Appendix 14-A

ASSESSMENT OF ACCIDENTS AND MALFUNCTIONS - TECHNICAL SUPPORTING DOCUMENT FOR THE WHEELER RIVER PROJECT

REPORT PREPARED FOR:

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ASSESSMENT OF ACCIDENTS AND MALFUNCTIONS - TECHNICAL SUPPORTING DOCUMENT FOR THE WHEELER RIVER PROJECT

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EXECUTIVE SUMMARY

Proposed Project

The Denison Wheeler River Project (Wheeler or the Project) is a proposed uranium mine and processing plant in northern Saskatchewan, Canada. The Project is located in a relatively undisturbed area of the boreal forest about 4 km off of Highway 914 and approximately 35 km north-northeast of the Key Lake uranium operation. The deposit will be mined via In Situ Recovery (ISR) that involves injecting a low-pH mining solution into the uranium deposit through a series of cased drill holes (injection wells) and subsequently pumping the uranium-rich solution to surface through recovery wells. Once on surface, the uranium rich mining solution recovered from the wellfield will be pumped to the on-site processing plant. Inside the processing plant a relatively simple precipitation process will be used to separate the uranium from the mining solution. Once separated, the uranium will be dried, packaged and trucked off site, destined for eventual use in a nuclear power plant. The main phases of the Project are construction, operation, decommissioning, and post-decommissioning. Construction would last for approximately three years; production activities would commence following commissioning of the facilities and would last 15 years with a production rate of up to 12 M lbs U_3O_8 per year. Decommissioning is expected to last for five years and post-decommissioning a further 15 years.

Scope and Objective

The scope of this assessment includes consideration of potential accidents and malfunctions within the context of the key Project components that define the Project scope for the purposes of the Environmental Assessment.

The objective of the assessment is to evaluate the potential human health or biophysical environmental effects resulting from radiological and conventional accidents and malfunctions in consideration of proposed environmental protection measures.

Assessment Methodology The assessment of accidents and malfunctions is designed to provide a clear definition of the potential Project-associated hazards that fall outside the range of "typical" day-to-day events and to provide a framework for quantifying the risks associated with these hazards.

The four basic steps in the process of risk assessment for the accidents and malfunctions assessment are as follows:

- Hazard identification / bounding scenario: the identification of physical situations with the potential for harming the human health or biophysical environment. In this study, "Hazards" and "Accidents and Malfunctions" are used interchangeably. The hazards are identified for several potential events, such as releases of chemical and radiological constituents, fires, and explosions. Identification of bounding scenarios involve initial screening of the hazard scenarios and selection of bounding scenarios that encompass

the risk of scenarios screened in each category. This completion of this step was documented Wheeler River ISR Project Hazard Identification Report (Appendix A). Section 5.0 describes the selected bounding scenarios.

- Assessment of probabilities: the estimation of the probability of occurrence of the scenario occurring within a specific time period or in specified circumstances. Section 7.0 includes the assessment of probabilities. This section considers the existing preventive and mitigative measures (provided in Section 4.0) put in place to manage the risk.

- Assessment of potential effects: the identification of the effects of a hazard on human health or biophysical environment. Section 8.0 includes the assessment of potential effects.

- Risk estimation and ranking: the estimation of the consequences of a scenario and the probability with which it is likely to occur; that is, risk is the product of consequence and probability (risk = consequence × probability of occurrence). Section 9.0 provides summary and risk estimation for the selected bounding scenarios.

For reference, the temporal and spatial extents of the assessment are as follows:

- The temporal extent of the evaluation includes all mine and mill life-cycle phases – construction, operations, decommissioning, and post-decommissioning.

- The spatial extent of the evaluation includes the Project site and the site access road. Three off-site scenarios, involving a release to water (Scenarios 1 and 2) and ground (Scenario 7) that would have the potential to affect a temporary community of interest camp along the mine-related transportation route were also considered. These scenarios were developed with the Denison team and reflected the result of and input from Denison's interested party engagement activities.

<u>Hazard Identification and Screening</u>

A total of 69 hazard scenarios were identified and evaluated.

Five of the hazard scenarios characterized as high-risk, three of which are recommended for further assessment. The two high-risk scenarios that were not recommended for further detailed assessment are associated with occupational fatalities for the site preparation activities. These scenarios have not been advanced since it is assumed that the Denison health and safety program will be "best practice" and therefore in these cases the risk is considered ALARP (as low as reasonably practical).

Twenty-three of the scenarios evaluated were characterized as moderate-risk scenarios. Of these twenty-three, nineteen of the moderate-risk scenarios were deemed to represent a tolerable level of risk in consideration of proposed safeguards and design features that reduce the risk level to ALARP. Four moderate / ALARP-moderate scenarios require further detailed assessment for more accurate characterization of risk. The four moderate risk scenarios that are subsequently assessed in more detail are associated with a contaminant release to the environment whose potential effects maybe may be more far reaching than can adequately assessed by the screening assessment and therefore additional more quantitative evaluation is appropriate.

The balance of the scenarios evaluated, 41, were characterized as low-risk scenarios, based on low likelihood of occurrence and/or consequence in consideration planned existing safeguards and design features. Low-risk scenarios are not carried forward for more detailed analysis as they are adequately characterized by the screening process.

<u>Bounding Scenarios</u>

As indicated above, six hazard scenarios were selected as bounding scenarios for more detailed risk analysis (Table ES-1). Herein, a bounding scenario is used to represent an event whose potential consequences are considered to represent those associated with other accident and malfunction scenarios; or, alternatively, the potential consequences of scenarios that are bounded by another are expected to fit within the envelope of those associated with the bounding scenario. Utilizing the bounding scenario approach makes it possible to avoid duplication in the evaluation process while at the same time ensuring the evaluation is completed in a conservative manner.

Table ES-1: Bounding Scenarios Identified for Further Assessment by the Hazard Identification Process

No.	Potential Accident or malfunction	Project Phase	Potential Effect Pathway
1	Vehicle accident including rollover, collision, run off road	Op	Aquatic release of radioactivity
2	Vehicle accident including rollover, collision, run off road	Co / Op / De	Aquatic release of fuel, hazardous chemicals and reagents
3	Loss of freeze capacity	Op	Loss of freeze wall and secondary underground containment
4	Failure of freeze wall	Op	Loss secondary underground containment and groundwater contamination
5	Process vessel and piping system failure	Op	Release of radon from storage tank
6	Facility fire / explosion	Op	Release of radioactivity and uranium concentrate powder to atmosphere
7	Vehicle accident including rollover, collision, run off road	Co / Op / De	Terrestrial release of radioactivity and chemicals

Notes: Red and yellow shading indicates high and moderate risk scenarios, respectively. "Effect Pathway" describes nature of the event and therefore the nature of the assessment of consequence. C = Construction, O = Operation, and De = Decommissioning.

<u>Assessment of Potential Effects of the Bounding Scenarios</u>

Detailed assessment of the seven bounding scenarios was considered in terms of both probability and consequence to determine an overall level of risk. The results of the assessment are summarized in Table ES-2. As can be seen, the more rigorous assessment has shown that the risk of the selected bounding scenarios is low to moderate. No high-risk scenarios have been identified.

Table ES2 Bounding Scenarios Probability, Consequence, and Risk Ranking

No.	Potential Accident /or Malfunction	Potential Effect pathway	Probability	Effect Severity	Overall Risk Rating[1]
1	Vehicle accident including rollover, collision, run off road	Aquatic release of radioactivity	Highly unlikely	Moderate	Low
2	Vehicle accident including rollover, collision, run off road	Aquatic release of fuel, hazardous chemicals and reagents	Unlikely	Moderate	Low
3	Loss of freeze capacity	Loss of freeze wall and secondary underground containment	Highly unlikely	Major	Moderate
4	Failure of freeze wall	Loss secondary underground containment and groundwater contamination	Highly unlikely	Major	Moderate
5	Process vessel and piping system failure	Release of radon from storage tank	Likely	Minor	Low
6	Facility fire / explosion	Release of radioactivity and uranium concentrate powder to atmosphere	Highly unlikely	Moderate	Low
7	Vehicle accident including rollover, collision, run off road	Terrestrial release of radioactivity and chemicals	Unlikely	Minor	Low

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abbreviations

Acronym	Definition
ac	aqueous
AEGL	Acute Exposure Guideline Level
ALARP	As low as reasonably practicable
ALOHA	Areal Locations of Hazardous Atmospheres
ARF	airborne release fraction
ATSDR	Agency for Toxic Substances and Disease Registry
CNSC	Canadian Nuclear Safety Commission
DOE	Department of Energy
DR	damage ratio
EPA	Environmental Protection Agency
ERA	environmental risk assessment
ERAP	Emergency Response Assistance Plans
ERPG	Emergency Response Planning Guideline
GEIS	Generic Environmental Impact Statement
HDPE	high density polyethylene
ISR	In Situ Recovery
LPF	leak path factor
MAR	material at risk
NPAG	non-potentially acid generating
NRC	Nuclear Regulatory Commission
OECD	Organisation for Economic Co-operation and Development
PAC	Protective Action Criteria
PAHs	polyaromatic hydrocarbons
Project	Wheeler River Project
RF	respirable fraction
REGDOC	Regulatory Document
TDG	Transportation of Dangerous Goods
TEEL	Temporary Emergency Exposure Limit
UOC	uranium ore concentrate
WTP	Water treatment plant

Units of Measure

Units	Definition
%	percent
µg/L	micrograms per litre
µm	micrometre
Bq/g	becquerels per gram
Bq/L	becquerels per litre
cm	centimetre
cm/s	centimetres per second
g/cm^3	grams per cubic centimetre
g/m^3	grams per cubic metre
g/s	grams per second
gal	imperial gallon
GBq	giga-becquerels
GBq/h	giga-becquerels per hour
kg	kilogram
kg/d	kilograms per tonne
kg/m^3	kilograms per cubic metre
kg/t	kilograms per tonne
h	hour
ha	hectare
km	kilometre
km^2	square kilometres
km/h	kilometres per hour
L	litre
L/(m^2/s)	litres per square metre per second
L/s	litres per second
m	metre
m/s	metres per second
m^2	square metres
m^3	cubic metres
m^3/d	cubic metres per day
m^3/hr	cubic metres per hour

Units	Definition
m^3/s	cubic metres per second
m^3/yr	cubic metres per year
masl	metres above sea level
mg/L	milligrams per litre
mg/m^3	milligrams per cubic metre
MBq	mega-becquerels
MBq/h	mega-becquerels per hour
mil	millimetre
min	minute
mm	millimetre
mm/°C/day	millimetres per degree day
mm/yr	millimetres per year
ppm	parts per million
t	tonne
t/d	tonnes per day
t/h	tonnes per hour
uswg	U S Water Gallon

1.0 INTRODUCTION

EcoMetrix Incorporated (EcoMetrix) was retained by Denison Mines Corp. (Denison) to complete the accidents and malfunctions (A&M) assessment for the Wheeler River Project as part of the environmental assessment process. The Project is a proposed in-situ recovery (ISR) uranium operation in Saskatchewan. This report details that assessment.

1.1 Overall Scope and Objective of the Assessment

The scope of this assessment includes consideration of potential accidents and malfunctions within the context of the key Project components that define the Project scope for the purposes of the Environmental Assessment.

The objective of the assessment is to evaluate the potential human health or biophysical environmental effects resulting from radiological and conventional accidents and malfunctions in consideration of proposed environmental protection measures.

1.2 Background Information

The Denison Wheeler River Project (Wheeler or the Project) is a proposed uranium mine and processing plant in northern Saskatchewan, Canada. The Project is located in a relatively undisturbed area of the boreal forest about 4 km off of Highway 914 and approximately 35 km north-northeast of the Key Lake uranium operation. The deposit will be mined via ISR that involves injecting a low-pH mining solution into the uranium deposit through a series of cased drill holes (injection wells) and subsequently pumping the uranium-rich solution to surface through recovery wells. Once on surface, the uranium rich mining solution recovered from the wellfield will be pumped to the on-site processing plant. Inside the processing plant a relatively simple precipitation process will be used to separate the uranium from the mining solution. Once separated, the uranium will be dried, packaged and trucked off site, destined for eventual use in a nuclear power plant. The main phases of the Project are construction, operation, decommissioning and post-decommissioning. Construction would last for approximately three years, production activities would commence following commissioning of the facilities and would last 15 years with a production rate of up to 12 M lbs U3O8 per year. Decommissioning is expected to last for five years and post-decommissioning a further 15 years.

Further Project-related information is provided in **Section 2.0**, Project Information.

