SAC Resin at Resin Exhaustion

Radionuclide	Concentration in SAC resin (Bq per L of resin)	Activity in SAC resin (Bq)	Concentration in SAC effluent water (Bq/L)	Activity in SAC effluent water (Bq)
Ag-108m	9.46E-02	2.41E+02	6.75E-06	2.48E-02
Am-241	1.47E+00	3.75E+03	1.05E-04	3.86E-01
Am-243	8.93E-04	2.28E+00	6.38E-08	2.35E-04
C-14	9.77E-01	2.49E+03	3.10E+00	1.14E+04
Cl-36	1.86E-02	4.74E+01	5.90E-02	2.17E+02
Co-60	2.66E+05	6.78E+08	1.90E+01	6.98E+04
Cs-135	7.75E-08	1.98E-04	2.46E-07	9.05E-04
Cs-137	1.76E-03	4.48E+00	5.58E-03	2.05E+01
H-3	4.41E+04	1.12E+08	1.40E+05	5.15E+08
I-129	2.87E-02	7.31E+01	9.10E-02	3.35E+02
Mo-93	1.29E-07	3.29E-04	4.10E-07	1.51E-03
Nb-94	7.88E+00	2.01E+04	5.63E-04	2.07E+00
Ni-59	6.03E-06	1.54E-02	1.91E-05	7.04E-02
Ni-63	1.56E-03	3.98E+00	4.95E-03	1.82E+01
Np-237	3.31E-04	8.44E-01	2.36E-08	8.69E-05
Pu-239	2.31E+00	5.90E+03	1.65E-04	6.07E-01
Pu-241	4.15E+01	1.06E+05	2.96E-03	1.09E+01

Radionuclide	Concentration in SAC resin (Bq per L of resin)	Activity in SAC resin (Bq)	Concentration in SAC effluent water (Bq/L)	Activity in SAC effluent water (Bq)
Pu-242	1.73E-03	4.42E+00	1.24E-07	4.55E-04
Ra-226	3.36E-01	8.58E+02	2.40E-05	8.83E-02
Se-79	1.26E-02	3.22E+01	9.00E-07	3.31E-03
Sn-126	3.78E-03	9.65E+00	2.70E-07	9.94E-04
Sr-90	3.77E+02	9.62E+05	8.00E-03	2.94E+01
Tc-99	1.80E+00	4.58E+03	5.70E+00	2.10E+04
Th-230	1.16E-01	2.95E+02	8.25E-06	3.04E-02
Th-232	5.04E-01	1.29E+03	3.60E-05	1.32E-01
U-233	1.59E-06	4.05E-03	5.05E-06	1.86E-02
U-234	4.28E-04	1.09E+00	1.36E-03	4.99E+00
U-235	1.81E-05	4.61E-02	5.74E-05	2.11E-01
U-238	4.17E-04	1.06E+00	1.32E-03	4.87E+00
Zr-93	2.31E+01	5.90E+04	1.65E-03	6.07E+00

I.1.3 On-site Receptor and Location

As depicted in Figure I-1, the WWTP worker is assumed to be 30 cm away from the edge of the spilled resins, without respiratory protection. The worker is assumed to have a breathing rate of 1.2 m^3/h [I-4], and remains in the area for 10 minutes in an attempt to mitigate the spill.

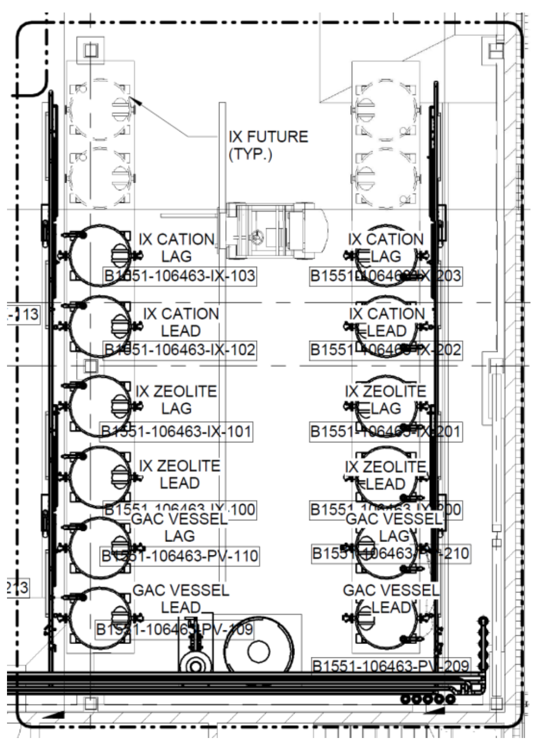


Figure I-1 Area of the Spilled Resins and Worker Location

I.2 Assumptions and Inputs

The following assumptions were made to conservatively calculate the radiological consequences to the on-site receptor, WWTP worker, in the event of a spill of resins:

- Radionuclide concentrations in the wastewater are the maximum during the 50 year operations of the NSDF, accounting for waste package failure of the placed waste.
- The SAC IX resin is exhausted (712 bed volumes of wastewater treated).
- All of the SAC IX resin and wastewater in the IX vessel is spilled.
- The affected volume (for evaporation and resuspension) is conservatively assumed to be half the room volume of the residuals and IX area: ½ (18 m x 28.5 m x 10 m) = 2 565 m^3 to account for the tanks and equipment in the room.
- There is no ventilation in the IX area (or there is a complete failure of the ventilation system).
- The worker remains in the affected area for 10 minutes in an attempt to mitigate the spill.
- The worker inhalation DCFs are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm AMAD (ICRP 119, Table A) [I-5].
- Tritium and C-14 are considered to be HTO and CO_2, respectively (inhalation DCFs from ICRP 119 Table B for workers) [I-5].
- A factor of 1.5 is applied to tritium inhalation DCFs to account for skin absorption [I-6].

I.3 Calculations

This section details the calculation of radiological consequence to the WWTP worker resulting from the spill of SAC IX resin. As shown in Table I-2, radiological consequence to the WWTP worker is assumed to be from the exposure pathways, external radiation and inhalation.

Table I-2
Exposure Pathways for the On-site Worker

Exposure pathway	Included in dose calculation (Yes/No)	Rationale
External	Yes	The worker will be exposed to radiation from the unshielded spent resins.
Immersion	No	It is assumed that the worker will be splashed with wastewater when the pipe ruptures; however, the small amount of radioactivity remaining on the worker's clothes is expected to result in a dose much lower than that from inhalation.
Inhalation	Yes	The tritium in the spilled wastewater will evaporate and be inhaled by the worker. Additionally, the free-fall spill of liquid will generate airborne tritium, which will be inhaled by the worker. Finally, a small portion of the SAC IX resin material will re-suspend into the air and be inhaled by the worker.

Exposure pathway	Included in dose calculation (Yes/No)	Rationale
		Skin absorption of tritium is accounted for by applying a factor of 1.5 to the tritium inhalation DCF [I-6].
Ingestion	No	It is assumed that the worker will not ingest water or IX resin.

The external dose to the worker (D_{ext}) is determined by equation I1:

$$D_{ext} = DR_{ext} \times t \qquad \text{(I1)}$$

Where:

DR_{ext} - effective dose rate from the spilled resins (mSv/h)
t - duration of exposure (h), assumed to be 10 min = 0.17 hours or 1 hour for the sensitivity case.

The dose rate at 30 cm from the spilled resin was calculated using MicroShield. The inputs and results of MicroShield are shown in Appendix H. A rectangular volume was used to model the spilled resins in MicroShield. The dimensions are shown in Table I-3.

Table I-3
Resins Spill Dimensions and Material

Dimension	Assumed value
Length	3.57 m
Width	3.57 m
Height	0.20 m
Total volume	2.55 m^3
Density (material)	1 g/cm^3 (water)

The dose rate at 30 cm from the edge of the spill is 3.1E-02 mSv/h. With a ten minute exposure time, the dose is 5.2E-03 mSv.

The total inhalation dose to the worker ($D_{inh,TOT}$) is determined by equation I2:

$$D_{inh,TOT} = D_{inh,res} + D_{inh,evp} + D_{inh,drop} \qquad \text{(I2)}$$

Where:

$D_{inh,res}$ - inhalation dose due to resuspension of radioactive material from the spent resins (mSv)
$D_{inh,evp}$ - inhalation dose due to the evaporation of tritium in the spilled wastewater from the IX vessel (mSv)
$D_{inh,drop}$ - inhalation dose due to the free-fall spill of liquid and subsequent resuspension of water droplets (mSv)

Resuspension of Radioactive Material

The respirable source term for the spill and resuspension of spilled SAC resin is determined by equation I3:

$$Q = MAR \times DR \times LPF \times ARF \times RF \qquad \text{(I3)}$$

Where:

MAR	- material at risk, the total activity in SAC resins at exhaustion (Bq), see Table I-1
DR	- damage ratio, the fraction of MAR actually impacted by the accident, assumed to be 1
LPF	- leakpath factor, the fraction of the radionuclides passing through filtration systems, assumed to be 1
ARF	- airborne release fraction, the fraction of radioactive material suspended in air as an aerosol, assumed to be 5E-05, which is bounding for a free-fall spill of slurries (<40% solids) from 3 m or less [I-7]
RF	- respirable fraction, the fraction of airborne radionuclides inhaled, assumed to be 0.8, which is bounding for a free-fall spill of slurries (<40% solids) from 3 m or less [I-7]

The inhalation dose due to resuspension of radioactive material ($D_{inh,res}$) is determined by equation I4:

$$D_{inh,res} = \frac{Q \times B \times DCF_{inh} \times t_{exp}}{V} \times \frac{1\ hr}{3600\ s} \times \frac{1000\ mSv}{1\ Sv} \qquad \text{(I4)}$$

Where:

Q	- respirable source term (Bq)
DCF_{inh}	- inhalation dose conversion factor (Sv/Bq) [I-5]
B	- breathing rate for the worker (m^3/h), assumed to be 1.2 m^3/h [I-4]
t_{exp}	- worker exposure time (s), assumed to be 600 s or 3 600 s (sensitivity case for 1 hour exposure)
V	- effective volume of air contaminated by resuspension from the spill (m^3), assumed to be 2 565 m^3

The committed effective dose to the WWTP worker resulting from a resuspension of spent resin particulates is 3.8E-05 mSv. Details of the calculation are provided in Table 1-4.