1.3 Regulatory Context to the A&M Assessment

For the purpose of this assessment, accidents and malfunctions refer to events or conditions that are not part of any activity or normal operation of the Project as proposed by Denison Mines Corp. (Denison). This is consistent with the definition of an accident as described in REGDOC 3.6, "… *any unintended event, including operating errors, equipment failures, and other mishaps, the consequences, or potential consequences of which are significant from the point of* *view of protection or safety*" (CNSC 2021). Despite rigorous planning and the implementation of best practices and preventative measures, the potential exists for accidents and malfunctions to occur during any Project phase. If such unplanned events or conditions occur, adverse effects on human health or the biophysical environmental could result if not addressed or responded to in an appropriate manner.

Federal guidance concerning the assessment of accidents and malfunctions is provided in Canadian Nuclear Safety Commission (CNSC) REGDOC-2.9.1: Environmental Protection: Environmental Principles, Assessments and Protection Measures (CNSC 2020). Specific considerations regarding the scope of such assessments are described in REGDOC-2.9.1, which indicates that the Environmental Impact Statement should provide an assessment of potential health and environmental effects resulting from postulated radiological and conventional malfunctions and/or accidents. The Environmental Impact Statement should also include any mitigation measures such as monitoring, contingency, clean up, or restoration work in the surrounding environment that would be required during or immediately following the postulated malfunction and accident scenarios (CNCS 2020).

Section 5.4 of the Transportation of Dangerous Goods Regulations (Government of Canada 2021) sets out the requirements for the loading and securing of dangerous goods to prevent damage to the container or to the means of transport that could lead to an accidental release. Sections 8 of the Transportation of Dangerous Goods Regulations is relevant to accidental release and accidental release reporting requirements.

The provincial mandate is less specific than that provided within CNSC REGDOC-2.9.1. Both the technical proposal guidelines (Government of Saskatchewan 2014a) and the guidelines for the preparation of the terms of reference (Government of Saskatchewan 2014b) that have been prepared by the Environmental Assessment Branch of the Ministry of Environment under the Saskatchewan Environmental Assessment Act make reference to addressing effects associated with accidents and malfunctions that may occur during all Project phases within the Environmental Impact Statement submission. Denison has included these commitments in the Project's Terms of Reference (Denison 2019).

1.4 Report Format

Following this introductory section, the remainder of this report is organized as follows:

- **Section 2.0**: provides Project-related information;
- **Section 3.0**: describes the methodology for the accidents and malfunctions assessment;
- **Section 4.0**: presents general considerations and context for the accident and malfunctions assessment;
- **Section 5.0**: provides the description of the bounding scenarios identified through the initial hazards identification and screening process (see Appendix A);
- **Section 6.0**: provides the chemical, occupational, and radiological benchmarks used to facilitate the quantitative assessment of identified bounding scenarios;

- **Section 7.0**: presents the assessment of probabilities of the bounding scenarios;
- **Section 8.0**: presents the assessment of the potential effects of the bounding scenarios on the environment;
- **Section 9.0**: provides a summary of the overall estimate of risks from bounding accidents and malfunctions scenarios.
- **Section 10.0**: provides a list of references cited in this report.

The detailed hazard identification evaluation that was completed in support of this assessment is provided in **Appendix A**. The hazard identification evaluation is used to identify a comprehensive list of potential accident and malfunction scenarios that may occur in consideration of Project-related work processes and activities, screen these scenarios as to potential risks and, based on this screening, recommend scenarios that could pose a relative high risk that should be carried forward for more detailed consideration. It is noted that the hazard identification evaluation focusses on risks to the human health or biophysical environment.

2.0 PROJECT INFORMATION

2.1 Project Location

The Project would be located in northern Saskatchewan about 4 km off of Highway 914 and approximately 35 km north-northeast of the Key Lake uranium operation (**Figure 2-1**).

The Project site plan and the facility layout are shown in **Figure 2-2** and **Figure 2-3**, respectively.

Figure 2-1: Location of the Wheeler River Project Site in Saskatchewan

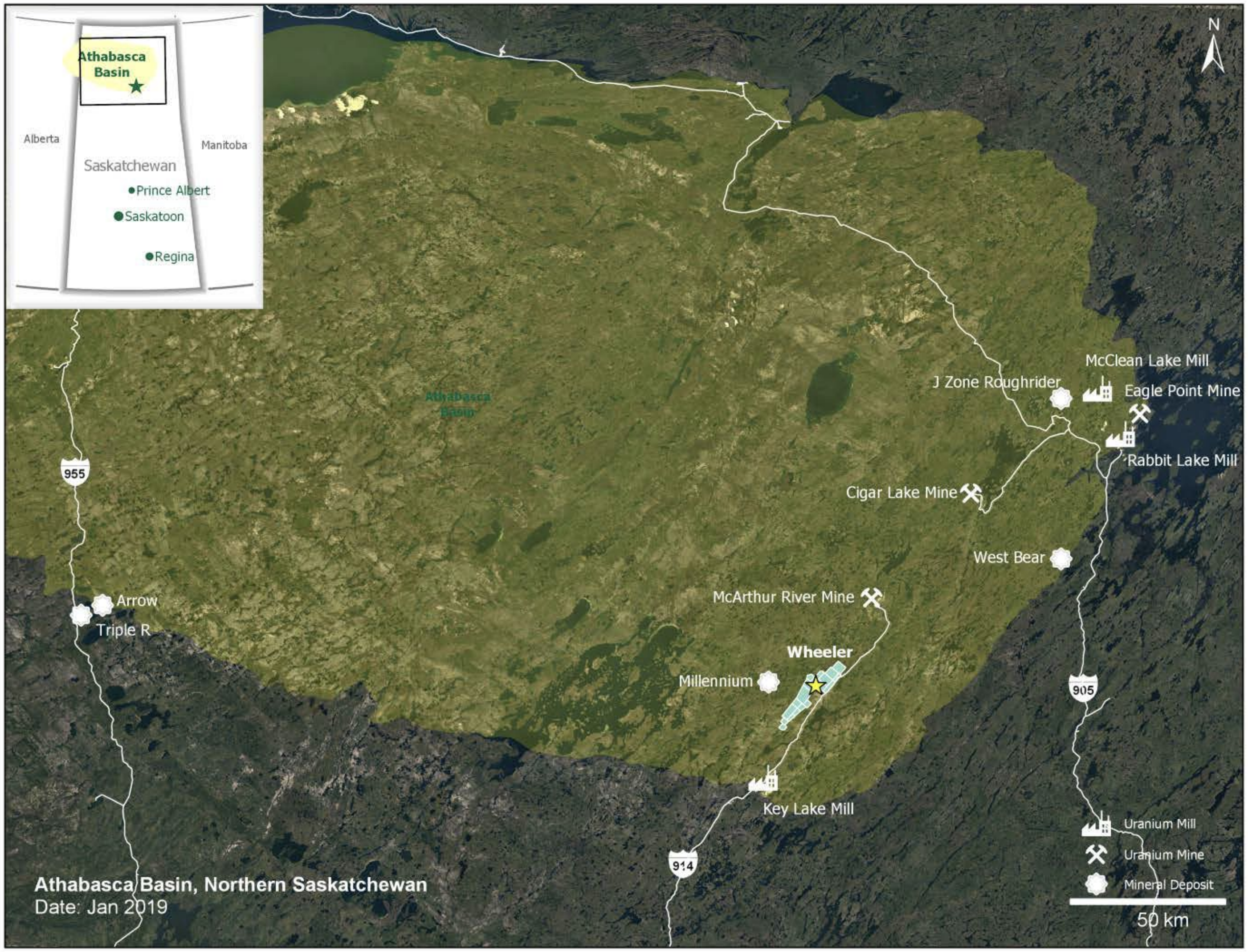


Figure 2-2: Wheeler River Project Site Plan Overview

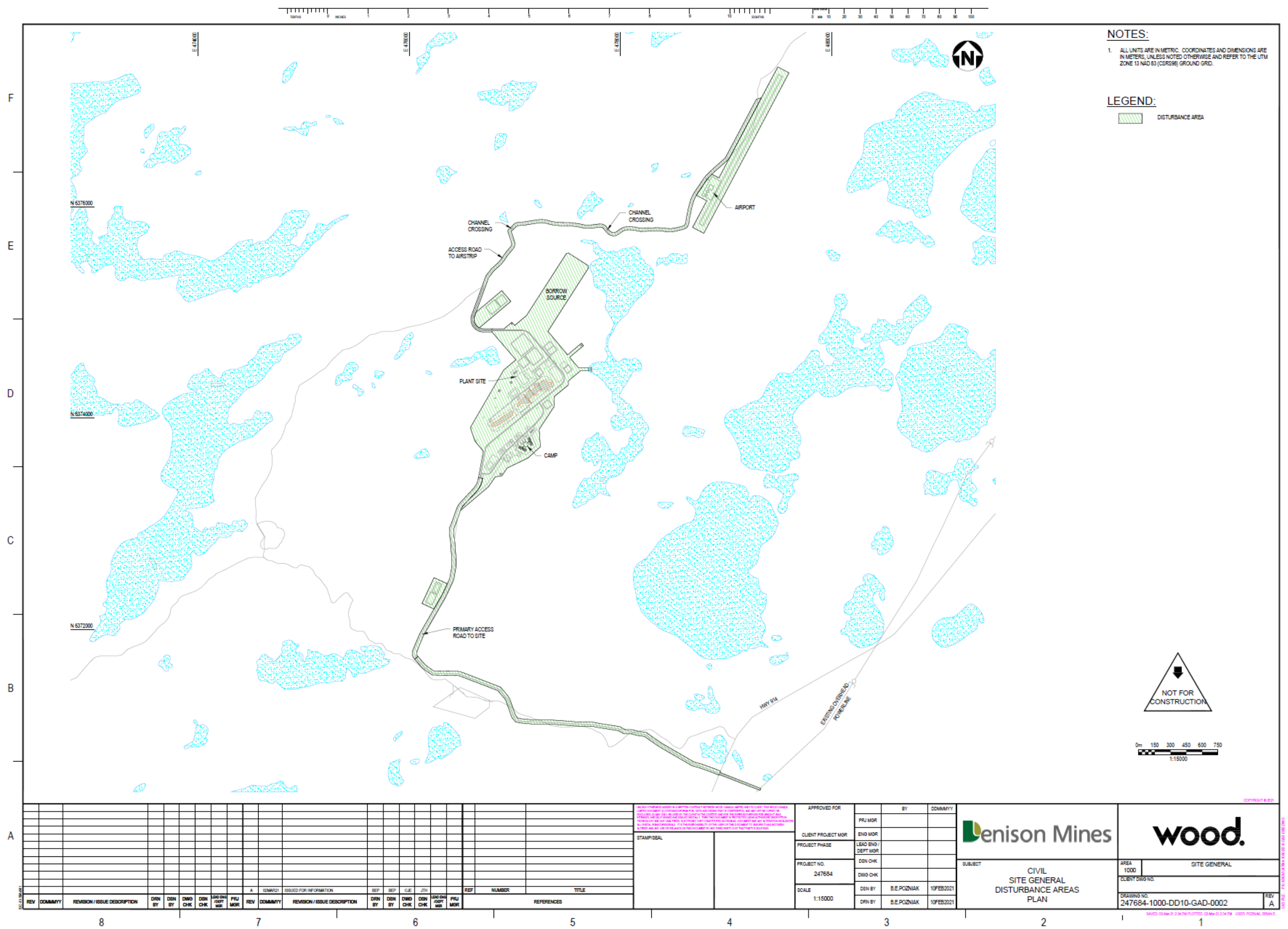
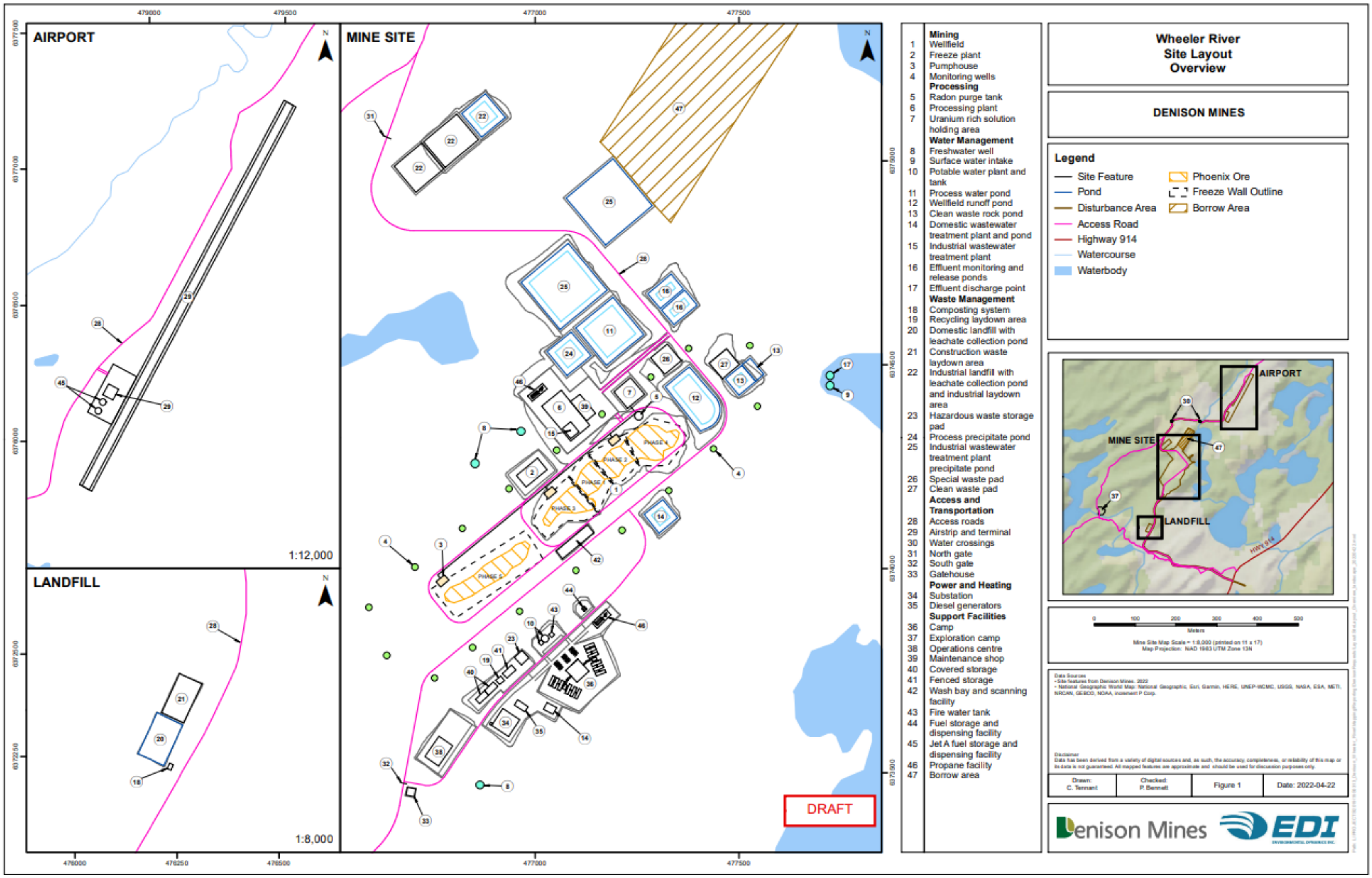


Figure 2-3: Wheeler River Project Facility Layout



2.2 Project Details and Components

As indicated in **Section 1.2**, the Project includes four principal phases: construction, operations, decommissioning and post-decommission. These project phases are summarized in **Table 2-1**.

Table 2-1: Key Wheeler River Project Phases Description

Phase	Duration	Description
Construction	3 years	• Development of access roads and air strip • Site preparation and earthworks; clearing, levelling, and grading of the Project Area • Power generation – generators • Installation of main substation and distribution of power around site • Wellfield and freeze hole drilling; ground freezing • Batch plant operation (concrete); crusher at borrow area • Development of surface infrastructure (camp, operations centre, plants, ponds, pads, and support facilities) • Waste management (composting, domestic and industrial landfill operation, recycling) • Water management (including treatment and site runoff) • Groundwater supply • Surface water withdrawal • Fuel management (e.g., propane for comfort heating; vehicle and aircraft fuel) • On-site and off-site operation of vehicles and transport of materials • Air transportation for workers • Regulatory site inspections • Engagement – site visit from Interested Parties
Operation	15 years	• Operation of the ISR wellfield • Wellfield and freeze wall drilling • Operation and expansion of freeze wall • Batch plant operation (grout and cement); crusher at borrow area • Expansion of pond and pads • Operation of the processing plant and production of uranium concentrate • Water withdrawal from groundwater or surface water body • Management of surface water (including seepage and site runoff) • Water treatment, both domestic and industrial

Phase	Duration	Description
		• Water release to surface water body • Waste management (composting, domestic and industrial landfill operation, recycling) • Hazardous waste management (temporary storage, handling, and off-site transportation) • Storage and disposal of drill waste rock, process precipitates, and industrial wastewater treatment plant precipitates • On-site and off-site operation of vehicles and transport of materials • Power supply – primarily power from the grid, also generators and back-up generators • Package and transport of nuclear substances • Fuel management (e.g., propane for comfort heating; vehicle and aircraft fuel) • Air transportation for workers • Progressive decommissioning and reclamation • Regulatory site inspections • Engagement – site visit from Interested Parties
Decommissioning	5 years	• Site water management, treatment, and release • Mining horizon remediation and thawing of freeze wall • Process water treatment and release • Closure of ISR and freeze wells and related infrastructure • Decontamination of surface facilities and injection, recovery, and monitoring wells • Asset removal (including site power transmission lines and electrical infrastructure) • Demolition and disposal of non-salvageable surface infrastructure and materials • Remediation of contaminated areas (wellfield, pads, ponds, domestic wastewater treatment location, and process plant area) • Power generation – generators • Waste management (composting and landfill operation) • Decommissioning of landfills; hazardous materials management (temporary storage and off-site disposal) • On-site and off-site operation of vehicles and transport of materials • Reclamation of disturbed areas • Regulatory site inspections

Phase	Duration	Description
		• Engagement – site visit from Interested Parties
Post-Decommissioning	15 years	• Environmental monitoring • Regulatory site inspections • Engagement – site visit from Interested Parties

Further to the description of Project phases provided in Table 2-1, key project details and components are highlighted in Table 2-2 and in the report subsections that follow.

Table 2-2: Key Wheeler River Project Details and Components

Item	Details
Access Road	A seven-kilometer section of road from highway 914 to the Wheeler site and a five-kilometer section of the road from the Wheeler site to the airstrip.
Air Strip	A 1,600 m long airstrip is positioned in a natural and relatively flat valley to the northeast of the Wheeler site including a terminal building and two double-walled Jet A fuel tanks.
Site Works	Site works includes site preparation, construction, equipment installation and decommissioning activities.
Orebody and Wellfield	The Phoenix deposit, the highest-grade undeveloped uranium deposit in the world, is geologically situated at or immediately above the unconformity between the Athabasca Basin sandstone and older basement rocks, approximately 400 metres below surface. The ISR wellfield is a group of wells, installed and completed in an area of uranium mineralized within the Phoenix deposit. The wellfield includes the piping and pumping systems, as well as monitoring wells.
Freeze Wall	The freeze wall would be established by drilling parallel cased holes from surface, anchoring into the impermeable basement rock and would be constructed to surround the mining horizon, from bedrock to surface. The freeze wall would be established in stages, consistent with the mining schedule. The freeze plant will be constructed on surface based on a modular design for easy installation and operation.
Processing Plant	The processing plant includes pH adjustment, impurities removal, uranium precipitation, uranium concentrate dewatering/drying and packaging, and mining solution refortification.
Accommodation Facility	The accommodation facility will be sized to accommodate a peak load of about 100-150 individuals during operations.
Operations Centre	The operations complex will be a standalone, multi-functional building that will serve the administrative, technical, and maintenance needs of the site.
Security Houses and Truck Scales	The security and truck scale buildings will be modular, prefabricated units that will be manufactured off-site and shipped to site for installation and commissioning.
Wash Bay and Scanning Facility	A wash bay will be available to clean items, equipment and vehicles that may have been in contact with potential contaminants.

Item	Details
Power Supply	Primary Power Supply to the site will be provided via an approximate 5 km extension tap from the existing 138 kV overhead transmission line that runs along Highway 914. Emergency diesel generator will serve as the back-up power supply.
Site Runoff Management	The site runoff management will include the runoff from waste pads and clean waste rock pads and other site runoff.
Fresh Water Supply and Distribution	Fresh water will be sourced from either a shallow groundwater well or an intake from a nearby surface water body to supply the fire water system, potable water, processing plant, wash bay, and temporary batch plant.
Potable Water Treatment Plant	Potable water will be generated on site by a prefabricated modularized (40 ft shipping container) potable Water Treatment Plant (WTP) comprised of a treatment plant, a 2,000 L storage tank, and a bottle filling station.
Sewage Treatment Plant	The sewage treatment plant will be a modular facility comprised of two heated and insulated units (likely containers), a holding tank, ancillary filtration, ancillary treatment process equipment, and sludge handling system.
Water Treatment Plant	The WTP will be designed to treat any contaminated water removed from the ISR process (e.g., backwash of sand filters, bleed solution), runoff collected from the waste pad, and any other contact water such as water from the wash bay and process sumps. The WTP will be located inside of the processing plant.
Landfill and Compost	The inert non-hazardous wastes such as wood and plastics will be disposed in an on-site landfill and food waste will be composted.
Waste Pad and Ponds	the waste pad is expected to contain mineralized drill cuttings from wellfield development, solid impurities (mainly iron and/or radium) removed from the uranium rich mining solution, and dewatered reject solids from the sewage and water treatment processes.
Clean Waste Pad and Ponds	Clean waste rock will be stored on an unlined pad and can be used for road or concrete construction.
Hazardous Substance Storage and Dispensing	Hazardous substance storage will include liquid Fuel Storage and Dispensing Facility, propane facility, and other hazardous substances including sulphuric acid, hydrogen peroxide, sodium hydroxide, barium chloride and flocculants

2.2.1 Access Road

Mainland access to the site will be from Highway 914. An assessment of several routes was completed and considered factors such as: safety, environment (total disturbance), capital costs and risk. In addition, specific workshops were held in the Indigenous and non-Indigenous communities to capture community input into the final route selection. After the engagement process and using community input, the preferred route was selected and incorporated into the current Project design. A seven-kilometer (7 km) section of road will be constructed from the highway to the Wheeler site and a five kilometer (5 km) long road will also be constructed from the Wheeler site to the airstrip; the total road length is twelve kilometers (12 km). Additional site roads will include a service loop to the camp and a short service road to the runoff pond and the potential treated effluent discharge point. The development of the access road options considered distance from waterbodies among other factors. Denison anticipates the need for installation of two water crossings over the Icelander River along the section of the road from the Wheeler site to the airstrip.

2.2.2 Airstrip

A 1,600 m long airstrip is proposed to be positioned in a natural and relatively flat valley to the northeast of the Wheeler site. The magnetic headings are 03/21, which is similar to both the Collins Bay airport and Key Lake airstrip. The runway has been designed to accommodate the aircraft presently used by existing mining operations in northern Saskatchewan to transport personnel into and out of site. The approach line to the airstrip from the southwest clears the Wheeler surface facilities by 500 m. An airstrip terminal building and two double-walled Jet A fuel tanks, to provide site service to aircraft as required, will be constructed near the airstrip. The airstrip and terminal will not be connected to the substation; a small diesel genset will be used to provide terminal building services, communications, and runway lighting.

2.2.3 Site Works

The site works associated with the implementation of the Project include:

- Site preparation.
- Road construction.
- Installation of piping.
- Building construction.
- Construction of ponds and pads.
- Installation of process equipment.
- Construction of utility systems.
- Batch plant operation.
- Mining horizon remediation.
- Decontamination.
- Asset removal.
- Demolition and disposal.
- Reclamation.

2.2.4 Orebody and Wellfield

Several areas of uranium mineralization amendable to ISR have been defined at Wheeler, with the most prominent area being the Phoenix deposit. Phoenix is the highest-grade undeveloped uranium deposit in the world. It is geologically situated at or immediately above the unconformity between the Athabasca Basin sandstone and older basement rocks, approximately 400 metres below surface.

The ISR wellfield is a group of wells, installed and completed in an area of uranium mineralized (**Figure 2-3**). The Wheeler wellfield will consist of a combination of injection and recovery wells, potentially in the general arrangement of one recovery well in the centre surrounded by 6 to 8 injection wells. At surface, the spacing between the recovery well and each injection well is anticipated to be roughly 10 metres apart, with certain areas requiring closer spacing (approximately 5 meters) or further spacing (approximately 15 metres). With these configuration options, the final wellfield for Phoenix is expected to include approximately 310 wells over a 90 m x 900 m area.

Wellfield piping system will transport the mining solution to and from the processing plant. The flow rates and pressures of the individual well lines will be monitored in the pumphouses. This data will be transmitted to the processing plant for remote monitoring through a master control system. Through the master control system, operators will be capable of controlling pumphouse production lines remotely.