Inhalation of Fine Water Droplets Following Free-Fall Spill of Liquid

The respirable source term for the spill and resuspension of wastewater in the IX vessel is determined by equation I3:

$$Q = MAR \times DR \times LPF \times ARF \times RF \qquad \text{(I3)}$$

Where:

MAR	- material at risk, the total activity in the IX vessel water (Bq), see Table I-1
DR	- damage ratio, the fraction of MAR actually impacted by the accident, assumed to be 1.
LPF	- leak path factor, the fraction of the radionuclides passing through filtration systems, assumed to be 1.
ARF	- airborne release fraction, the fraction of radioactive material suspended in air as an aerosol, assumed to be 2E-04, which is bounding for free-fall spill of aqueous solutions from a height of 3 m or less [I-7].
RF	- respirable fraction, the fraction of airborne radionuclides inhaled, assumed to be 0.5, which is bounding for free-fall spill of aqueous solutions from a height of 3 m or less [I-7].

The inhalation dose to the worker as a result of airborne water droplets ($D_{inh,drop}$) is determined by equation I5:

$$D_{inh,drop} = \frac{Q \times B \times DCF_{inh} \times t_{exp}}{V} \times \frac{1\,h}{3600\,s} \times \frac{1000\,mSv}{1\,Sv} \qquad \text{(I5)}$$

The committed effective dose to the worker resulting from a resuspension of water is 1.2E-07 mSv. Details of the calculation are provided in Table I-4.

Evaporation of Tritium

The air concentration of tritium (C_{air}) from evaporation of the IX vessel wastewater is determined by equation I6:

$$C_{air}(t) = \frac{\varphi_{HTO} \times M_{HTO} \times C_{H3,fw} \times \frac{1\,L}{1000\,g} \times A_{spill}}{V_{air}} \times t \qquad \text{(I6)}$$

Where:

φ_{HTO}	- molar flux of HTO into air (mol·m^{-2}·s^{-1})
M_{HTO}	- molar mass of HTO (g/mol), 20 g/mol
$C_{H3,fw}$	- concentration of tritium in the IX vessel free water (Bq/L), 1.40E+05 Bq/L
A_{spill}	- surface area of the spill (m^2), assumed to be 184 m^2
V_{air}	- effective volume of air contaminated by resuspension from the spill (m^3), assumed to be 2 565 m^3
t	- time since the spill occurred assumed to be 600 s or 3 600 s (sensitivity case for 1 hour exposure) (s)

The molar flux of HTO into air (φ_{HTO}) is determined by equation I7 [1-8]:

$$\varphi_{HTO} = 2.494 \times 10^{-7} |P^* - P^a|^{0.22} \times (P^* - P^a) \qquad \text{(I7)}$$

Where:

P^*	- saturated vapour pressure of HTO at room temperature, 20 ºC (Pa), 1,995 Pa [I-10]
P^a	- partial pressure of water in air (Pa), assumed to be zero

It is assumed that the constant molar flux gives rise to an initially linearly increasing concentration of tritium in the air. The inhalation dose due to evaporation of tritium from the IX vessel wastewater ($D_{inh,evp}$) is determined by equation I8:

$$D_{inh,evp} = \int_{t=0}^{t_{exp}} C_{air}(t) \times DCF_{inh,H3} \times B \times \frac{1\,h}{3600\,s} \times \frac{1000\,mSv}{1\,Sv}\, dt \qquad \text{(I8)}$$

$$D_{inh,evp} = \frac{\varphi_{HTO} \times M_{HTO} \times C_{H3,fw} \times \frac{1\,L}{1000\,g} \times A_{spill}}{V_{air}} \times DCF_{inh,H3} \times B \times \frac{1\,h}{3600\,s} \times \frac{1000\,mSv}{1\,Sv} \int_{t=0}^{t_{exp}} t\, dt$$

$$D_{inh,evp} = \frac{\varphi_{HTO} \times M_{HTO} \times C_{H3,fw} \times \frac{1\,L}{1000\,g} \times A_{spill}}{V_{air}} \times DCF_{inh,H3} \times B \times \frac{1\,h}{3600\,s} \times \frac{1000\,mSv}{1\,Sv} \times \frac{t^2}{2}$$

Where:

$DCF_{inh,H3}$	- inhalation dose conversion factor for tritium (Sv/Bq) [I-5]
B	- breathing rate for the worker (m^3/h), assumed to be 1.2 m^3/h [I-4]

The concentration in air and the resulting inhalation dose to the worker is shown in Figure I-2. With an exposure time of 10 minutes, the radiological consequence to the worker is 8.6E-07 mSv. With an exposure time of one hour, the radiological consequence to the worker would be 3.1E-05 mSv.

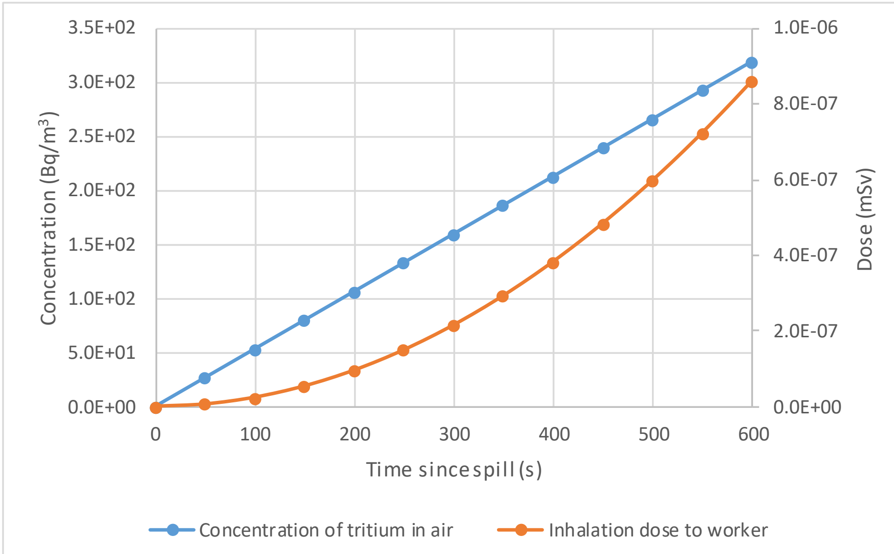


Figure I-2 Concentration in Air and Dose to Worker due to the Evaporation of Tritiated Wastewater

Table I-4
Inhalation Dose to the Worker from Failure of Ion Exchange System

1	2	3	4	5	6	7	8
Radionuclide	**Concentration in SAC resin (Bq/L)**	**Activity in SAC resin (Bq)**	**Concentration in SAC ion exchange vessel water (Bq/L)**	**Activity in SAC ion exchange water (Bq)**	**Inhalation DCF (Sv/Bq)**	**Inhalation dose from resins (mSv)**	**Inhalation dose from free-fall of water (mSv)**
Ag-108m	9.46E-02	2.41E+02	6.75E-06	2.48E-02	1.90E-08	1.43E-11	3.68E-15
Am-241	1.47E+00	3.75E+03	1.05E-04	3.86E-01	2.70E-05	3.16E-07	8.13E-11
Am-243	8.93E-04	2.28E+00	6.38E-08	2.35E-04	2.70E-05	1.92E-10	4.94E-14
C-14	9.77E-01	2.49E+03	3.10E+00	1.14E+04	6.50E-12	5.05E-14	5.78E-13
Cl-36	1.86E-02	4.74E+01	5.90E-02	2.17E+02	5.10E-09	7.54E-13	8.63E-12
Co-60	2.66E+05	6.78E+08	1.90E+01	6.99E+04	1.70E-08	3.60E-05	9.27E-09
Cs-135	7.75E-08	1.98E-04	2.46E-07	9.05E-04	9.90E-10	6.10E-19	6.99E-18
Cs-137	1.76E-03	4.49E+00	5.58E-03	2.05E+01	6.70E-09	9.38E-14	1.07E-12
H-3	4.41E+04	1.12E+08	1.40E+05	5.15E+08	2.70E-11	9.47E-09	1.08E-07
I-129	2.87E-02	7.32E+01	9.10E-02	3.35E+02	5.10E-08	1.16E-11	1.33E-10
Mo-93	1.29E-07	3.29E-04	4.10E-07	1.51E-03	1.40E-09	1.44E-18	1.65E-17
Nb-94	7.88E+00	2.01E+04	5.63E-04	2.07E+00	2.50E-08	1.57E-09	4.04E-13
Ni-59	6.03E-06	1.54E-02	1.91E-05	7.03E-02	2.20E-10	1.06E-17	1.21E-16
Ni-63	1.56E-03	3.98E+00	4.95E-03	1.82E+01	5.20E-10	6.45E-15	7.39E-14
Np-237	3.31E-04	8.44E-01	2.36E-08	8.68E-05	1.50E-05	3.95E-11	1.02E-14
Pu-239	2.31E+00	5.89E+03	1.65E-04	6.07E-01	3.20E-05	5.88E-07	1.51E-10
Pu-241	4.15E+01	1.06E+05	2.96E-03	1.09E+01	5.80E-07	1.91E-07	4.93E-11
Pu-242	1.73E-03	4.41E+00	1.24E-07	4.56E-04	3.10E-05	4.27E-10	1.10E-13
Ra-226	3.36E-01	8.57E+02	2.40E-05	8.83E-02	2.20E-06	5.88E-09	1.51E-12
Se-79	1.26E-02	3.21E+01	9.00E-07	3.31E-03	3.10E-09	3.11E-13	8.01E-17
Sn-126	3.78E-03	9.64E+00	2.70E-07	9.94E-04	1.80E-08	5.41E-13	1.39E-16
Sr-90	3.77E+02	9.61E+05	8.00E-03	2.94E+01	7.70E-08	2.31E-07	1.77E-11
Tc-99	1.80E+00	4.59E+03	5.70E+00	2.10E+04	3.20E-09	4.58E-11	5.23E-10
Th-230	1.16E-01	2.96E+02	8.25E-06	3.04E-02	2.80E-05	2.58E-08	6.63E-12
Th-232	5.04E-01	1.29E+03	3.60E-05	1.32E-01	2.90E-05	1.16E-07	3.00E-11
U-233	1.59E-06	4.05E-03	5.05E-06	1.86E-02	6.90E-06	8.73E-14	1.00E-12
U-234	4.28E-04	1.09E+00	1.36E-03	5.00E+00	6.80E-06	2.31E-11	2.65E-10
U-235	1.81E-05	4.62E-02	5.74E-05	2.11E-01	6.10E-06	8.78E-13	1.00E-11
U-238	4.17E-04	1.06E+00	1.32E-03	4.86E+00	5.70E-06	1.89E-11	2.16E-10
Zr-93	2.31E+01	5.89E+04	1.65E-03	6.07E+00	2.90E-08	5.33E-09	1.37E-12
					TOTAL	**3.75E-05**	**1.19E-07**

Notes for each column:

1 The list of radionuclides in NSDF waste [I-2].

2 The concentration of radionuclides in SAC resin (activity per L of resin) are from the WWTP Material and Energy Balance [I-1].