Double-walled high-density polyethylene (HDPE), or equivalent, piping will be used in the wellfields and will be designed and selected to meet design operating and environmental conditions. The lines from the processing plant, pumphouses, and individual well lines will be freeze protected and secured to minimize pipe movement.

Based on the current designs for the Project, approximately three pumphouses will be needed. A pumphouse is a small building or container on surface where pipes from injection and recovery wells are operated and flows of mining solution are monitored.

Pumphouses will contain pumps and equipment that will distribute the mining solution to the injection wells, as well as collect the uranium rich mining solution from the recovery wells. Each pumphouse will be connected to two production trunk lines. One of the trunk lines will be used for receiving mining solution from the processing plant, and the other will be used for returning uranium rich mining solution back to the processing plant. Each pumphouse will include a manifold, valves, flow meters, pressure meters, and instrumentation, as required, to fully operate, monitor and control the process. Pumphouse control monitoring systems enable operators to individually adjust each recovery or injection well as well as allow for sampling. Operators can also use the master control system in the processing plant to remotely control pumphouse production lines.

2.2.5 Freeze Wall

At Wheeler site, the very low permeability basement rock below the uranium deposit serves as a natural aquitard; however, the sandstone hosting the uranium deposit is permeable and groundwater can flow horizontally through the deposit. To achieve containment at Wheeler, the uranium deposit will be surrounded by an engineered freeze wall from the basement rock to surface, isolating the uranium from regional groundwater movement.

The freeze wall will be established by drilling parallel cased holes from surface, anchoring into the impermeable basement rock, spaced approximately 6 m apart. A total of over 300 freeze holes are planned for the Wheeler River Project. The ground will be frozen from surface down to the low permeability basement rock to create a continuous wall around the mining area which is completely contained from the surrounding regional groundwater. Once the drill holes have been installed, a low temperature brine solution will be circulated through the cased holes to remove heat from the ground, ultimately freezing the natural groundwater. While the freeze wall is expected to be several metres thick, it will be developed around the uranium deposit, to ensure the uranium deposit itself does not freeze.

Each section of the freeze wall will require approximately twelve months to be established. The freeze wall will remain in place until mining is complete and into the decommissioning phase until remediation is completed. After decommissioning, once the refrigeration is turned off, it will take a minimum of twelve months for the freeze wall to thaw depending on how long the freeze wall was active and actual ground conditions encountered.

To supply the cold brine, a freeze plant will be constructed on surface based on a modular design for easy installation and operation. Each chiller unit produces about 300 tons of refrigeration (TR) and contains an ammonia compressor, which is run by a 1,000 hp motor. The brine distribution system is handled by a surface brine mixing tank that can move brine to the freeze holes at 300 m^3/hr. The freeze plant capacity is expected to be scaled up throughout the mining phases based on refrigeration requirements, from two chiller units at the start of Phase 1, to a total of six units at Phase 5 of mining and beyond to the decommissioning phase.

2.2.6 Processing Plant

The processing plant will house the tanks and equipment to fully process uranium rich mining solution recovered from the ISR wellfield into uranium concentrate and refortify the mining solution for continued use in the ISR wellfield. The processing plant will also contain filtration systems, bulk chemical storage, process solution storage tanks, and a control room.

Bulk storage tanks for the processing chemicals, such as sulphuric and/or hydrochloric acid, sodium hydroxide, and hydrogen peroxide, will be located outside the processing plant building. The storage tanks will sit inside appropriately designed and sized concrete secondary containment basins.

The uranium bearing solution will be pumped from the wellfield pumphouse(s) to the processing plant and pumped through the following circuits:

- Radon purge tank: When the uranium bearing solution comes to surface, radon gas will naturally move out of solution and into the atmosphere. To keep worker radiation exposure ALARA, a radon purge tank will be used to remove this initial volume of radon before the solution enters the processing plant. The radon purge tank will vent radon from the uranium bearing solution to the air outside of the plant.

- Uranium bearing solution holding area: the ISR mining and subsequent processing of uranium will not always occur at the same rates. Additionally, there will be times when parts of the processing plant are down for routine maintenance. For these reasons, Denison has incorporated a UBS holding area into the current design of the processing plant. It will be a controlled area where UBS can be safely stored on surface, prior to processing. The UBS holding area will be adjacent to the processing plant and under a fabric tension building system. The fabric tensioned roof will help to keep precipitation from entering the uranium bearing solution. The volume of the UBS holding area is anticipated to be 5,000 m^3. The area will be contained by a double composite liner system with leak detection

- Process precipitate removal – Uranium bearing solution will be pumped to a process precipitate removal circuit where the pH of the solution will be adjusted to allow for precipitation of impurities such as iron hydroxides, radium-226, thorium-230, and other metals, collectively referred to as process precipitates. Removal of process precipitates will be done by adding chemicals including hydrogen peroxide, barium chloride, sulphuric acid, flocculant, and lime. Once the impurities have precipitated out of the UBS, the solution is routed to the yellowcake precipitation circuit. Process precipitates removed at this step will be pumped or placed into totes and moved to the process precipitate storage area. The precipitates will contain approximately 2- 3% uranium and will be removed and processed at an offsite facility as part of the decommissioning phase.

- Yellowcake precipitation – Upon completion of the process precipitate removal step, the remaining solution will be further refined by reagent addition and pH adjustments in agitated tanks to precipitate yellowcake. The final step of yellowcake precipitation occurs through a thickener that provides time for dewatering of the uranium oxide precipitates. The precipitated uranium will accumulate at the bottom of the thickener and the remaining solution will rise to the top. The precipitated uranium will be transferred to the yellowcake dewatering, drying, and packaging area and the remaining solution will be transferred to the industrial wastewater treatment circuit.

- Yellowcake dewatering, drying, and packaging – Moisture from the precipitated uranium will be removed through filtering then conveyed through enclosed conveyor to the dryer where any remaining moisture will be evaporated. Any water collected from the drying process will be condensed and reused in the plant for reagents preparation. Denison is evaluating the use of either low temperature dryers or calciners for the drying step in the processing plant. Calcining allows for further removal of impurities from the produced yellowcake to meet certain purchasers' requirements. Once the moisture is removed from the yellowcake product, the yellowcake is packaged into 55 gallon steel drums via gravity.

2.2.7 Accommodation Facility

Located to the southeast of the wellfield, the proposed accommodations facility is anticipated to be a turnkey building manufactured offsite and assembled and commissioned on-site. The building's design will be sized to accommodate a peak load of about 100 to 150 individuals during operations; however, due to its modularized design, additional modules can be easily installed should additional beds be required in the future.

The facility will include a central services complex with:

- Kitchen with food preparation area and serving area;
- Dining room;
- Camp office;
- Commissary;
- Recreation area; and
- Exercise facilities.

2.2.8 Operations Centre

The operations complex is planned to be a standalone, multi-functional building that will serve the administrative, technical, and maintenance needs of the site. The building is proposed to be a two-story pre-engineered structure with total usable space of 38,000 ft^2: 27,000 ft^2 on the first floor and 11,000 ft^2 on the second floor.

The first floor will house the two-story shops, dry space, and warehouses. The shops will include three full-sized maintenance bays, with one being equipped as a welding bay. Areas of the operations centre will be designed to have containment and sumps as required. Change areas (dries) will be provided, with contamination control and suitable wash spaces for each, including laundry facilities. The warehouse has two receiving doors adjacent to the shops. Office spaces will also be provided in these areas for warehouse and procurement staff as well as maintenance supervisors.

The second floor will have administrative space with offices, a boardroom, meeting rooms, lunchroom, and washrooms.

Additional facilities include:

- Medical or nursing station with waiting area;
- Parking space for emergency response vehicles;
- Space for storage of mine rescue/emergency response gear and supplies;
- Laboratory facilities;
- Training room; and
- Mechanical and electrical services rooms.

2.2.9 Security Houses and Truck Scales

Access to the property will be controlled by both a north and south security gate. The main, south gate security house will be staffed as required and be equipped with an 80-tonne weigh scale that is hard-wired into the shack. The security and truck scale buildings are planned to be modular, prefabricated units that will be manufactured off-site and shipped to site for installation and commissioning. The south gate facilities will have appropriate power and communications capability. The north gate will be a simple locked gate.

2.2.10 Wash Bay and Scanning Facility

A wash bay will be constructed to clean items, equipment and vehicles that may have been in contact with potential contaminants. Contaminated water from wash bay will be collected in a sump tank and routed to the water treatment plant for treatment and discharge. Radiological clearance scanning required for any items, equipment and vehicles leaving the site will be conducted in the same building.

2.2.11 Power Supply

Site infrastructure anticipated to draw power from the provincial power grid, includes the camp buildings, operations buildings, the ISR precipitation plant, and the freeze plants.

- Primary Power Supply - Electrical service to Wheeler will be provided via an approximate 5 km extension tap from the existing 138 kV overhead transmission line that runs along Highway 914. Power transmission to the site (e.g., assessment, obtaining necessary permits, and construction) will be led by SaskPower and is not considered part of this Project.
- Back-up Power Supply - To provide electrical service during times of utility outages, emergency diesel generator will be installed in strategic locations to service the site and maintain essential functions. The generators will be used to maintain power to the processing plant and the accommodations facility, as well as to maintain other essential services as required.

2.2.12 Site Runoff Management

Water will be collected from the waste pond (which collected runoff from the waste pad) and the processing plant terrace and then directed to the water treatment plant. Runoff for the small clean waste rock pile may be collected into a settling pond to remove total suspended solids if necessary. Other site runoff collection needs will be examined and identified as needed; conceptually the strategy runoff management strategy is to ensure all waters potentially influenced by site aspects are diverted in into the site water management system and only released to the environment when their quality is appropriate to do so.

2.2.13 Fresh Water Supply and Distribution

A freshwater distribution system will be designed to provide fresh water to the fire water system (freshwater tank, two electric fire water pumps, and a back-up diesel fire water pump for on-site fire suppression needs), the potable WTP, the processing plant, wash bay and temporary batch plant (required during construction phase). Fresh water will be sourced from either a shallow groundwater well or an intake from a nearby surface water body.

2.2.14 Potable Water Treatment Plant

Potable water will be treated on site by a prefabricated modularized (40 ft shipping container) potable WTP comprised of a treatment plant, a 2,000 L storage tank, and a bottle filling station. Potable water will be piped to the camp, the operations centre, and the processing plant to provide water for safety showers and eyewash stations. Other locations, such as the airstrip terminal, gate houses and satellite lunch trailers (during construction) will receive bottled water as required.

Ultrafiltration or reverse osmosis with UV filtration are proposed. Chlorination will be needed prior to distribution. The modular plant will be capable of all necessary processes and will contain required HVAC and lighting. The potable WTP will be placed on a concrete pad and will generate 1.4 m^3/hr (33 m^3) of potable water per day based on 300 L per person per day.

2.2.15 Sewage Treatment Plant

Domestic wastewater and sewage were assumed to be generated at the rate of 300 L per person per day. Sewage will either be collected in septic tanks and transported by a vacuum truck or piped directly to the on-site sewage treatment plant. The sewage treatment plant will be a modular facility comprised of two heated and insulated units (likely containers), a holding tank, ancillary filtration, ancillary treatment process equipment, and sludge handling system. Denison may investigate options to dispose of treated sewage underground or through a septic field. Alternatively, the sewage treatment plant will generate effluent suitable for discharge to local surface water. Treated effluent will first be discharged to surface testing ponds where the water quality will be checked to ensure it meets regulatory limits. Reject solids from the treatment process will be collected, dewatered, and stored on the waste pad on site prior to permanent disposal.

2.2.16 Water Treatment Plant

The Wheeler WTP will be designed to treat any contaminated water removed from the ISR process (e.g., backwash of sand filters, bleed solution), runoff collected from the waste pad, and any other contact water such as water from the wash bay and process sumps. The WTP will be located inside of the processing plant.

It is Denison's intent to incorporate treated water back into the mining water balance as make-up water in the processing plant, to the extent possible. Any excess treated water from the WTP will be pumped to appropriately sized holding ponds. The holding ponds will be sized to hold effluent for a period of 24 hours for testing before discharge to the environment.

Treated water in the ponds will be monitored prior to release to a surface water body or injected into groundwater via deep well injection. All treated effluent released to surface water will meet federal and provincial regulatory discharge limits.