3 The activity in SAC resin, calculated as Column 2 x volume of SAC resin (2 550 L) [I-1].

4 The concentration of radionuclides in SAC IX vessel water are from the WWTP Material and Energy Balance [I-1].

5 The activity in SAC ion exchange water, calculated as Column 4 x volume of IX vessel (3.68 m^3) [I-3].

6 Taken from ICRP 119, Table A. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.

7 $D_{inh,res} = \frac{Q \times B \times DCF_{inh} \times t_{exp}}{V} \times \frac{1\,hr}{3600\,s} \times \frac{1000\,mSv}{1\,Sv}$, Q=Column 3 x ARF=5E-05 x RF=0.8, B = 1.2 m^3/h, DCF_{inh}=Column 6, t_{exp} = 600 s, V = 2 565 m^3

8 $D_{inh,drop} = \frac{Q \times B \times DCF_{inh} \times t_{exp}}{V} \times \frac{1\ hr}{3600\ s} \times \frac{1000\ mSv}{1\ Sv}$, Q=column 5 x ARF=2E-04 x RF=0.5, B = 1.2 m^3/h, DCF_{inh}=Column 6, t_{exp} = 600 s, V = 2 565 m^3

I.4 Results

As shown in Table I-5, the radiological consequence to the worker for a spill of spent resin for a 10 minute exposure time is 5.2E-03 mSv. To address the uncertainty with the exposure duration, doses were calculated for a one hour exposure and are also shown in Table I-5. The dominant contributor to the radiological consequence (dose) is the external gamma radiation from the spent resin.

Table I-5
Radiological Consequence to the Worker from Failure of Ion Exchange System

Exposure Pathway	Dose for 10 minute exposure (mSv)	Dose for 1 hour exposure (mSv)
External radiation (at 30 cm)	5.2E-03	3.1E-02
Inhalation of re-suspended radionuclides	3.8E-05	2.3E-04
Inhalation of water droplets	1.2E-07	7.2E-07
Inhalation of evaporated tritium	8.6E-07	3.1E-05
TOTAL	**5.2E-03**	**3.1E-02**

I.5 References

[I-1] AECOM, *WWTP Material and Energy Balance Report*, B1551-503212-REPT-001, Revision 2, 2018 November.

[I-2] AECOM, *Leachate and Wastewater Characterization (Quantity and Quality)*, B1551-508600-REPT-001, Revision 3, 2019 May.

[I-3] AECOM, *Equipment List*, B1551-508234-EL-001, Revision 0, 2017 March.

[I-4] *Standard Assumptions and Input Parameters for the Calculation of On-Site and Off-Site Doses Following Hypothetical Accidental Atmospheric Radioactive Releases from Facilities at CRL*, 145-508770-NSN-001, Revision 1, 2017 March.

[I-5] International Commission on Radiological Protection (ICRP), *Compendium of Dose Coefficients based on ICRP Publication 60,* ICRP Publication 119, Ann. ICRP 41(s), 2012.

[I-6] CNSC, *Health Effects, Dosimetry and Radiological Protection of Tritium*, INFO-0799, 2010 April.

[I-7] U.S. Department of Energy, *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, Reaffirmed 2013.

[1-8] A. Busigin and K. Kalyanam, *Estimation of the Tritium Release Rate from a Spill of Tritiated Water*, DND Report No. 90031, Volume 21, 1992 March.

[1-9] Oak Ridge National Laboratory, *Thermophysical Properties of Saturated Light and Heavy Water for Advanced Neutron Source Applications*, ORNL/TM-12322, 1993.

Appendix J

Failure of the Residuals Management System

The residuals management system includes storage and conditioning tanks to provide equalization and chemical conditioning of residuals produced by the chemical precipitation and membrane filtration processes, and a recessed chamber filter press for de-watering residuals. The two residuals storage tanks will each have approximately 80 m^3 capacity. The filter press feed tank has a capacity of approximately 9.5 m^3.

Residuals are separated from the water in the filter press, and the dewatered residuals are stored in the dewatered residuals bin, and eventually disposed of in the ECM. The filter press area is designated as a Radiological Safety Zone 3. The residuals management support systems include compressed air for operating filter press, a body feed chemical system for conditioning the residuals in the filter press feed tank, and a pre-coat system used for applying a diatomaceous earth or Perlite (alumina silicate) pre-coat solution to enhance filter press operation, if needed.

J.1 Analysis Methodology

J.1.1 Event Scenario

The event involves a spill of all residuals from a full dewatered residuals bin inside the filter press enclosure during the transfer of the container to the processing area (e.g. for compressing or grouting). Since this event involves the maximum amount of radioactive material available, it is considered to bound other possible events involving the filter press, including:

- Small amounts of residual filter cake being ejected from the filter press during pressurization or loading of the residuals.
- Small amounts of residual filter cake becoming airborne during cleaning of the filter plates after they have been separated.

The worker remains in the area for 10 minutes in an attempt to mitigate the spill. Given the uncertainty of the exposure duration, the analysis includes a sensitivity calculation for an exposure duration of 1 hour.

J.1.2 Radionuclide Distribution (Source Term)

The concentration of radionuclides in the dewatered filter press cake is calculated in the WWTP Material and Energy Balance Report [J-1] and is shown in Table J-1. The radionuclide concentrations are based on wastewater characteristics that are considered to be maximum during the operations phase (i.e. during the last five years of the operations phase), and includes the anticipated failure of normal waste packages [J-2].

The total activity for a given radionuclide in the dewatered filter press cake is calculated by multiplying the concentration by the inner volume of the dewatered residuals bin, flexible container, which is 2.72 m^3 or 2 720 L (1.83 m long x 1.22 m wide x 1.22 m high) [J-3]. It is also assumed that when spilled, the height of the filter press cake on the floor is 0.5 m, with a square area of 5.45 m^2 (2.33 m x 2.33 m).

Table J-1
Concentration and Activity of Radionuclides in De-watered Filter Press Cake Inside a Flexible Container (De-watered Residuals Bin)

Radionuclide	Concentration in filter press cake (Bq/L)	Activity in filter press cake (Bq)
Ag-108m	1.26E-02	3.43E+01
Am-241	1.96E-01	5.34E+02
Am-243	1.19E-04	3.24E-01
C-14	2.17E+00	5.91E+03
Cl-36	4.13E-02	1.12E+02
Co-60	2.56E+05	6.97E+08
Cs-135	2.87E-05	7.82E-02
Cs-137	6.51E-01	1.77E+03
H-3	9.80E+04	2.67E+08
I-129	6.37E-02	1.74E+02
Mo-93	2.87E-07	7.82E-04
Nb-94	1.05E+00	2.86E+03
Ni-59	4.18E-02	1.14E+02
Ni-63	1.08E+01	2.94E+04
Np-237	4.40E-05	1.20E-01
Pu-239	3.07E-01	8.36E+02
Pu-241	5.52E+00	1.50E+04
Pu-242	2.30E-04	6.26E-01
Ra-226	4.47E-02	1.22E+02
Se-79	1.68E-03	4.58E+00
Sn-126	5.03E-04	1.37E+00
Sr-90	2.52E+03	6.86E+06
Tc-99	3.99E+00	1.09E+04
Th-230	1.54E-02	4.19E+01
Th-232	6.70E-02	1.82E+02
U-233	6.64E-03	1.81E+01
U-234	1.79E+00	4.88E+03
U-235	7.56E-02	2.06E+02
U-238	1.74E+00	4.74E+03
Zr-93	3.07E+00	8.36E+03

J.1.3 Dose Receptor and Location

As depicted in Figure J-1, the WWTP worker is assumed to be 30 cm away from the spilled residuals, inside the filter press enclosure, without respiratory protection. The worker is assumed to breathe at a rate of 1.2 m^3/h [J-4] for 10 minutes while attempting to mitigate the spill.

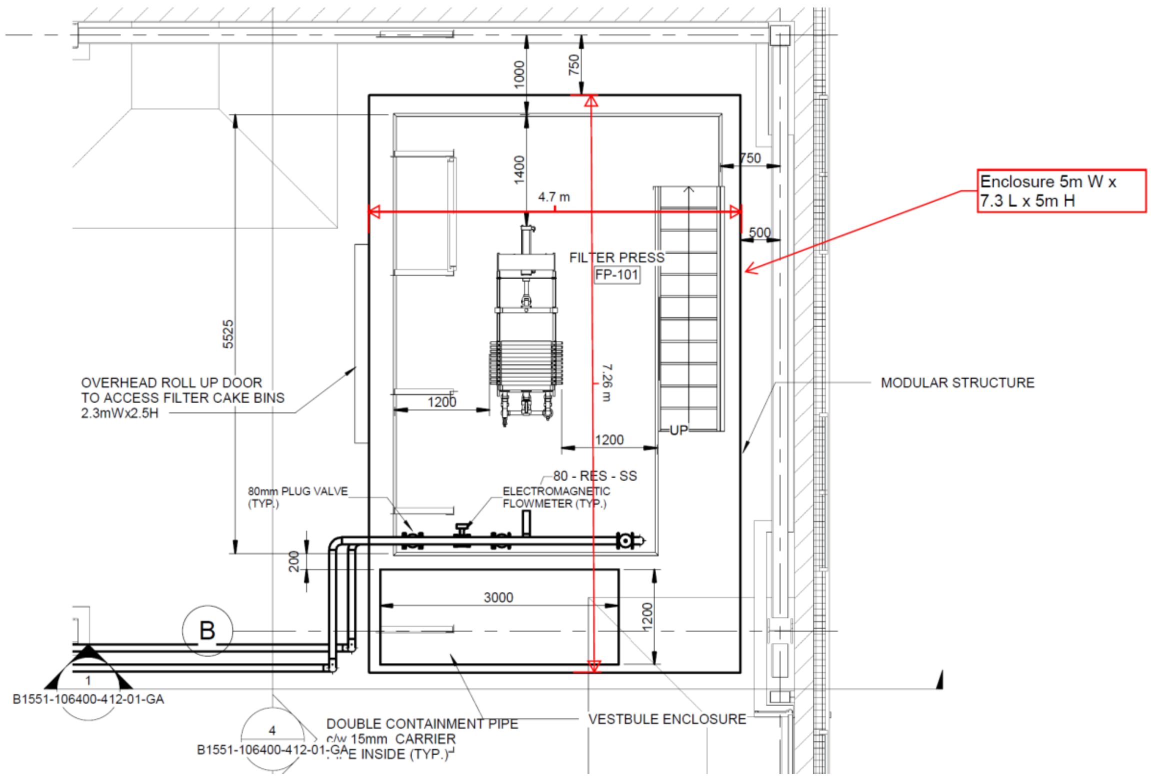


Figure J-1 Area of the Spilled Residuals and Worker Location Inside the Filter Press Enclosure

J.2 Assumptions and Inputs

The following assumptions were made to conservatively calculate the radiological consequences to a WWTP worker in the event of a spill of residuals:

- Radionuclide concentrations in wastewater are the maximum during the 50 years of operations, accounting for waste package failure of placed waste.
- The entire inner volume of the residuals container is filled with filter press cake.
- All of the filter press cake is spilled within the filter press enclosure. Note: this is bounding of a spill in a different area, since the enclosure volume results in a higher air concentration.
- The affected volume (for resuspension) is half the volume of the filter press enclosure: ½ (5 m x 7.3 m x 5 m) = 91 m^3 to account for the filter press equipment.
- There is no ventilation in the filter press enclosure (or there is a complete failure of the ventilation system).

- The worker remains in the affected area for 10 minutes in an attempt to mitigate the spill.
- The worker inhalation DCFs are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm AMAD (ICRP 119, Table A) [J-5].
- Tritium and C-14 are considered to be HTO and CO_2, respectively (inhalation DCFs from ICRP 119 Table B for workers) [J-5].
- A factor of 1.5 is applied to tritium inhalation DCF to account for skin absorption [J-6].

J.3 Calculations

This section details the radiological consequence calculation or radiation dose to the worker resulting from the failure of the residuals management system. As shown in Table J-2, the radiation dose to the WWTP worker, is assumed to be from the exposure pathways, external radiation and inhalation.

Table J-2
Exposure Pathways for the On-site Worker

Exposure pathway	Included in dose calculation (Yes/No)	Rationale
External	Yes	The worker will be exposed to radiation from the unshielded filter press cake.
Immersion	No	The dewatered residuals contain negligible amounts of free water, therefore it is assumed that there is a negligible release of water, which could result in a splashing of the worker. Any dose from splashing is negligible compared to inhalation dose.
Inhalation	Yes	A small portion of the residuals will re-suspend into the air and be inhaled by the worker. Skin absorption of tritium is accounted for by applying a factor of 1.5 to the tritium inhalation DCF [J-6].
Ingestion	No	It is assumed that the worker will not ingest solids.

The external dose to the worker (D_{ext}) is determined by equation J1:

$$D_{ext} = DR_{ext} \times t \qquad \text{(J1)}$$

Where:

DR_{ext} - effective dose rate from the spilled filter press cake (mSv/h)
t - duration of exposure (h), assumed to be 10 min = 0.17 hr, or 1 hour in sensitivity case

The dose rate at 30 cm from the spilled filter press cake was calculated using MicroShield. The inputs and results of MicroShield are shown in Table J-6. A rectangular volume was used to model the spilled filter press cake in MicroShield. The dimensions are shown in Table J-3.

Table J-3
Residuals Spill Dimensions and Materials

Dimension	Assumed value
Length	2.33 m
Width	2.33 m
Height	0.5 m
Total volume	2.72 m^3
Density (material)	1.5 g/cm^3 (soil)

The dose rate at 30 cm from the edge of the spill is 2.8E-02 mSv/h. With a 10 minute exposure time, the dose is 4.6E-03 mSv.

The respirable source term for the spill and resuspension of spilled filter press cake is determined by equation J2:

$$Q = MAR \times DR \times LPF \times ARF \times RF \qquad \text{(J2)}$$

Where:

- MAR - material at risk, the total activity in filter press cake (Bq), see Table J-1.
- DR - damage ratio, the fraction of MAR actually impacted by the accident, assumed to be 1
- LPF - leakpath factor, the fraction of the radionuclides passing through filtration systems, assumed to be 1
- ARF - airborne release fraction, the fraction of radioactive material suspended in air as an aerosol, assumed to be 1E-04. This is based on the bounding ARF of 5E-05 for a free-fall spill of slurries (< 40% solids) from 3 m or less [J-7], and has been multiplied by two to conservatively account for the fact that a slurry may not be an exact representation of spilled resin media or filter press cake. The actual drop of residuals would occur from a height of approximately 1.5 m, and the majority would be contained within the container and not a free-fall.
- RF - respirable fraction, the fraction of airborne radionuclides inhaled, assumed to be 1. While the bounding RF for a free-fall spill of liquid slurry (< 40% solids) from 3 m or less is 0.8, a value of 1 is selected to conservatively address uncertainty in filter press cake physical characteristics compared to a slurry [J-7].

The inhalation dose due to resuspension of radioactive material ($D_{inh,res}$) is determined by equation J3:

$$D_{inh,res} = \frac{Q \times B \times DCF_{inh} \times t_{exp}}{V} \times \frac{1\,h}{3600\,s} \times \frac{1000\,mSv}{1\,Sv} \qquad \text{(J3)}$$

Where:

- Q - respirable source term (Bq)
- DCF_{inh} - inhalation dose conversion factor (Sv/Bq) [J-6]
- B - breathing rate for the worker (m^3/h), assumed to be 1.2 m^3/h [J-4]]
- t_{exp} - worker exposure time (s), assumed to be 600 s or 3 600 s (sensitivity case for 1 hour exposure).
- V - effective volume of air contaminated by resuspension from the spill (m^3), assumed to be 91 m^3

The committed effective dose to the worker resulting from a resuspension of radioactive particulates is 2.7E-03 mSv. Details of the calculation are provided in Table J-4.

Table J-4
Inhalation Dose to the Worker from Spilled Filter Press Cake

1 Radionuclide	2 Concentration in filter press cake (Bq/L)	3 Activity in residuals bin (Bq)	4 Inhalation DCF (Sv/Bq)	5 Inhalation dose from residuals (mSv)
Ag-108m	1.26E-02	3.43E+01	1.90E-08	1.43E-10
Am-241	1.96E-01	5.34E+02	2.70E-05	3.16E-06
Am-243	1.19E-04	3.24E-01	2.70E-05	1.92E-09
C-14	2.17E+00	5.91E+03	6.50E-12	8.42E-12
Cl-36	4.13E-02	1.12E+02	5.10E-09	1.26E-10
Co-60	2.56E+05	6.97E+08	1.70E-08	2.60E-03
Cs-135	2.87E-05	7.82E-02	9.90E-10	1.70E-14
Cs-137	6.51E-01	1.77E+03	6.70E-09	2.60E-09
H-3	9.80E+04	2.67E+08	2.70E-11	1.58E-06
I-129	6.37E-02	1.74E+02	5.10E-08	1.94E-09
Mo-93	2.87E-07	7.82E-04	1.40E-09	2.40E-16
Nb-94	1.05E+00	2.86E+03	2.50E-08	1.57E-08
Ni-59	4.18E-02	1.14E+02	2.20E-10	5.49E-12
Ni-63	1.08E+01	2.94E+04	5.20E-10	3.35E-09
Np-237	4.40E-05	1.20E-01	1.50E-05	3.94E-10
Pu-239	3.07E-01	8.36E+02	3.20E-05	5.86E-06
Pu-241	5.52E+00	1.50E+04	5.80E-07	1.91E-06
Pu-242	2.30E-04	6.26E-01	3.10E-05	4.26E-09
Ra-226	4.47E-02	1.22E+02	2.20E-06	5.87E-08
Se-79	1.68E-03	4.58E+00	3.10E-09	3.11E-12
Sn-126	5.03E-04	1.37E+00	1.80E-08	5.41E-12
Sr-90	2.52E+03	6.86E+06	7.70E-08	1.16E-04
Tc-99	3.99E+00	1.09E+04	3.20E-09	7.62E-09
Th-230	1.54E-02	4.19E+01	2.80E-05	2.57E-07
Th-232	6.70E-02	1.82E+02	2.90E-05	1.16E-06
U-233	6.64E-03	1.81E+01	6.90E-06	2.74E-08
U-234	1.79E+00	4.88E+03	6.80E-06	7.27E-06
U-235	7.56E-02	2.06E+02	6.10E-06	2.75E-07
U-238	1.74E+00	4.74E+03	5.70E-06	5.92E-06
Zr-93	3.07E+00	8.36E+03	2.90E-08	5.32E-08
			TOTAL	**2.74E-03**

Notes for each column

The list of radionuclides in NSDF waste [J-8].

The concentration of radionuclides in dewatered filter press cake (activity per L of filter press cake), taken from the WWTP Material and Energy Balance [J-1].

The activity in filter press cake, calculated as Column 2 x volume of filter press cake, which is assumed to be the inner volume of the flexible container (1.83 m x 1.22 m x 1.22 m = 2.72 m^3) [J-3].

Taken from ICRP 119, Table A. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.

$D_{inh,res} = \frac{Q \times B \times DCF_{inh} \times t_{exp}}{V} \times \frac{1\ hr}{3600\ s} \times \frac{1000\ mSv}{1\ Sv}$, Q=Column 3 x ARF=1E-04, B = 1.2 m^3/h, DCF_{inh}=Column 4, t_{exp} = 600 s, V = 91.25 m^3

J.4 Results

As shown in Table J-5, the radiological consequence to the WWTP worker for a spill of dewatered filter press cake for a 10 minute exposure time is 7.4E-03 mSv. To address the uncertainty with the exposure duration, doses were calculated for a 1 hour exposure, and are also shown in Table J-5.