2.2.17 Landfill, Recycling and Compost Management

- Domestic Waste Landfill - Denison plans to construct, operate, monitor and decommission a domestic landfill on site. A waste management plan will be developed for the Project which will detail how each type of waste generated on site will be managed. In general, only inert non-hazardous wastes such as wood and plastics will be suitable for disposal in the on-site landfill. The domestic landfill will have a composite liner system with leachate collection.
- Industrial Waste Landfill - Denison plans to construct, operate, monitor and decommission an industrial landfill on site. A waste management plan will be developed for the Project which will detail how each type of waste generated on site will be managed. The industrial landfill will be designed to accept industrial wastes generated at site including waste with chemical and/or radiological contamination. The landfill will have a double composite liner system with leak detection between the composite liners and leachate collection system above the primary, or upper composite liner.
- Composter - Denison plans to operate an composter for food waste. A contained and partially automated composter, such as the Brome composting system, is the preferred option.

2.2.18 Waste Pad and Ponds

During operation, the special waste pad is expected to contain primarily mineralized core and cuttings from wellfield development.

Special waste from drilling activities is defined as uranium containing materials that cannot be disposed of in the clean waste pile. Special waste will be determined by Denison geologists based on ore zone intersection expectations and probe reading taken during wellfield drilling activities. Based on the current wellfield and freeze wall design, approximately 150 m^3 of special waste rock will be generated.

Denison will examine opportunities to reprocess the mineralized core and cuttings generated during wellfield development. This may be done by placing the material in tanks with mining solution or place the material underground into the leaching zone (at the tail end of a well's production) to complete the leaching underground.

The special waste pad may be used to temporarily store other materials that may be radioactive (e.g., contaminated soil) prior to disposal in the industrial landfill.

The special waste pad is estimated to be 2,500 m^2 in size and will be constructed with a double composite liner system with leak detection capabilities. Any contact water coming off the special waste pad will be directed to the wellfield runoff pond.

2.2.19 Clean Waste Pad and Ponds

Clean waste rock will be generated from the sandstone cuttings from drilling activities. This includes the drilling of the injection and recovery wells to create the ISR wellfield and the drilling of freeze holes to create the freeze wall. Clean waste rock will be stored on an unlined pad and can be used for road or concrete construction. A pond may be constructed beside the pad to collect runoff if required.

2.2.20 Hazardous Substance Storage and Dispensing

- Fuel Storage and Dispensing Facility - Fuel consumption at Wheeler may be limited to back-up power supply, auxiliary vehicles (i.e., ATVs and snowmobiles), miscellaneous equipment (i.e., portable pumps), and freight and personnel transportation to site. Tanker trucks will deliver diesel and gasoline to the site on an as-needed basis. Fuels will be stored in approved, above-ground, 25,000 L double-walled storage tank(s) equipped with secondary containment in accordance with provincial regulations and standards.

- Propane Facility - Propane may be used as a primary or backup means to support the camp kitchen, the incinerator, and to heat the buildings. The propane facility will be sized to meet the needs of the site activities and will a feature a storage tank (assumed to be 30,000 uswg), vaporizers, a propane bottle fill station, and a propane bottle weigh station. Propane will be delivered to site on an as needed basis.

- Other Hazardous Substances - Sulphuric acid, hydrogen peroxide, sodium hydroxide, barium chloride and flocculants are the main chemicals anticipated to be used in the processing plant and in mining. Bulk storage tanks for the processing chemicals, such as sulphuric and/or hydrochloric acid, sodium hydroxide, and hydrogen peroxide, will be located outside the processing plant. The storage tanks will sit inside appropriately designed and sized concrete secondary containment. The secondary containment for each applicable chemical system will be physically separated from the containment basins for other chemical systems.

2.3 Project Timeline

The Project timeline, and therefore the timeline over which potential accident and malfunction scenarios has been considered, is summarized in **Table 2-1**. The full life cycle of the Project is anticipated to be 38 years

3.0 ASSESSMENT METHODOLOGY

The methodology by which the accident and malfunction assessment has been carried out is described below.

For reference, the temporal and spatial extents of the assessment are as follows:

- The temporal extent of the evaluation includes all mine and mill life-cycle phases – construction, operations, decommissioning, and post-decommissioning.
- The spatial extent of the evaluation includes the Project site and the site access road. In addition, three off-site scenarios, involving a release to water (Scenarios 1 and 2) and ground (Scenario 7) that would have the potential to affect a community of interest along the mine-related transportation route were also considered. These scenarios were developed with the Denison team and reflected the result of and input from Denison's Interested Party engagement activities.

3.1 Overview

The assessment of accidents and malfunctions is designed to provide a clear definition of the potential Project-associated hazards that fall outside the range of "typical" day-to-day events and to provide a framework for quantifying the risks associated with these hazards.

The four basic steps in the process of risk assessment for the accidents and malfunctions assessment are as follows:

- Hazard identification and identification of bounding scenarios: Includes the identification of physical situations with the potential for harming the human health or biophysical environment. In this study, "Hazards" and "Accidents and Malfunctions" are used interchangeably. Hazard scenarios were identified using a systematic approach with consideration of the existence of sources of hazards and initiating events for each project component and activity. The hazards were identified for several potential events, such as releases of chemical and radiological constituents, fires, and explosions. Hazard scenarios were screened qualitatively for the perceived effects and probability of occurrence as well as the potential risk using a risk matrix approach (**Section 3.2.2**). Project information, experience from similar projects, particularly those located in Northern Saskatchewan, and professional judgment were used for this initial screening. Among the high or moderate-risk scenarios, bounding scenarios were selected. The bounding scenarios encompass the effects of other scenarios screened for each Project component and activity. The subsequent analysis focussed on these bounding scenarios. **Section 5.0** describes the selected bounding scenarios. The detailed methods and the complete list of identified scenarios are provided in the Wheeler River ISR Project Hazard Identification Report (**Appendix A**).

- Assessment of probabilities: Includes the estimation of the probability of occurrence of the selected bounding scenario occurring within a specific time period or in specified circumstances. **Section 7.0** describes the assessment of probabilities for each bounding scenario.

- Assessment of potential effects: Includes the quantitative evaluation of the potential effects of a selected bounding scenario to the human health or biophysical environment. **Section 8.0** includes the assessment of potential effects for each bounding scenario.

- Risk estimation and ranking: Includes the estimation of the combination of the effects of a scenario and the probability with which it is likely to occur; that is, risk is the product of consequence and probability (risk = consequence × probability of occurrence). Risk was evaluated using the risk matrix presented in risk matrix approach (**Section 3.2.2**). **Section 9.0** provides the overall risk estimation for the selected bounding scenarios.

3.2 Hazard Identification

As indicated above, the Wheeler River ISR Project Hazard Identification Report is provided in **Appendix A**. The hazard identification process is used to identify a comprehensive list of potential accident and malfunction scenarios that may occur in consideration of Project-related work processes and activities, screen these scenarios as to potential risks and, based on this screening, recommend scenarios that could pose a relative high risk that should be carried forward for more detailed consideration. The hazard identification evaluation focusses on risks to the human health or biophysical environment. An overview of the hazard identification process and the results of the hazard identification evaluation are provided below.

3.2.1 Scope and Applicability

As described in **Section 1.2**, Regulatory Context, there are regulatory drivers that require the potential effects of accidents and malfunctions related to the Project components and activities be assessed. The first step in the assessment of accidents and malfunctions is the completion of the hazard identification.

The objective of the hazard identification process is to identify all Project-related scenarios that have the potential to present a risk to the human health or biophysical environment. The hazard identification process includes a screening assessment of potential scenarios to identify those that require more detailed assessment in terms of probability and consequence. The initial screening evaluation is applied to a given scenario by qualitatively evaluating consequence severity and likelihood to determine an overall risk ranking. The evaluations of the probabilities and severity of the consequences, as well as the characterization of the risk of the selected scenarios, are included in the assessment of accidents and malfunctions.

Consistent with the overall accidents and malfunctions assessment, the scope of the hazard identification process included consideration of all Project phases (i.e., Construction, Operations, Decommissioning, and Post-decommissioning) and the Project site and associated access road to its junction with Highway 914, as well as at locations of interest to Interested Parties along the mine-related transportation route.

Generally, the evaluation focused on potential human health or biophysical environmental risks associated with Project components and activities. It is noted that some hazards related to worker safety were identified; however, worker safety (i.e., risks and consequences) is beyond the scope of this assessment.

3.2.2 Process Hazards Analysis

The hazard identification process is a systematic approach to identify possible hazards in a work process. A hazard can be defined as a physical condition that has the potential for causing damage to people, property, or the environment (e.g., fire, explosion, release of chemicals, or radioactivity). Potential nodes for hazard identification are selected through the review of the Project-related components. A node is a Project component that represents a physical system or activity with the potential to present a risk to the human health or biophysical environment. Hazard scenarios are developed on consideration of these nodes.

The hazard identification for each node involves the consideration of the sources of hazard (e.g., presence of hazardous materials), hazardous situations (e.g., height or extreme heat), and initiating events (e.g., natural causes, technical failure, or human error) that in combination present a risk to the human health or biophysical environment. A screening evaluation is applied to a given scenario by qualitatively evaluating consequence severity and probability to determine a risk level.

While there are standards and regulatory documents (e.g., REGDOC-2.4.2, Safety Analysis, Probabilistic Safety Assessment (PSA) for Reactor Facilities (CNSC 2014)) that govern the assessment of the probability of the hazard scenarios for nuclear reactors, no such documents exist for non-reactor facilities. The focus of these documents is design-basis and beyond design-basis accidents that affect the integrity of the reactor core. The annual probability of releases from these accidents can be $1x10^{-6}$ and lower, while the consequence of these accidents could be very severe. In contrast, the probability of accidents and malfunctions at non-reactor facilities such as mines and process plants can be higher, as derived from the operating experience of similar installations. The International Atomic Energy Agency's TECDOC-1267 (IAEA 2002) states that while a plant-specific qualitative risk analysis should be conducted for a nuclear reactor facility, for non-nuclear facilities hazard identification and screening, evaluation of selected accident scenarios, and a combination of qualitative and quantitative analysis should be conducted. This document does not prescribe what probabilities should be considered.

On a scale of increasing likelihood, scenarios are categorized as highly unlikely, unlikely, likely, very likely, and almost certain as follows:

1. highly unlikely: ≤ 1 occurrence in 1,000 years;

2. unlikely: ≤ 1 occurrence in 100 years and > 1 occurrence in 1,000 years;
3. likely: ≤ 1 occurrence in 10 years and > 1 occurrence in 100 years;
4. very likely: ≤ 1 occurrence in 1 year and > 1 occurrence in 10 years; and
5. almost certain: > 1 occurrence in 1 year.

On a scale of increasing severity, scenarios are categorized as none, minor, moderate, major, and catastrophic as follows:

1. none: no human health or biophysical environmental consequences;
2. minor: short-term (less than one month) minor effect on small area or minor first aid injuries with no lost time;
3. moderate: reversible or repairable effect (less than one year) off site or reversible injuries with lost time;
4. major: extended-range, long-term effect off site (e.g., 10 years) or severe injuries with long lasting effects and/or disability; and
5. catastrophic: long-lasting with long-lasting or irreversible environmental effects, fatalities or multiple disabilities.

The resulting risk levels are defined according to the matrix shown in **Figure 3-1**.

For the purpose of the assessment, risks are identified as being low (coloured green in the matrix) where the screening evaluation considers the risk as generally being acceptable, as the likelihood of these scenarios can be effectively managed through application of planned controls and/or the consequence would be low in magnitude. Low-risk scenarios have a severity of none to moderate with the likelihood ranging from highly unlikely to almost certain.

Risks are identified as being moderate (i.e., coloured yellow in the matrix) where the screening evaluation considers the risk as generally being tolerable. In some cases, a moderate-risk scenario can encompass the risk of several screened scenarios for each effect category (e.g., toxic release, fire). In these cases, a moderate-risk scenario can be carried forward as a bounding scenario for more detailed analysis. Moderate-risk scenarios have a consequence of minor to catastrophic, with the likelihood ranging from highly unlikely to almost certain. In many cases, risk-reduction activities would reduce the risk associated with these scenarios to as low as reasonably practicable (ALARP). Under this condition, the risk may be characterized as tolerable.

Risks are identified as being high (coloured red in the matrix) where the screening evaluation considers the risk as generally being unacceptable. High-risk scenarios have major to catastrophic severity with the likelihood ranging from unlikely to almost certain. As the evaluation of the risk at this hazard identification stage is qualitative and is associated with some uncertainty, the hazard scenarios identified as high risk were advanced for further detailed assessment so that a more fulsome evaluation of risk and potential management activities can be considered.