Table J-5
Radiological Consequence to the Worker from Spilled Filter Press Cake

Exposure Pathway	Dose for 10 min exposure (mSv)	Dose for 1 hour exposure (mSv)
External (at 30 cm)	4.6E-03	2.8E-02
Inhalation of re-suspended radionuclides	2.7E-03	1.6E-02
TOTAL	**7.4E-03**	**4.4E-02**

Table J-6
MicroShield - Dose Rate Spilled Filter Press Cake

MicroShield 9.07 ISR (9.07-0000)

Date	By	Checked

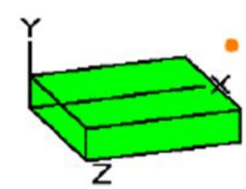
Filename	Run Date	Run Time	Duration
spilled residuals _ new inventory.msd	November 5, 2018	12:10:14 PM	00:00:00

Project Info	
Case Title	Residuals spill
Description	Dose rate to worker 30 cm from the residuals spill
Geometry	13 - Rectangular Volume

Source Dimensions	
Length	233.0 cm (7 ft 7.7 in)
Width	233.0 cm (7 ft 7.7 in)
Height	50.0 cm (1 ft 7.7 in)

Dose Points			
A	X	Y	Z
#1	263.0 cm (8 ft 7.5 in)	100.0 cm (3 ft 3.4 in)	116.5 cm (3 ft 9.9 in)

Shields			
Shield N	Dimension	Material	Density
Source	2.71e+06 cm³	Soil	1.5
Air Gap		Air	0.00122
Immersion		Air	0.00122



Source Input: Grouping Method - Linear Energy Number of Groups: 25 Lower Energy Cutoff: 0.015 Photons < 0.015: Included Library: Grove				
Nuclide	Ci	Bq	μCi/cm³	Bq/cm³
Ag-108m	9.2536e-010	3.4238e+001	3.4090e-010	1.2613e-005
Am-241	1.4394e-008	5.3258e+002	5.3027e-009	1.9620e-004
Am-243	8.7395e-012	3.2336e-001	3.2196e-012	1.1913e-007
Ba-137m	4.5336e-008	1.6774e+003	1.6702e-008	6.1797e-004
C-14	1.5975e-007	5.9108e+003	5.8852e-008	2.1775e-003
Cl-36	3.0403e-009	1.1249e+002	1.1200e-009	4.1442e-005
Co-60	1.8809e-002	6.9593e+008	6.9292e-003	2.5638e+002
Cs-135	2.1128e-012	7.8174e-002	7.7835e-013	2.8799e-008
Cs-137	4.7924e-008	1.7732e+003	1.7655e-008	6.5324e-004
H-3	7.2143e-003	2.6693e+008	2.6577e-003	9.8336e+001
I-129	4.6893e-009	1.7350e+002	1.7275e-009	6.3919e-005
Mo-93	2.1128e-014	7.8174e-004	7.7835e-015	2.8799e-010
Nb-94	7.7113e-008	2.8532e+003	2.8408e-008	1.0511e-003
Ni-59	3.0798e-009	1.1395e+002	1.1346e-009	4.1980e-005
Ni-63	7.9713e-007	2.9494e+004	2.9366e-007	1.0865e-002
Np-237	3.2387e-012	1.1983e-001	1.1931e-012	4.4146e-008
Pu-239	2.2620e-008	8.3694e+002	8.3332e-009	3.0833e-004
Pu-241	4.0613e-007	1.5027e+004	1.4962e-007	5.5359e-003
Pu-242	1.6965e-011	6.2771e-001	6.2499e-012	2.3125e-007
Ra-226	3.2902e-009	1.2174e+002	1.2121e-009	4.4848e-005

Se-79	1.2338e-010	4.5651e+000	4.5453e-011	1.6818e-006
Sn-126	3.7014e-011	1.3695e+000	1.3636e-011	5.0453e-007
Sr-90	1.8535e-004	6.8580e+006	6.8283e-005	2.5265e+000
Tc-99	2.9373e-007	1.0868e+004	1.0821e-007	4.0038e-003
Th-230	1.1310e-009	4.1847e+001	4.1666e-010	1.5416e-005
Th-232	4.9352e-009	1.8260e+002	1.8181e-009	6.7270e-005
U-233	4.8913e-010	1.8098e+001	1.8019e-010	6.6672e-006
U-234	1.3156e-007	4.8677e+003	4.8467e-008	1.7933e-003
U-235	5.5660e-009	2.0594e+002	2.0505e-009	7.5869e-005
U-238	1.2819e-007	4.7430e+003	4.7225e-008	1.7473e-003
Y-90	1.8535e-004	6.8580e+006	6.8283e-005	2.5265e+000
Zr-93	2.2620e-007	8.3694e+003	8.3332e-008	3.0833e-003

Buildup: The material reference is Source Integration Parameters	
X Direction	10
Y Direction	20
Z Direction	20

Nominal Case	
Dose Point #1	**(263, 100, 116.5) cm**
Variable	**Not Applicable**

Nominal Case			
Dose Point #1	**(263, 100, 116.5) cm**		
Variable	**Not Applicable**		
Results (Summed over energies)	**Units**	**Without Buildup**	**With Buildup**
Effective Dose (ICRP 74 - 1997)			
Antero-posterior Geometry	mSv/hr	1.464e-002	2.789e-002
Postero-anterior Geometry	mSv/hr	1.301e-002	2.478e-002
Left Lateral Geometry	mSv/hr	1.046e-002	1.993e-002
Lateral Geometry	mSv/hr	0.000e+000	0.000e+000
Right Lateral Geometry	mSv/hr	9.919e-003	1.889e-002
Rotational Geometry	mSv/hr	1.238e-002	2.358e-002
Isotropic Geometry	mSv/hr	1.081e-002	2.059e-002

J.5 References

[J-1] AECOM, *WWTP Material and Energy Balance Report*, B1551-503212-REPT-001, Revision 2, 2018 December.

[J-2] AECOM, *Leachate and Wastewater Characterization (Quantity and Quality)*, B1551-508600-REPT-001, Revision 3, 2018 July.

[J-3] AECOM, *Material Handling Design*, 232-508500-REPT-001, Revision 1, 2018 August.

[J-4] *Standard Assumptions and Input Parameters for the Calculation of On-Site and Off-Site Doses Following Hypothetical Accidental Atmospheric Radioactive Releases from Facilities at CRL*, 145-508770-NSN-001, Revision 1, 2017 March.

[J-5] International Commission on Radiological Protection (ICRP), *Compendium of Dose Coefficients based on ICRP Publication 60*, ICRP Publication 119. Ann. ICRP 41(s), 2012.

[J-6] Canadian Nuclear Safety Commission, *Health Effects Dosimetry and Radiological Protection of Tritium*, INFO-0799, 2010.

[J-7] United States Department of Energy (DOE), *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities,* DOE-HDBK-3010-94, Reaffirmed 2013.

[J-8] AECOM, Waste Characterization, 232-508600-REPT-002, Revision 4, 2020 February.

Appendix K

Fire Inside the WWTP Residuals Management Area

K.1 Description of the WWTP Residuals Management Area

The WWTP Residual Management Area, consists of the IX systems (containing spent resins), and a residuals management system.

Ion Exchange systems are used to remove low concentrations of metals and radionuclides from the wastewater, after the chemical precipitation, membrane filtration, and GAC adsorption steps in the WWTP treatment process. Feed and pH adjustment tanks, as well as associated pumping equipment, are situated on the inlet to the GAC and IX system, to transfer wastewater into the system and optimize the effectiveness of the IX system. The pH adjustment tanks are sized to provide 20 minutes of hydraulic detention time at a design flow rate of 11.36 m^3/h, while the IX feed tank will accommodate eight hours of wastewater flow at this rate. Each IX vessel contain resin specific to the contaminant to be removed from the wastewater. The design includes two zeolite and SAC IX resin vessels in a lead-lag arrangement for removal of heavy metals and cationic radionuclides.

The residuals management system includes storage and conditioning tanks to provide equalization and chemical conditioning of residuals produced by the chemical precipitation and membrane filtration processes, and a recessed chamber filter press for de-watering residuals. The residuals storage and conditioning tanks each have approximately 80 m^3 capacity.

Residuals are separated from the water in the filter press, and the dewatered residuals are stored in the dewatered residuals bin located under the filter press, and eventually disposed of in the ECM.

The residuals management support system include compressed air for operating the filter press, a body feed chemical system for conditioning the residuals in the storage and conditioning tanks, and a pre-coat system used for applying a diatomaceous earth or Perlite (alumina silicate), pre-coat solution to enhance filter press operation if needed.

K.2 Analysis Methodology

K.2.1 Event Scenario

This event involves a fire inside the Residuals Management Area that is sustained long enough to damage all treatment systems and dry out all contaminated solids (i.e. spent SAC resins and dewatered filter press cake). Due to thermal stress from the fire, a fraction of all contaminated solids breach their containers, become airborne and are released to the environment through the ventilation system. For the purpose of this analysis, no filtration of contaminants is assumed.

This scenario would require all of the following:

- An amount of combustible material in the residuals management area, sufficient to fuel a sustained fire hours in duration (e.g. fresh resin or GAC).
- An ignition source (e.g. electrical fire).
- Failures of the fire detection system.
- A long response time (hours), for fire response personnel.

K.2.1.1 Radionuclide Distribution (Source Term)

The radionuclide activity concentrations in the GAC, zeolite resin, SAC resin, and dewatered filter press cake are shown in Table K-1.

The radionuclide concentrations in GAC, zeolite, SAC media and filter press cake were calculated using the radionuclide concentrations (Bq/L) in the WWTP Material and Energy Balance Report [K-1], and the volumes of spent media. The volumes of zeolite, SAC resin, and GAC are 1.93 m^3, 2.55 m^3, and 1.93 m^3, respectively [K-1]. The volume of the filter press cake is based on the dimensions of the flexible container, dewatered residuals bin, used for filter press cake disposal, 1.83 m x 1.22 m x 1.22 m = 2.72 m^3 [K-2].

The radionuclide activity concentrations are based on wastewater characteristics that are considered to be maximum during the operations phase (i.e. during the last five years of the operations phase), and includes the anticipated failure of normal waste packages [K-3].

Table K-1
Radionuclides Activity Concentrations in WWTP Residuals Management Area

Radionuclide	Activity in GAC (Bq)	Activity in Zeolite Resin (Bq)	Activity in SAC Resin (Bq)	Activity in Filter Press Cake (Bq)	Total Activity (Bq)
Ag-108m	1.15E-01	1.53E-01	2.41E+02	3.43E+01	2.76E+02
Am-241	1.78E+00	2.37E+00	3.75E+03	5.34E+02	4.29E+03
Am-243	1.08E-03	1.44E-03	2.28E+00	3.24E-01	2.61E+00
C-14	2.62E+03	3.51E+03	2.49E+03	5.91E+03	1.45E+04
Cl-36	5.02E+01	6.68E+01	4.74E+01	1.12E+02	2.76E+02
Co-60	3.22E+05	4.28E+05	6.78E+08	6.97E+08	1.38E+09
Cs-135	3.47E-02	6.45E+01	1.98E-04	7.82E-02	6.46E+01
Cs-137	7.89E+02	1.46E+06	4.49E+00	1.77E+03	1.46E+06
H-3	1.19E+08	1.58E+08	1.12E+08	2.67E+08	6.56E+08
I-129	7.72E+01	1.03E+02	7.32E+01	1.74E+02	4.27E+02
Mo-93	3.47E-04	4.63E-04	3.29E-04	7.82E-04	1.92E-03
Nb-94	9.55E+00	1.27E+01	2.01E+04	2.86E+03	2.30E+04
Ni-59	1.63E-02	2.16E-02	1.54E-02	1.14E+02	1.14E+02

Radionuclide	Activity in GAC (Bq)	Activity in Zeolite Resin (Bq)	Activity in SAC Resin (Bq)	Activity in Filter Press Cake (Bq)	Total Activity (Bq)
Ni-63	4.21E+00	5.60E+00	3.98E+00	2.94E+04	2.94E+04
Np-237	4.01E-04	5.35E-04	8.44E-01	1.20E-01	9.65E-01
Pu-239	2.80E+00	3.72E+00	5.89E+03	8.36E+02	6.73E+03
Pu-241	5.04E+01	6.70E+01	1.06E+05	1.50E+04	1.21E+05
Pu-242	2.10E-03	2.80E-03	4.41E+00	6.26E-01	5.04E+00
Ra-226	4.07E-01	5.42E-01	8.57E+02	1.22E+02	9.80E+02
Se-79	1.53E-02	2.03E-02	3.21E+01	4.58E+00	3.67E+01
Sn-126	4.59E-03	6.10E-03	9.64E+00	1.37E+00	1.10E+01
Sr-90	4.42E+02	5.87E+02	9.61E+05	6.86E+06	7.82E+06
Tc-99	4.84E+03	6.45E+03	4.59E+03	1.09E+04	2.68E+04
Th-230	1.40E-01	1.87E-01	2.96E+02	4.19E+01	3.38E+02
Th-232	6.12E-01	8.14E-01	1.29E+03	1.82E+02	1.47E+03
U-233	4.28E-03	5.71E-03	4.05E-03	1.81E+01	1.81E+01
U-234	1.15E+00	1.53E+00	1.09E+00	4.88E+03	4.88E+03
U-235	4.88E-02	6.48E-02	4.62E-02	2.06E+02	2.06E+02
U-238	1.12E+00	1.50E+00	1.06E+00	4.74E+03	4.74E+03
Zr-93	2.80E+01	3.72E+01	5.89E+04	8.36E+03	6.73E+04

K.2.2 On-site Receptor and Location

All WWTP workers are assumed to have evacuated the WWTP building by the time the contaminated solids have been heated to the point of being dewatered and released to the environment. Therefore, the on-site receptor is assumed to be located at CRL Building 700, approximately 1 km away from the NSDF site.

For exposure to airborne contaminant, the member of the public is assumed to be a cottager, located approximately 3 km away from the NSDF site. For the cottager, the atmospheric dilution factor is 7.21E-05 s/m^3 [K-4]. For a resident at Chalk River (five km from the NSDF site), the atmospheric dilution factor is 2.25E-05 s/m^3 [K-4]. Therefore, the concentration of radionuclides at the cottager location is 3.2 times greater than at Chalk River; and the dose from predominant exposure pathways (e.g. inhalation and immersion), are proportionally greater assuming all other factors are the same (e.g. plume rise, deposition, wind characteristics). Therefore, the radiological consequence to the cottager bounds the radiological consequence to a resident at Chalk River, and only the cottager is considered in this assessment. The radiological consequence (dose) is calculated for both an infant (1 year old) and adult receptor at the cottager location.

K.3 Assumptions and Inputs

The following assumptions and inputs were made to calculate the worse-case radiological consequences in the event of a fire in the WWTP:

- Radionuclide concentrations in wastewater, are the maximum during the 50 years of operations accounting for waste package failure of the placed waste.
- All of the GAC and IX vessels completely fail, resulting in all of the GAC and IX resin media being dried out and affected by the fire.
- The entire inner volume of the dewatered residuals bin (1.83 m x 1.22 m x 1.22 m = 2.72 m^3 [K-2]) is filled with filter press cake, which is affected by the fire, and there is no containment of the filter press cake during the fire.
- A ground-level release is assumed. Given the elevation of the NSDF site relative to Building 700, this is a conservative assumption that maximizes the exposure at the receptor location.
- There is no depletion of contaminants from the plume.
- The plume is not considered to be affected by nearby buildings.
- Wind speed is assumed to be 2 m/s [K-4], and is assumed to be constant therefore, there are no meteorological time averaging effects.
- The worker inhalation DCFs are based on the most restrictive dosimetric form (slow, moderate, or fast) and 5 µm AMAD (ICRP 119, Table A) [K-5].
- The public inhalation DCFs are based on the most restrictive dosimetric form (slow, moderate, or fast) and 1 µm AMAD (ICRP 119, Table G) [K-5].
- Tritium and C-14 are assumed to be in the form of HTO and CO_2 respectively (inhalation DCFs from ICRP 119 Table B for workers, Table H for public) [K-5].
- Air immersion (i.e. cloudshine) DCFs are based on Health Canada's Recommendations of Dose Coefficients for Assessing Doses from Accidental Radionuclide Releases to the Environment [K-6].
- A factor of 1.5 is applied to adult immersion DCFs to represent infant immersion DCFs [K-6].
- A factor of 1.5 is applied to tritium inhalation DCFs to account for skin absorption [K-7].
- The wind is in the direction of the receptor (towards Building 700 for the worker or towards the cottages for the member of the public).
- The worker breathing rate is 1.2 m^3/h [K-8]. The adult member of the public breathing rate is 0.925 m^3/h; the infant breathing rate is 0.215 m^3/h [K-8].

K.4 Calculations

This section details the calculation of the radiological consequence to the on-site receptor, and members of the public resulting from a fire in the WWTP Residuals Management Area. As shown in Table K-2, the radiological consequence to the worker is assumed to be from inhalation only.

Table K-2
Exposure Pathways for the On-site and Off-site Receptors

Exposure pathway	Included in dose calculation (yes/no)	Rationale
External	No	All of the contaminants in the vicinity of the receptor are in the form of airborne particulates.
Immersion	No	It is assumed that the immersion dose will be significantly less than the inhalation dose.
Inhalation	Yes	A small portion of the residuals will re-suspend within the WWTP, released into the air and be inhaled by the receptor downwind. Skin absorption of tritium is accounted for by applying a factor of 1.5 to the tritium inhalation DCF [K-7].
Ingestion	No	It is assumed that the receptor will not ingest contaminated particulates.

The respirable source terms for combustible and non-combustible material (denoted with subscripts C and NC) are determined by equations K1 and K2:

$$Q_C = MAR_C \times DR \times LPF \times ARF_C \times RF_C \quad \text{(K1)}$$
$$Q_{NC} = MAR_{NC} \times DR \times LPF \times ARF_{NC} \times RF_{NC} \quad \text{(K2)}$$

Where:

MAR_C, MAR_{NC} - material at risk, the total combustible (i.e. resins) and non-combustible (i.e. filter press cake) activity in Residuals Management Area (Bq), see Table K-1.

DR - damage ratio, the fraction of MAR actually impacted by the accident, assumed to be 1.

LPF - leakpath factor, the fraction of the radionuclides passing through filtration systems, assumed to be 1.

ARF_C, ARF_{NC} - airborne release fraction, the fraction of radioactive material suspended in air as an aerosol, for combustible and non-combustible material respectively.

RF_C, RF_{NC} - respirable fraction, the fraction of airborne radionuclides inhaled, for combustible and non-combustible material respectively.

For packaged, contaminated combustible materials heated/burned in packages, the bounding ARF is 5E-04 and the RF is 1.0 [K-9]. For non-combustible solids such as the dewatered filter press cake under thermal stress, the bounding ARF is 6E-03 and the RF is 0.01 [K-9].

The inhalation dose is determined by equation K3 [K-10].

$$D_{inh} = (Q_C + Q_{NC}) \times ADF \times B \times DCF_{inh} \times \frac{1\,hr}{3600\,s} \times \frac{1000\,mSv}{1\,Sv} \quad \text{(K3)}$$

$$D_{inh} = (MAR_C \times ARF_C \times RF_C + MAR_{NC} \times ARF_{NC} \times RF_{NC}) \times DR \times LPF \times ADF \times B \times DCF_{inh} \times \frac{1\,hr}{3600\,s} \times \frac{1000\,mSv}{1\,Sv}$$

Where:

Q_C, Q_{NC}	- Respirable source term (Bq) for combustible and non-combustible material, respectively.
ADF	- atmospheric dilution factor at the location of the human receptor, 2.47E-04 s/m^3 for the worker and 7.21E-05 s m^{-3} for the member of the public at cottage locations 3 km away [K-4].
B	- breathing rate, assumed to be 1.2 m^3/h for a worker, 0.925 m^3/h for an adult member of the public, and 0.215 m^3/h for the infant [K-8].
DCF_{inh}	- inhalation dose conversion factor for a worker or member of the public (Sv/Bq) [K-5]

The ADFs selected for the worker and member of the public is applicable for a wind speed of 2 m/s, short-term ground-level release, and Stability Class F wind [K-4]. A ground-level release is assumed since this release yields the highest ADF. In reality, a sustained fire (e.g. hours in duration) would likely loft the release to a considerable height and the ADF would be lower.

The details of the calculation of inhalation dose to the on-site receptor and the off-site receptors, members of the public are shown in Table K-3.

K.5 Results

The radiological consequence, inhalation dose, to the on-site worker is 5.57E-07 mSv. The radiological consequence, inhalation dose, to the members of the public are 2.36E-07 mSv for the adult, and 1.49E-07 mSv for the infant. The additional radiological consequence due to immersion (i.e. external dose from radiation emitted from the passing plume), is expected to be negligible.