Figure 3-1: Hazard Analysis Risk Matrix

Likelihood		Consequence Severity				
		1	2	3	4	5
		None	Minor	Moderate	Major	Catastrophic
5	Almost certain	Low	Moderate	Moderate	High	High
4	Very likely	Low	Low	Moderate	High	High
3	Likely	Low	Low	Moderate	Moderate	High
2	Unlikely	Low	Low	Low	Moderate	High
1	Highly unlikely	Low	Low	Low	Moderate	Moderate

3.2.3 Evaluation of Project Components and Activities

Based on the review of Project-related information provided in Section 2.2, the following key Project components and activities were identified and selected as nodes for hazard identification process. They form the basis of consideration of potential accident and malfunction scenarios:

1. Site works.
2. Drilling of wells.
3. Access road / land transportation.
4. Air strip / air transportation.
5. Operation of the freeze plant.
6. Maintenance of the freeze wall.
7. Production facility (operation of the processing plant).
8. Clean waste rock pads.
9. Special and mineralized waste rock pads.
10. Precipitates disposal area.
11. Wastewater treatment system.
12. Ponds and retention berms.
13. Electrical system and power plant.
14. Fire protection system.

15. Hazardous waste management system.

In consideration of sources of hazards and initiating events and as described in more detail in the hazard identification analysis (**Appendix A**), a total of 69 hazard scenarios were identified and evaluated.

Following the screening evaluation outlined in **Section 3.2.2**, five high risk scenarios were identified, three of which were recommended for further assessment. The two that were not carried forward involve occupational health and safety hazards and are beyond the scope of this current analysis.

Twenty-three of the scenarios evaluated were characterized as moderate-risk scenarios. Of these twenty-three, nineteen of the moderate-risk scenarios were deemed to represent a tolerable level of risk in consideration of proposed safeguards and design features that reduce the risk level to ALARP. Four moderate / ALARP-moderate scenarios were identified as requiring further detailed assessment for more accurate characterization of risk. The four moderate risk scenarios that are subsequently assessed in more detail beginning in **Section 5.0** are associated with a contaminant release to the environment whose potential effects maybe may be more far reaching than can adequately assessed by the screening assessment and therefore additional more quantitative evaluation was deemed appropriate.

The balance of the scenarios evaluated, 41, were characterized as low-risk scenarios, based on low likelihood of occurrence and/or consequence in consideration planned existing safeguards and design features. Low-risk scenarios are not carried forward for more detailed analysis as they are adequately characterized by the screening process.

3.2.4 Bounding Scenarios

From the initial screening process detailed in the hazard identification report (**Appendix A**), seven hazard scenarios have been selected as bounding scenarios for more detailed risk analysis (**Table 3-1**). Herein, a bounding scenario is used to represent an event whose potential consequences are considered to represent those associated with other accident and malfunction scenarios; or, alternatively, the potential consequences of scenarios that are bounded by another are expected to fit within the envelope of those associated with the bounding scenario. Utilizing the bounding scenario approach makes it possible to avoid duplication in the evaluation process while at the same time ensuring the evaluation is completed in a conservative manner.

This further assessment includes the quantification of the probability and consequences of each of these selected scenarios. For the seven identified bounding scenarios, a general description of the hypothetical event, the release characterization (e.g., contaminants, quantities), the probabilities of the events, and their potential effects on the human health and biophysical environment are provided. This more in-depth process results in more a representative characterization of the risk of these scenarios, as the estimation of the risk in the hazard identification report (**Appendix A**) was preliminary and completed at the screening level (i.e., qualitative).

Table 3-1: Bounding Scenarios Identified for Further Assessment by the Hazard Identification Process

No.	Potential Accident or Malfunction	Project Phase	Potential Effect Pathway
1	Vehicle accident including rollover, collision, run off road	Op	Aquatic release of radioactivity
2	Vehicle accident including rollover, collision, run off road	Co / Op / De	Aquatic release of fuel, hazardous chemicals and reagents
3	Loss of freeze capacity	Op	Loss of freeze wall and secondary underground containment
4	Failure of freeze wall	Op	Loss secondary underground containment and groundwater contamination
5	Process vessel and piping system failure	Op	Release of radon from storage tank
6	Facility fire / explosion	Op	Release of radioactivity and uranium concentrate powder to atmosphere
7	Vehicle accident including rollover, collision, run off road	Co / Op / De	Terrestrial release of radioactivity and chemicals

Notes:

"Co" is construction
"Op" is operations
"De" is Decommissioning
Red and yellow shading indicates high and moderate risk scenarios, respectively. "Effect Pathway" describes nature of the event and therefore the nature of the assessment of consequence.

The detailed assessment of the bounding scenarios is presented in the subsequent sections of this report (**Section 6.0**, **Section 7.0** and **Section 8.0**). The detailed assessment of bounding scenarios involves the quantification of the probability and the consequence(s) of the scenario.

The assessment of the probability requires the identification of the probability of the initiating events leading to the hazard scenario and the conditional probability of any of the associated events within the casual event chain.

The consequence assessment (e.g., the assessment of the fate and transport of a chemical or radiological release) of the scenario includes the characterization of the source terms when there is potential for the release of radioactivity and hazardous materials into the environment. The fate and transport of the released materials and the exposure to the receptors are then evaluated to quantify the severity of the consequences of the scenario.

4.0 GENERAL CONSIDERATIONS FOR THE ACCIDENT AND MALFUNCTIONS ASSESSMENT

Over the past four decades of global commercial nuclear facility operation, the probability and severity of accidents has been markedly lower than those in related industrial operations (OECD 2010). This can be attributed to the rigorous regulatory framework and well-developed plans and procedures for safe operation of nuclear facilities, including uranium mining and milling operations. The experience gained from the accidents that have occurred has resulted in improved engineered safety features and operating procedures, and the probability that similar accidents might occur in the future is considered low.

It is the intention of Denison to develop and operate the Project activities in a manner that mitigates potential adverse effects on the human health or biophysical environment to the extent that is possible. Denison would verify that all the work to be completed during the Project meets, or exceeds, the regulatory requirements stipulated by the CNSC and other regulatory authorities. Denison is committed to setting high standards for various aspects of its operations that will serves to mitigate potential Project-related effects, including those that may be associated with postulated accident and malfunction scenarios. In practice these standards would be upheld through adherence to corporate health, safety, environmental, and quality policies as manifested in various Project-related programs including, but not necessarily limited to:

- Quality Management Program;
- Occupational Health and Safety Program;
- Radiation Protection Program;
- Environmental Protection Program;
- Emergency Preparedness and Response Program;
- Fire Safety Program;
- Maintenance Program; and
- Wellfield and Surface Water Program.
- Within the aforementioned programs, detailed plans and procedures would be developed for the Project that would be site specific and in accordance with corporate policies, including:
- a radiation protection plan;
- a spill and emergency response plan;

- a traffic and transportation plan;
- a travel management plan;
- process monitoring and operational procedures;
- wellfield development and control procedures;
- security procedures;
- environmental monitoring procedures;
- personnel training procedures;
- regular and preventive inspection and testing procedures; and
- surface water and flood management procedures.

Together, these plans and procedures, and the work instructions that they contain, would be implemented throughout the life of the Project and help to mitigate the likelihood of occurrence of accident and malfunction scenarios. Project design features and considerations are the first line of defence in this regard. Examples of proposed design features and considerations are highlighted below:

- The processing plant will be designed with expert consideration of potential environmental and health and safety effects to mitigate interactions to the extent possible.
- The floor of the process plant will be graded as required and sumps will be installed to collect any spills.
- Ventilation in the processing plant will be designed with the ALARA principle in mind to provide sufficient worker protection and monitoring systems will be in place to ensure worker health and safety.
- Dust control and good housekeeping practices throughout the processing plant will also form a critical component of the Radiation Protection Management Plan developed for the Project.
- The processing plant exhaust, mainly from drying and packaging areas, will be directed through a stack and released outside of the building.
- The stack height will be designed based on results of air dispersion modelling to be an appropriate height for optimal dispersion.

- Bulk storage tanks for the processing chemicals, such as sulphuric and/or hydrochloric acid, sodium hydroxide, and hydrogen peroxide, will be located outside the processing plant.

- The storage tanks will sit inside appropriately designed and sized concrete secondary containment basins. The secondary containment basin for each applicable chemical system will be physically separated from the containment basins for other chemical systems.

- Each one of these materials will be stored, handled, recycled or disposed of in an appropriate manner and meet the requirements of the *Hazardous Substances and Waste Dangerous Goods Regulations (Government of Saskatchewan 2000)*.

- No fuels, oils or other hazardous substances will be stored within 100 m of any water body and no equipment maintenance or re-fuelling will be conducted within 100 m of a water body.

- Denison will maintain an up-to-date record of the various hazardous substances on site and will maintain Material Safety Data Sheets and appropriate procedures for spill management, handling and clean up in an accessible location.

- Fuel storage and distribution infrastructure will be constructed in accordance with applicable legislation requirements (e.g., *Hazardous Substances and Waste Dangerous Goods Regulations*) (*Government of Saskatchewan 2000*). Stationary and mobile equipment will be fueled with a fuel-dispensing truck.

- Ventilation in the pumphouses will be designed with the ALARA principle in mind to provide sufficient worker protection from potential radon and radon progeny exposure.

- Monitoring systems will be in place to ensure these mitigation measures are meeting design specifications.

- Double-walled high-density polyethylene (HDPE), or equivalent, piping will be used in the wellfields and will be designed and selected to meet design operating and environmental conditions.

- The lines from the processing plant, pumphouses, and individual well lines will be freeze protected and secured to minimize pipe movement.

- Groundwater monitoring wells will be installed at various depths and locations in and around the wellfield. The monitoring wells will allow for both groundwater sample collection and measurement of groundwater level.

- After an injection, recovery, or monitoring well has been completed, and before it is made operational, a mechanical integrity testing of the well casing will be completed to ensure the installation has been successful and the well is functioning as designed. Well casings that fail integrity tests will be repaired before the well is placed into service.

- At Wheeler, the very low permeability basement rock below the uranium deposit serves as a natural aquitard.
- The site access route was selected with consideration of distance from water bodies.
- Water will be collected from the waste pond (which collected runoff from the waste pad) and the processing plant terrace and then directed to the water treatment plant.
- The waste pad will be double lined, with leak detection capabilities and an associated monitoring program to ensure containment.
- Fuels will be stored in approved, above-ground, double-walled storage tank(s) equipped with secondary containment in accordance with provincial regulations and standards.
- Fuel storage and fuelling activities will be located at least 100 m from waterbodies.

5.0 DESCRIPTION OF THE BOUNDING SCENARIOS

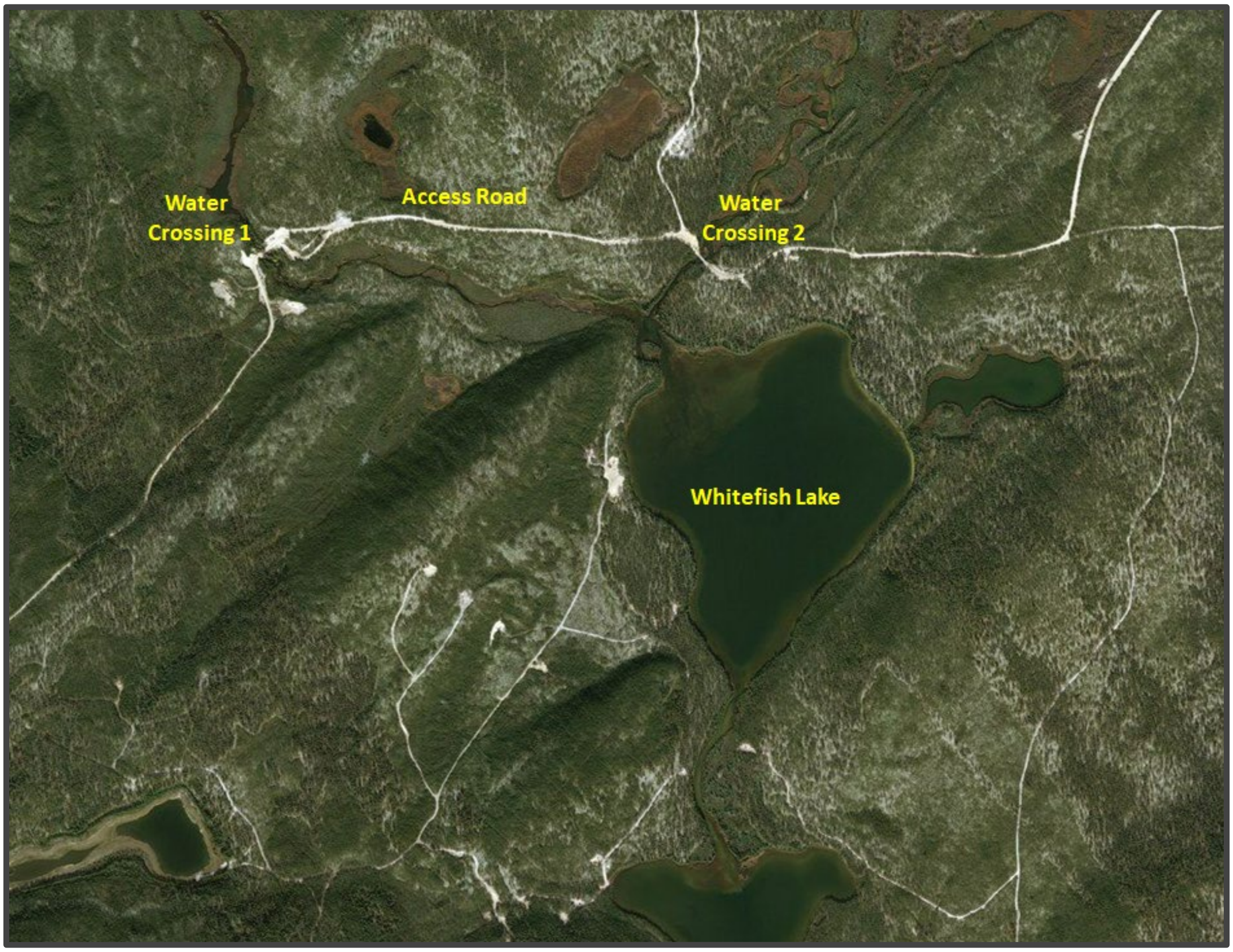
A description of each of the seven bounding scenarios identified by the hazard evaluation screening process is presented below. For each scenario, a general description of the event is provided and then, as all of the postulated scenarios are associated with releases to the environment, the characterization of the release (e.g., contaminants, quantities) is described. The probabilities of the events and their potential and effects on the human health or biophysical environment are considered in **Section 7.0** and **Section 8.0**, respectively.