Table K-3
Estimated Inhalation Dose to the On-site and Off-site Receptors for the WWTP Residual Management Area Fire

1	2	3	4	5	6	7	8	9	10	11	12
Radionuclide	**Activity in GAC (Bq)**	**Activity in Zeolite resin (Bq)**	**Activity in SAC resin (Bq)**	**Activity in filter press cake (Bq)**	**Total activity (Bq)**	**Inhalation DCF for the onsite receptor (Sv/Bq)**	**Inhalation DCF for the public adult (Sv/Bq)**	**Inhalation DCF for the public infant (Sv/Bq)**	**Inhalation dose to onsite receptor (mSv)**	**Inhalation dose to public adult (mSv)**	**Inhalation dose to public infant (mSv)**
Ag-108m	1.15E-01	1.53E-01	2.41E+02	3.43E+01	2.76E+02	1.90E-08	3.70E-08	8.70E-08	1.92E-13	8.41E-14	4.60E-14
Am-241	1.78E+00	2.37E+00	3.75E+03	5.34E+02	4.29E+03	2.70E-05	9.60E-05	1.80E-04	4.24E-09	3.40E-09	1.48E-09
Am-243	1.08E-03	1.44E-03	2.28E+00	3.24E-01	2.61E+00	2.70E-05	9.60E-05	1.70E-04	2.58E-12	2.06E-12	8.50E-13
C-14	2.62E+03	3.51E+03	2.49E+03	5.91E+03	1.45E+04	6.50E-12	6.20E-12	1.90E-11	2.50E-15	5.36E-16	3.82E-16
Cl-36	5.02E+01	6.68E+01	4.74E+01	1.12E+02	2.76E+02	5.10E-09	7.30E-09	2.60E-08	3.73E-14	1.20E-14	9.96E-15
Co-60	3.22E+05	4.28E+05	6.78E+08	6.97E+08	1.38E+09	1.70E-08	3.10E-08	8.60E-08	5.34E-07	2.19E-07	1.41E-07
Cs-135	3.47E-02	6.45E+01	1.98E-04	7.82E-02	6.46E+01	9.90E-10	8.60E-09	2.40E-08	2.63E-15	5.14E-15	3.34E-15
Cs-137	7.89E+02	1.46E+06	4.49E+00	1.77E+03	1.46E+06	6.70E-09	3.90E-08	1.10E-07	4.03E-10	5.28E-10	3.46E-10
H-3	1.19E+08	1.58E+08	1.12E+08	2.67E+08	6.56E+08	2.70E-11	2.70E-11	7.20E-11	4.68E-10	1.05E-10	6.53E-11
I-129	7.72E+01	1.03E+02	7.32E+01	1.74E+02	4.27E+02	5.10E-08	3.60E-08	8.60E-08	5.76E-13	9.15E-14	5.08E-14
Mo-93	3.47E-04	4.63E-04	3.29E-04	7.82E-04	1.92E-03	1.40E-09	2.30E-09	4.80E-09	7.11E-20	2.63E-20	1.27E-20
Nb-94	9.55E+00	1.27E+01	2.01E+04	2.86E+03	2.30E+04	2.50E-08	4.90E-08	1.20E-07	2.11E-11	9.29E-12	5.29E-12
Ni-59	1.63E-02	2.16E-02	1.54E-02	1.14E+02	1.14E+02	2.20E-10	4.40E-10	1.50E-09	1.24E-16	5.60E-17	4.44E-17
Ni-63	4.21E+00	5.60E+00	3.98E+00	2.94E+04	2.94E+04	5.20E-10	1.30E-09	4.30E-09	7.58E-14	4.26E-14	3.28E-14
Np-237	4.01E-04	5.35E-04	8.44E-01	1.20E-01	9.65E-01	1.50E-05	5.00E-05	9.30E-05	5.31E-13	3.98E-13	1.72E-13
Pu-239	2.80E+00	3.72E+00	5.89E+03	8.36E+02	6.73E+03	3.20E-05	1.20E-04	2.00E-04	7.90E-09	6.67E-09	2.58E-09
Pu-241	5.04E+01	6.70E+01	1.06E+05	1.50E+04	1.21E+05	5.80E-07	2.30E-06	2.90E-06	2.58E-09	2.30E-09	6.74E-10
Pu-242	2.10E-03	2.80E-03	4.41E+00	6.26E-01	5.04E+00	3.10E-05	1.10E-04	1.90E-04	5.73E-12	4.57E-12	1.84E-12
Ra-226	4.07E-01	5.42E-01	8.57E+02	1.22E+02	9.80E+02	2.20E-06	9.50E-06	2.90E-05	7.90E-11	7.68E-11	5.45E-11
Se-79	1.53E-02	2.03E-02	3.21E+01	4.58E+00	3.67E+01	3.10E-09	6.80E-09	2.00E-08	4.17E-15	2.06E-15	1.41E-15
Sn-126	4.59E-03	6.10E-03	9.64E+00	1.37E+00	1.10E+01	1.80E-08	2.80E-08	1.00E-07	7.27E-15	2.55E-15	2.11E-15
Sr-90	4.42E+02	5.87E+02	9.61E+05	6.86E+06	7.82E+06	7.70E-08	1.60E-07	4.00E-07	5.66E-09	2.65E-09	1.54E-09
Tc-99	4.84E+03	6.45E+03	4.59E+03	1.09E+04	2.68E+04	3.20E-09	1.30E-08	3.70E-08	2.26E-12	2.07E-12	1.37E-12
Th-230	1.40E-01	1.87E-01	2.96E+02	4.19E+01	3.38E+02	2.80E-05	1.00E-04	2.00E-04	3.47E-10	2.79E-10	1.30E-10
Th-232	6.12E-01	8.14E-01	1.29E+03	1.82E+02	1.47E+03	2.90E-05	1.10E-04	2.20E-04	1.57E-09	1.34E-09	6.22E-10
U-233	4.28E-03	5.71E-03	4.05E-03	1.81E+01	1.81E+01	6.90E-06	9.60E-06	3.00E-05	6.21E-13	1.94E-13	1.41E-13
U-234	1.15E+00	1.53E+00	1.09E+00	4.88E+03	4.88E+03	6.80E-06	9.40E-06	2.90E-05	1.65E-10	5.13E-11	3.68E-11
U-235	4.88E-02	6.48E-02	4.62E-02	2.06E+02	2.06E+02	6.10E-06	8.50E-06	2.60E-05	6.25E-12	1.96E-12	1.39E-12
U-238	1.12E+00	1.50E+00	1.06E+00	4.74E+03	4.74E+03	5.70E-06	8.00E-06	2.50E-05	1.34E-10	4.24E-11	3.08E-11
Zr-93	2.80E+01	3.72E+01	5.89E+04	8.36E+03	6.73E+04	2.90E-08	2.50E-08	6.40E-09	7.16E-11	1.39E-11	8.26E-13
								TOTAL	**5.57E-07**	**2.36E-07**	**1.49E-07**

1 The list of radionuclides in NSDF waste [K-11].

2 Total activity in GAC at exhaustion, radionuclide concentration in GAC (Bq/L) from [K-1] multiplied by the volume of GAC (1.93 m^3).

3 Total activity in zeolite resin at exhaustion, radionuclide concentration in zeolite resin (Bq/L) from [K-1] multiplied by the volume of zeolite resin (1.93 m^3).

4 Total activity in SAC resin at exhaustion, radionuclide concentration in SAC resin (Bq/L) from [K-1] multiplied by the volume of SAC resin (2.55 m^3).

5 Total activity in filter press cake for a full B25 box, radionuclide concentration in filter press cake (Bq/L) from [K-1] multiplied by the volume of dewatered residuals bin (2.72 m^3).

6 Total activity in the Residuals Management Area (Sum of Columns 2 to 5).

7 Taken from ICRP 119, Table A [K-5]. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.

8 Adult values from ICRP 119, Table G, 1 µm particulate size [K-5]. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.

9 1-year old values from ICRP 119, Table G, 1 µm particulate size [K-5]. Tritium and C-14 are considered to be HTO and CO_2, respectively, with DCFs from Table H. A factor of 1.5 has been applied to the tritium inhalation DCF to account for skin absorption.

10 $$D_{inh} = (MAR_C \times ARF_C \times RF_C + MAR_{NC} \times ARF_{NC} \times RF_{NC}) \times ADF \times B \times DCF_{inh} \times \frac{1\,hr}{3600\,s} \times \frac{1000\,mSv}{1\,Sv}$$

MAR_C=Column 2 + Column 3 + Column 4, ARF_C=5E-04, RF_C=1, MAR_{NC}=Column 5, ARF_{NC}=6E-03, RF_{NC}=0.01, ADF=2.47E-04 s/m^3, B = 1.2 m^3/h, DCF_{inh}=Column 7

11 $$D_{inh} = (MAR_C \times ARF_C \times RF_C + MAR_{NC} \times ARF_{NC} \times RF_{NC}) \times ADF \times B \times DCF_{inh} \times \frac{1\,hr}{3600\,s} \times \frac{1000\,mSv}{1\,Sv}$$

MAR_C=Column 2 + Column 3 + Column 4, ARF_C=5E-04, RF_C=1, MAR_{NC}=Column 5, ARF_{NC}=6E-03, RF_{NC}=0.01, ADF=7.21E-05 s/m^3, B = 0.925 m^3/h, DCF_{inh}=Column 8

12 $$D_{inh} = (MAR_C \times ARF_C \times RF_C + MAR_{NC} \times ARF_{NC} \times RF_{NC}) \times ADF \times B \times DCF_{inh} \times \frac{1\,hr}{3600\,s} \times \frac{1000\,mSv}{1\,Sv}$$

MAR_C=Column 2 + Column 3 + Column 4, ARF_C=5E-04, RF_C=1, MAR_{NC}=Column 5, ARF_{NC}=6E-03, RF_{NC}=0.01, ADF=7.21E-05 s/m^3, B = 0.215 m^3/h, DCF_{inh}=Column 9

K.6 References

[K-1] AECOM, *WWTP Material and Energy Balance Report*, B1551-503212-REPT-001, Revision 2, 2018 November.

[K-2] AECOM, *Material Handling Design,* 232-508500-REPT-001, Revision 1, 2018 August.

[K-3] AECOM, *Leachate and Wastewater Characterization (Quantity and Quality)*, B1551-508600-REPT-001, Revision 3, 2019 May.

[K-4] *Dose Calculations for Ground Level Releases from Facilities at CR*L, 900-508770-FID-016, Revision 0, 2019 August.

[K-5] International Commission on Radiological Protection (ICRP), *Compendium of Dose Coefficients based on ICRP Publication 60,* ICRP Publication 119. Ann. ICRP 41(s), 2012.

[K-6] Health Canada, *Recommendations on Dose Coefficients for Assessing Doses from Accidental Radionuclide Releases to the Environment,* H46-1-33-1999, 1999.

[K-7] Canadian Nuclear Safety Commission, *Health Effects Dosimetry and Radiological Protection of Tritium,* INFO-0799, 2010.

[K-8] *Standard Assumptions and Input Parameters for the Calculation of On-Site and Off-Site Doses Following Hypothetical Accidental Atmospheric Radioactive Releases from Facilities at CRL*, 145-508770-NSN-001, Revision 1, 2017 March.

[K-9] United States Department of Energy (DOE), *Airborne Release Fractions/Rates and Respirable Fractions for Nonreactor Nuclear Facilities*, DOE-HDBK-3010-94, Reaffirmed 2013.

[K-10] Canadian Standards Association (CSA), *Guidelines for Calculating Radiation Doses to the Public from a Release of Airborne Radioactive Material under Hypothetical Accident Conditions in Nuclear Reactors*, CSA N288.2-M91, 1991.

[K-11] AECOM, *Waste Characterization*, 232-508600-REPT-002, Revision 4, 2020 February.