5.1 Bounding Scenario 1: Traffic Accident and Aquatic Release of Radioactivity

Vehicular access to the Project site would be via an access road from Provincial Highway 914 that leads to the Wheeler site. The access road would be used primarily to transport equipment and supplies to and from the Project, as well as the trucking of the uranium concentrate. Personnel would be typically flown to and from the site.

The access road is roughly 12 km long, 5 km of which is from highway 914 to the Wheeler site with the remaining 7 km from Wheeler site to the airstrip. Additional site roads would include a service loop to the camp and short service roads to other site features to facilitate access. Denison anticipates the need for installation of two water crossings in the Icelander River drainage upstream of Whitefish Lake along the section of the road from the Wheeler site to the airstrip. **Figure 5-1** shows the location of the water crossings along the access road.

Figure 5-1: Location of the Water Crossings Along Access Road



No trucks transporting uranium concentrate are expected to travel along the portion of the access road from the Wheeler site to the airstrip; however, Jet Fuel A will be transported to the airstrip along this portion of the road.

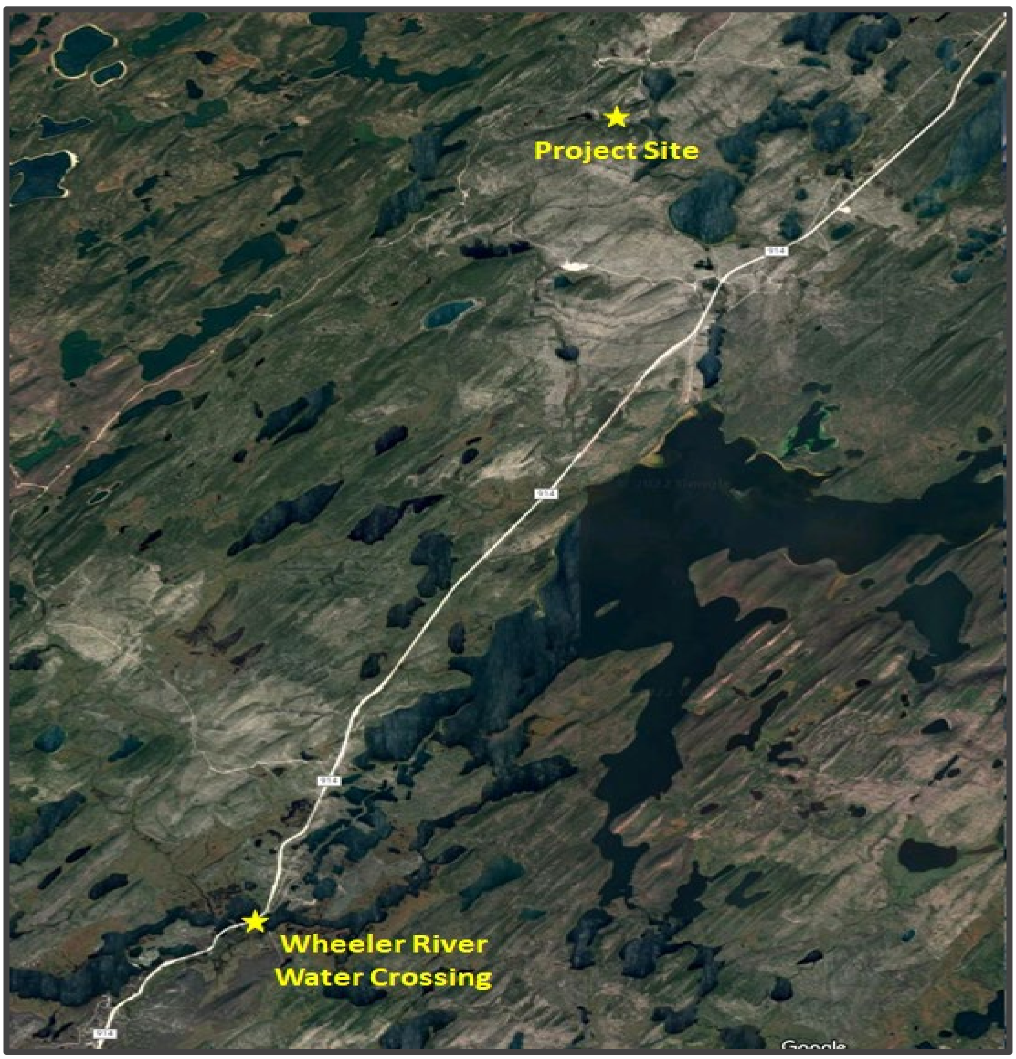
The portion of the access road between Highway 914 and the Wheeler site is not within 100 m of any waterbody at any location; therefore, an accidental release of hazardous substances, including uranium concentrate, to surface water is not expected along this portion of the road. Highway 914 crosses the Wheeler River 10 km southwest of the access road junction. **Figure 5-2** shows the location of the water crossings along Highway 914. The length of the bridge over the river at this crossing is approximately 100 m. The width of the river at the crossing is approximately 20 m. The crossing is equipped with guardrails along the entire length of the bridge. A traffic accident, collision, rollover, or run-off at or near the bridge could potentially result in a release of uranium concentrate into the surface water at this location. The flow direction at the Wheeler River water crossing is towards the northeast and towards Russell Lake.

The flow rates for the stream crossings and Wheeler River south of Russell Lake are provided in the table below (**Table 5-1**).

Table 5-1: Flow Rates for the stream crossings and Wheeler River south of Russell Lake

Location	Minimum Flow (L/s)	Average Flow (L/s)	Maximum Flow (L/s)
Water Crossing 1 - Inflow to Whitefish Lake from Kratchkowsky Lake	204	357	769
Water Crossing 2 - Inflow to Whitefish Lake from LA-9	494	917	2,132
Hydrometric Station 06DA005 - Wheeler River South of Russell Lake (https://wateroffice.ec.gc.ca/index_e.html)	10,900	17,340	24,670

Figure 5-2: Location of the Wheeler River Along Highway 914



For reference, the calcined (heated strongly to remove impurities) uranium concentrate would be packed into standard 205 L (55 gal) steel drums for shipping. The gross weight of each drum is between 430 kg and 450 kg. It is projected that there would be 35 to 40 drums packaged per mill operating day, requiring an average number of one trip per day. In uranium concentrate, the short-lived decay products of uranium-238 (i.e., thorium-234; protactinium-234m; protactinium-234, which has a relative concentration of 0.16% of uranium-238; and uranium-234) and uranium-235 (i.e., thorium-231) are assumed to be in equilibrium with their respective parents as it considers both uranium and its decay products. The radioactive equilibrium exists when a radionuclide decays at the same rate at which it is being produced by its parent decay. The activities of these radionuclides in uranium concentrate can be derived using the branching ratios as shown in the following table (**Table 5-2**). The branching ratio for a decay is the fraction of particles which decay by an individual decay mode with respect to the total number of particles which decay. These fractions are used to calculate the activity concentration of radionuclides in uranium concentrate.

Table 5-2: Radionuclides in Uranium Concentrate

Radionuclide	Half-Life	Branch Percentage
Uranium-238	$4.47 \times 10^{+09}$ yr	NA
Thorium-234	24.1 d	100% uranium-238
Protactinium-234m	1.16 min	100% uranium-238
Protactinium-234	6.7 h	0.16% uranium-238
Uranium-234	$2.45 \times 10^{+05}$ yr	100% uranium-238
Uranium-235 (4.6% of uranium-238)	$7.04 \times 10^{+08}$ yr	NA
Thorium-231	1.063 d	100% uranium-235

From other studies conducted for uranium mills in northern Saskatchewan, the particle size distribution for three uranium concentrate calcined samples were measured using a Beckman Coulter LS Particle Size Analyzer. **Table 5-3** provides a summary of particle size distribution information for these studies.

Table 5-3: Uranium Concentrate Particle Size Distribution[1]

Calcined Samples (three samples)		
Size Category (µm)	**Average Size (µm)**	**Percentage**
<5	2.5	4.0
5-15	8.6	14.7
15-25	19	46.1
25-35	30	32.8
35-55	44	2.5

[1] This information was obtained from Cameco Corporation during the assessment accidents and malfunctions for Millennium Mine project.

The solubility of the calcined uranium used herein is based on testing of samples from the McClean Lake Operation that were analyzed over 72 or 24 hour periods. The Organisation for Economic Cooperation and Development (OECD) Guideline for Testing of Chemicals; Water Solubility (adopted 27.07.95; OECD 1995), flask method, was followed for these tests. The results are shown in Table 5-4. Bulk and particle densities of UOC were considered at 2.1 and 9.6 g/cm^3. Based on the solubility data from the McClean Lake samples, a solution of about 0.125 g of UOC in 250 mL of water will lead to a uranium concentration of 4,800 µg/L.

Table 5-4: Solubility of Calcined Uranium Concentrate

Sample Source	Sample No.	Estimated Solubility (g/L) by Test Duration		
		24 h	48 h	72 h
McClean Lake (calcined)[2]	1	0.0035	0.0045	0.0046
	2	0.0060	0.0071	0.0067
	3	0.0053	0.0062	0.0090
	4	0.0038	0.0036	0.0039
	5	0.0070	0.0068	0.0064
	16 to 20 (average)	0.003 to 0.008 (0.005)	-	-

5.1.1 Release Characterization

The performance of drums similar to those proposed to be used for uranium concentrate shipment during transportation accident scenarios was determined by McSweeney et al. (2004). The authors concluded that, based on drum deformations performed in a previous analysis, if a drum experienced a crush force of 100,000 lbs, then the deformation of the drum would cause the lid to detach from the drum. Using this drum failure mechanism, and assuming the drums weigh 450 kg and are arranged four across in the truck, at a speed of 48 km/h the front 25% of the drums would fail, at 60 km/h to 97 km/h 55% would fail, at 145 km/h 75% would fail, and at ≥ 193 km/h all would fail.

Given that the speed of the truck is likely between 60 km/h to 97 km/h km/h, it was concluded that less than 55% of the drums would fail upon a traffic accident scenario. Assuming 40 drums in one shipment per day, each shipment would have approximately 40,000 lb of uranium concentrate:

40 drums x 450 kg/drum = 18,000 kg uranium concentrate = 40,000 lb

If 55% of this amount is released, the total release weight would be approximately 22,000 lb of uranium concentrate. The short-term dissolved release rate was estimated using solubility data.

[2] This information was obtained from Cameco Corporation during the assessment accidents and malfunctions for Millennium Mine project.

Solubility of calcined UOC was considered at an average value of 4,800 µg/L over the first 72 hours, which is the average solubility of McClean Lake UOC samples. It was assumed that such concentrations applied to a cross section of water defined by the lateral footprint of the spill (i.e., the total 20 m of the Wheeler River crossing) and a water column depth of 10 cm.