Appendix L

Engineered Containment Mound Aircraft Crash Frequency

L.1 Methodology

The calculation for estimating the frequency of an aircraft crash within CRL is documented in the CRL Site Characteristics [L-1]. The calculation in [L-1], produces conservative results and depending on the area will produce frequencies that are greater than 10^{-6} per year. Therefore, the methodology in [L-2] and [L-3] has been used to estimate the frequency of an aircraft crash. The following aircraft types have Canada total crash rates defined in [L-2]: ultralight aircraft, light aircraft, helicopters, small transport, large transport, and military combat. The aircraft categories with definitions are presented in Table L-1 [L-2], and are used as the basis for estimating aircraft crash frequency in this analysis.

Table L-1
Aircraft Categories [L-2]

Category	Definition
Category 0: Ultralight Aircraft	An aircraft that has a Maximum Certificated Take-Off Weight (MCTOW) of (1) 350 kg for a single place airplane, or (2) 560 kg for a two place.
Category 1: Light Aircraft	An aircraft that has a MCTOW of 2 000 kg (~2 300 kg in [L-4]) or under (excluding ultralight aircrafts). It can be a civil or military aircraft.
Category 2: Helicopters	All civil and military helicopters.
Category 3: Small Transport Aircraft	An aircraft covering the range 2 001 kg to 18 000 kg (approximately 2 300 kg to 23 000 kg in [L-4]) MCTOW including civil and military transport aircraft.
Category 4: Large Transport Aircraft	An aircraft that has a MCTOW of 18 001 kg (~23 000 kg in [L-4]) or over. It can be a civil or military aircraft, not covered in the light aircraft, small or military combat and jet trainer categories.
Category 5: Military Combat and Jet Trainers	All military aircraft used for, or capable of, aerobatic style flying.

The frequency of an aircraft crash in the ECM is estimated using the equation L1 [L-2] and [L-3]:

$$\sum F_{AC} = (CR_S * A_{eff}) + (CR_{L/T} * A_{eff}) \qquad \text{(L1)}$$

Where:

F_{AC} Aircraft crash frequency, (year^{-1})

CR_B	Background crash rate, $(km^2\ year)^{-1}$
$CR_{L/T}$	Landing/take-off crash rate, $(km^2\ year)^{-1}$
A_{eff}	Rectangular Facility effective target area, (km^2)

The landing/take-off crash rates can be ignored. Taking into consideration that the CRL site is far from larger and busier airports, and that the most aircraft accidents occur during the airport-related (i.e. take-off and landing) stages of flight, rather than the in-flight stages), only non-airport-related fatal accidents are taken into account for the background crash rates [L-2].

The effective area represents the ground surface area surrounding a Facility, such that if an unobstructed aircraft were to crash within the area, the crash would impact the Facility, either by direct fly-in or skid into the Facility [L-2] and [L-3]. The effective area depends on the length, width, and height of the Facility, as well as on the aircraft's wingspan, flight path angle, heading angle relative to the heading of the Facility, and the length of the skid [L-2] and [L-3]. The effective area consists of two parts, the fly-in area and the skid area [L-2] and [L-3]. The former represents the area corresponding to a direct fly-in impact and consists of two parts, the footprint area and the shadow area [L-3]. The footprint is the Facility area that an aircraft would hit on its descent even if the Facility height were zero [L-3]. The shadow area is the Facility area that an aircraft hits on its descent, but which it would have missed if the Facility height were zero [L-3].

The Facility is represented by a bounding rectangle, and the heading of the crashing aircraft with respect to the Facility is assumed to be perpendicular to the diagonal of the bounding rectangle, as shown in Figure L-1 [L-3]. These assumptions provide a conservative approximation to the true effective area [L-3].

To calculate the effective area, assume that the aircraft skids or flies into the structure in the direction that produces the largest area, i.e. crashing in a direction perpendicular to the largest diagonal of the building [L-3].

The formula for calculating the skid and fly-in areas for an aircraft crashing into a rectangular building is given in Equations L2, L3, L4, and L5 [L-2] and [L-3].

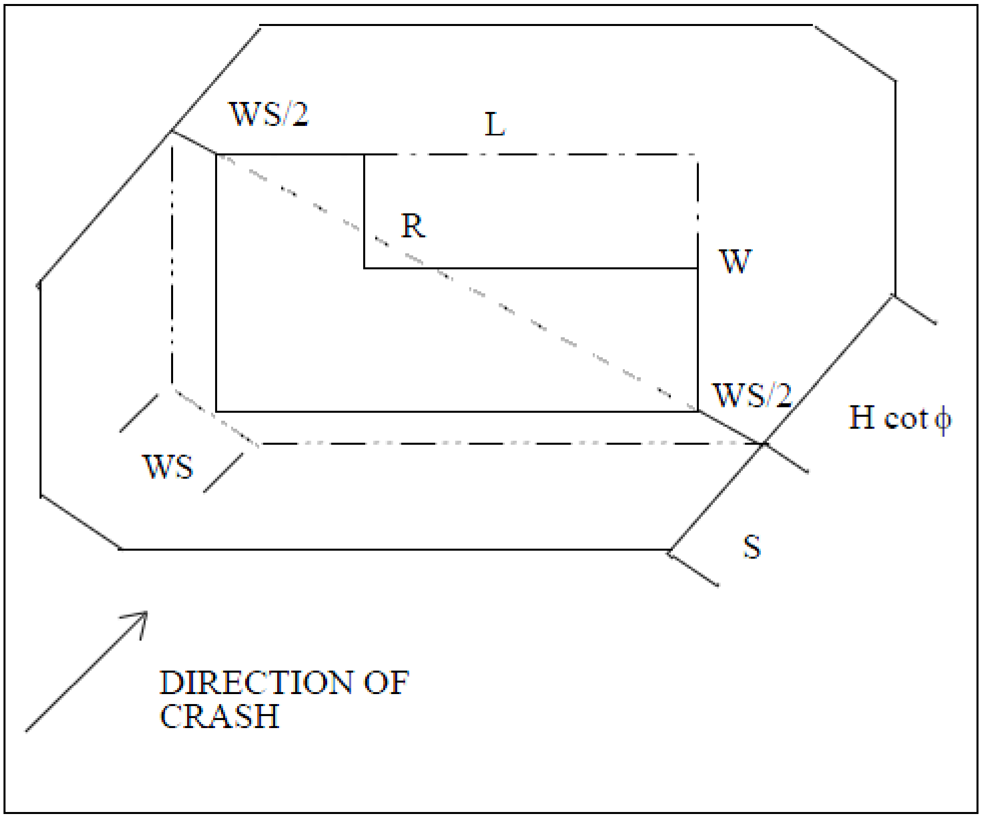


Figure L-1 Rectangular Facility Effective Target Area Elements

$$A_{eff} = A_f + A_s \qquad \text{(L2)}$$

Where:

$$A_f = (WS + R)\, H cot\theta + \frac{2\, L\, W\, WS}{R} + L\, W \qquad \text{(L3)}$$

$$A_s = (WS + R) S \qquad \text{(L4)}$$

A_f Effective fly-in area

A_s Effective skid area

WS Aircraft wingspan, provided in Table B-16 [L-3]

R Length of the diagonal of the Facility, and is calculated using Equation L5

$$R = (L^2 + W^2)^{0.5} \qquad \text{(L5)}$$

H Facility height, Facility-specific

$cot\theta$ Mean of the cotangent of the aircraft impact angle, provided in Table B-17 [L-3]

L	Length of Facility, Facility-specific
W	Width of Facility, Facility-specific
S	Aircraft skid distance (mean value), provided in Table B-18 [L-3]

L.2 Engineered Containment Mound Aircraft Crash Frequency

The NSDF Project proposed area for the ECM, is an irregular shape, approximately 110 000 m^2 area. The ECM area length and width are estimated to be 317 m and 347 m, respectively. The maximum height of the outer boundaries and sidewalls for the ECM is approximately 15 meters. Note that the area of the ECM is not shaped as a rectangle. Using this rectangular target area, the effective area is calculated and presented in Table L-2. The Category 5 skid distance is 447 feet, assuming that the military combat aircraft is a small aircraft – military aviation [L-3].

The Canada total crash rates for six aircraft categories are documented in Table L-2 and are from the NRU Hazard Basis Document [L-2].

Table L-3 shows the ECM annual aircraft crash impact frequency of the six aircraft categories and the Canada total crash rates for six aircraft categories from the NRU Hazard Basis Document [L-2]. The total annual impact frequency for all aircraft categories is 1.35E-07 per year, which does not exceed 10^{-6} per year.

Table L-2
Near Surface Disposal Facility ECM Effective Area

Parameter and Units	Aircraft Category					
	Category 0	Category 1	Category 2	Category 3	Category 4	Category 5
WS, m	15.24	22.25	15.24	17.98	29.87	33.53
R, m	470.0	470.0	470.0	470.0	470.0	470.0
H, m	15	15	15	15	15	15
Cotϕ	8.2	8.2	0.58	10.2	10.2	10.4
L, m	317	317	317	317	317	317
W, m	347	347	347	347	347	347
S, m	18.29	18.29	0	438.91	438.91	136.25
A_f,m^2	176816.8	180960.3	121354.2	193075.7	200460.4	204244.2
A_s, m^2	8875.0	9003.2	0.0	214178.4	219397.0	68605.7
A_{eff}, m^2	185691.8	189963.5	121354.2	407254.1	419857.4	272849.8
A_{eff}, km^2	0.186	0.190	0.121	0.407	0.420	0.273

Table L-3
Near Surface Disposal Facility ECM Annual Aircraft Impact Frequency

Aircraft	Category	Canada – Total Crash Rate (km^2 $yr)^{-1}$	NSDF Effective Area (km^2)	Canada – Impact Frequency per year (km^{-1})
Ultralight aircraft	Category 0	8.68E-08	0.186	1.61E-08
Light aircraft	Category 1	2.42E-07	0.190	4.60E-08
Helicopters	Category 2	2.57E-07	0.121	3.11E-08
Small transport	Category 3	8.68E-08	0.407	3.53E-08
Large transport	Category 4	1.19E-08	0.420	5.00E-09
Military Combat	Category 5	6.96E-09	0.273	1.90E-09
Total				**1.35E-07**

L.3 References

[L-1] *CRL Site Characteristics*, CRL-03510-SAB-001, Revision 5, 2018 June.

[L-2] *NRU Hazard Basis Document – Identification Screening of Internal and External Hazards*, NRU-96000-REPT-135, Revision 1, 2016 May.

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[L-4] UK HSE, *The Calculation of Aircraft Crash Risk in the UK*, Prepared by AEA Technology PLC for the Health and Safety Executive, 1997.