The water velocity was assumed to be 0.72 m/s. At an average depth of 1.2 m, the total flow rate is 17.3 m^3/s:

$$20 \text{ m} \times 1.2 \text{ m} \times 0.72 \text{ m/s} = 17.3 \text{ m}^3\text{/s}.$$

The dissolution rate is calculated as 6.9 g/s:

$$20 \text{ m} \times 0.1 \text{ m} \times 0.72 \text{ m/s} \times 4.8 \text{ g/m}^3 = 6.9 \text{ g/s}.$$

Long-term concentrations were also estimated to account for transfer of the settled uranium from sediment to water. The long-term release rate is based on the concentration estimated for sediment pore-water quality. It was assumed that such concentrations applied to a cross section of water defined by the lateral footprint of the spill and a water column depth of 5 cm.

5.2 Bounding Scenario 2: Traffic Accident and Aquatic Release of Fuel and Hazardous Chemicals

Bounding Scenario 2 is similar to Bounding Scenario 1, except it potentially results in the release of chemicals or fuel such as diesel, gasoline, propane, hydrogen peroxide, sulphuric acid, and sodium hydroxide at the bridge over the Wheeler River. The information related to the fuel and chemicals transported to the site is summarized in **Table 5-5**.

It was conservatively assumed that a volume equivalent to the entire cargo of a shipment would be released during an event. Based on the available project information, the following is assumed:

- Diesel and Jet Fuel A (30 m^3 or 30,000 L release): The released diesel forms a sheen on top of water with a thickness of approximately 1 micron (i.e., micrometre; µm). While as much as 15% of the diesel would dissolve in the water column (NOAA 2006, 2020), up to 30% would evaporate from the surface of water (Silver and Mackay 1984). The rest of the fuel, which is predominantly heavier components, would stay afloat or be adsorbed into shallow sediments along the river bank and downstream near-shore lake areas.
- Gasoline (30 m^3 release): The released gasoline forms a sheen on top of water with a thickness of approximately 1 µm. While as much as 25% of the gasoline would dissolve in the water column, up to 70% would evaporate from the surface of water (Silver and Mackay 1984). The rest of fuel, which is predominantly heavier components, would stay afloat or be

adsorbed into shallow sediments along the river bank and downstream near-shore lake areas.

- Propane (11,000 gallons or 41.58 m^3 release): The released propane would evaporate quickly and be released to the atmosphere with no measurable residue.
- Sulphuric acid (25 m^3 release): Sulphuric acid is completely dissolved in water resulting in low pH of affected waterbodies. It is assumed the entire volume of sulphuric acid mixes with water.
- Sodium hydroxide (25 m^3 release): Sodium hydroxide is completely dissolved in water resulting in high pH of affected waterbodies. It is assumed the entire volume of sodium hydroxide mixes with water.
- Hydrogen peroxide (~18 m^3 release): Hydrogen peroxide and water are miscible liquids; thus, upon release, the entire volume of hydrogen peroxide mixes with water.

Table 5-5: Chemicals Transported to The Site

Item	Annual Consumption, m^3	Truck Travel per year
Diesel Fuel	7,991	266
Jet A Fuel	195	10
Gasoline	163	6
Propane	4,740	114
Sulphuric Acid	15,417	617
Sodium hydroxide 50%	21	1
Hydrogen peroxide 70%	0.97 to 1.61	216
Total	NA	1,220

5.3 Bounding Scenario 3: Loss of Freeze Capacity to the Freeze Wall

The freeze wall is expected to be several metres thick as it is developed around the uranium deposit. The freeze wall provides full secondary containment of mining fluids within the mining zone and no fluids will be able to migrate across this barrier to the surrounding groundwater environment. Primary containment of mining fluids is achieved by the control of the mining solutions through inward hydraulic gradient created by the recovery wells pumps.

If freezing capacity is lost, the freeze wall would eventually thaw, and secondary containment lost. If this occurs the mining fluid could migrate into the local groundwater environment and cause the contamination. The scale of contamination is difficult to predict as there are large uncertainties associated with the amount of mining fluid that would migrate, the hydraulic conductivity of the thawed freeze wall, the static head, and other geological factors.

The freeze wall will require 14 months to be established. The freeze wall will be in place throughout the operations phase. After decommissioning once the refrigeration is turned off, it will take a minimum of 1 year for the freeze wall to thaw depending on how long the freeze wall was active and actual ground conditions encountered. This freeze and thaw time frame is very large compared with the time required to repair and establish the freeze capacity. Interruption of the freeze capacity due to mechanical failure of the freeze plant is not perceived to be a major concern, as there is low risk that such an event would result in the migration of mining fluids beyond secondary containment. For reference, intermittent artificial ground freezing has been shown to effectively maintain desired structural stability and hydraulic sealing while also providing a significant operational energy savings (Alzoubi et al. 2017). Intermittent freezing can be used as an analogue to temporary loss of freezing capacity and provides confirmation that temporary loss of freezing capacity would not likely present a substantial environmental concern.

5.4 Bounding Scenario 4: Failure of the Freeze Wall

In this scenario, the structural stability and hydraulic sealing of the freeze wall is compromised in its entirety. It is envisioned that such a scenario could result due to earth movement during major events such as earthquakes. Events such as surficial landslides and/or floods would not cause damage to the freeze wall to its full depth (~ 350 m below surface) that would result in freeze wall failure. The subsistence or response of rock mass to loss of volume at the mining area as uranium ore is removed could result in localized effects. The 3D strip numerical model predicted that stresses and displacements did not show instability in the altered sandstone or basement rock at the location that a freeze wall would been placed around the Phoenix Deposit boundary (RESPEC, 2021).

In the case of the complete failure of the freeze, groundwater and mining fluids within the mining theatre could migrate beyond the compromised section of the freeze wall. This migration process is likely to be very slow. The low temperature of the formation in and around the compromised section of the freeze wall would most likely cause the fluids to freeze and seal or partially seal the opening, further reducing the rate of contamination. The scale of any migration and resulting contamination of the local groundwater environment is difficult to predict as there are large uncertainties associated with the amount of mining fluid that would migrate, the hydraulic conductivity of the thawed freeze wall, the static head, and other hydrogeological / geological factors.

Shallow crevasses can form during earthquake-induced landslides, lateral spreads, or from other types of ground failures, but faults do not open up during an earthquake and surficial cracks which are the results of surficial land settlement are not likely of the depth (USGS 2021) that would pose a risk relative to the mining fluid. Moreover, shallow geological deformities such as crevasses and cracks are typically associated with earthquakes of large magnitudes (6+) – such magnitude earthquakes have not occurred in the past 500 years in area in which the Wheeler site is located (Government of Canada, 2021).

5.5 Bounding Scenario 5: Process System and Piping Failure

Large quantities of radon gas can be dissolved in the lixiviant returning from the mining horizon to the surface. The portion of the total dissolved radon in lixiviant which is above the solution's saturation value is released when encountering atmospheric pressures and temperatures (Brown, 2008). In order to prevent the release of radon in the working environment, atmospheric tanks and vessels are covered and maintained at negative pressure via ventilation systems. Under normal operating conditions, radon is vented from the processing building to the atmosphere through a stack at an appropriate height so as to maximize dispersion and minimize potential exposures at the ground surface. If the piping system, or vessels, such as a thickener tank failure, the dissolved radon is released inside the processing plant.

This accident scenario assumes a vessel or pipe leak that releases a portion of the thickener inside the processing building. In 2009, the NRC issued NUREG–1910, "Generic Environmental Impact Statement (GEIS) for In-Situ Leach Uranium Milling Facilities." (US NRC 2009). In the GEIS, the potential environmental impacts from the postulated accidents involving the operation of an ISR facility located in four geographic regions of the western United States were assessed. One of the scenarios assessed was the release of radon from failed or leaked thickener. The assessment assumed 20% of the contents of the thickener is released inside the processing building (US NRC 2009). Typical radon concentrations in circulating lixiviant ranges from 300 to 7,000 Bq/l (Brown 2008). GEIS used a concentration of approximately 4,000 Bq/l for its assessment.

Denison is planning to include a radon purge tank downstream of well field where most of radon in lixiviant will be released. The activity concentration of radon in the solution downstream of the purge tank before entering the processing building is estimated at 3,700 to 7,400 Bq/L[3]. This concentration range is consistent with the concentrations used by GEIS.

It should be noted that, despite potentially large quantities of the gas being evolved, it is fresh radon, and the progeny equilibrium factors are typically quite low. Most of the gas is released within the first few process areas, wherever first exposed to atmospheric pressure.

The capacity of the thickener at Wheeler ISR is 800 m^3. Assuming a release equivalent to 20% of the contents of the thickener, and a radon concertation of 4,000 Bq/l, the amount of radon released inside the processing plant would be:

$$800 \text{ m}^3 \times 0.2 \times 4{,}000 \text{ Bq/l} \times 1{,}000 \text{ l/m}^3 = 6.4 \times 10^8 \text{ Bq.}$$

[3] Memorandum from Mehran Monabbatti, Steve Brown, Kim Theobald, Paul Kirby [IEC] to Janna Switzer and Xavier Lu Dac [Denison] dated December 2, 2021.

5.6 Bounding Scenario 6: Facility Fire and / or Explosion

This scenario involves fire and explosion within the processing plant. The most credible event with potential for release of radioactivity is the explosion of the uranium concentrate dryer.

A fire or explosion that originates from the dryer could potentially release a large amount of uranium to the atmosphere.

5.6.1 Release Characterization

The quantification of uranium release from the uranium concentrate dryer followed the widely accepted methodology proposed by the United States (US) Department of Energy (DOE) to estimate source terms (USDOE 1994).

According to the USDOE, the airborne source term is typically estimated by the following five-component linear equation:

$$\text{source term} = MAR \times DR \times ARF \times RF \times LPF$$

where:

MAR = Material at risk is the amount of chemical or radionuclide available to be acted on by a given physical stress. For facilities, processes, and activities, the MAR is a value representing some maximum quantity of chemical present or reasonably anticipated for the process or structure being analyzed.

DR = Damage ratio is the fraction of the MAR actually affected by the initiating event(s) (i.e., accident-generated conditions). The DR is estimated based upon engineering analysis of the response of structural materials and materials of construction for containment to the type and level of stress or force generated by the event. These estimates often include a degree of conservatism due to simplification of phenomena to obtain a useable model.

ARF = Airborne release fraction, or airborne release rate for continuous release, is the coefficient used to estimate the amount of a chemical released or suspended in air as an aerosol or gas and thus available for transport due to physical stresses from a specific accident.

RF = Respirable fraction is the fraction of airborne chemical particles that can be transported through air and inhaled into the human respiratory system. The RF is commonly assumed to include particles of 10 µm aerodynamic equivalent diameter or less. Other definitions of "respirable particles" have been presented by various groups at different times, but for the present purposes 10 µm and smaller particles were considered respirable. For gaseous chemicals, the RF is 1.

LPF = Leak path factor is the fraction of the chemical or radionuclide transported through some confinement deposition or filtration mechanism. There can be many LPFs for some accident conditions (e.g., the fraction transported from the package, such as a shipping container, to the enclosure; the fraction leaked from the enclosure to the operating area around the enclosure or room; or the fraction leaked from the room to the building–atmosphere interface).

Background information on source term parameters for the fire scenario are summarized as follows:

- *MAR:*
  - The material at risk is the uranium content of the dryer. The content is estimate at 2,000 kg of uranium concentrate with the dryer.
  - MAR = 2,000 kg of uranium concentrate
- *DR:*
  - An explosion within the dryer can potentially affect the entire content of the dryer. Thus, the DR was assumed at 1.
- *ARF:*
  - The US DOE (US DOE 1994) suggests the value of 7.6×10^{-2} for ARF for unshielded blast effects from detonations and large volume, confined deflagrations.
- *RF:*
  - The US DOE (US DOE 1994) suggests the value of 0.14 for RF for unshielded blast effects from detonations and large volume, confined deflagrations.
- *LPF:*
  - Since the postulated accident scenario involves the explosion inside the dryer, much of the uranium concentrate will be trapped inside the damaged dryer. It was assumed that 90% of the content of the dryer is trapped. Thus, the LPF would be 0.1.

Based on the above the scenario source term is calculated as:

$$2{,}000 \times 1 \times 7.6 \times 10^{-2} \times 0.14 \times 0.1 = 2 \text{ kg uranium concentrate}$$

It should be noted that the above estimated value is based on a number of assumptions involving the content of uranium concentrate within the dryer and LPF for the explosion inside the dryer. In the GEIS (US NRC 2009), the potential environmental impacts from the postulated dryer explosion were assessed. This assessment used a number of conservative assumptions and estimated the source term for a dryer explosion at 1 kg of uranium concentrate.

5.7 Bounding Scenario 7: Traffic Accident and Terrestrial Release of Radioactivity, Fuel and Hazardous Chemicals

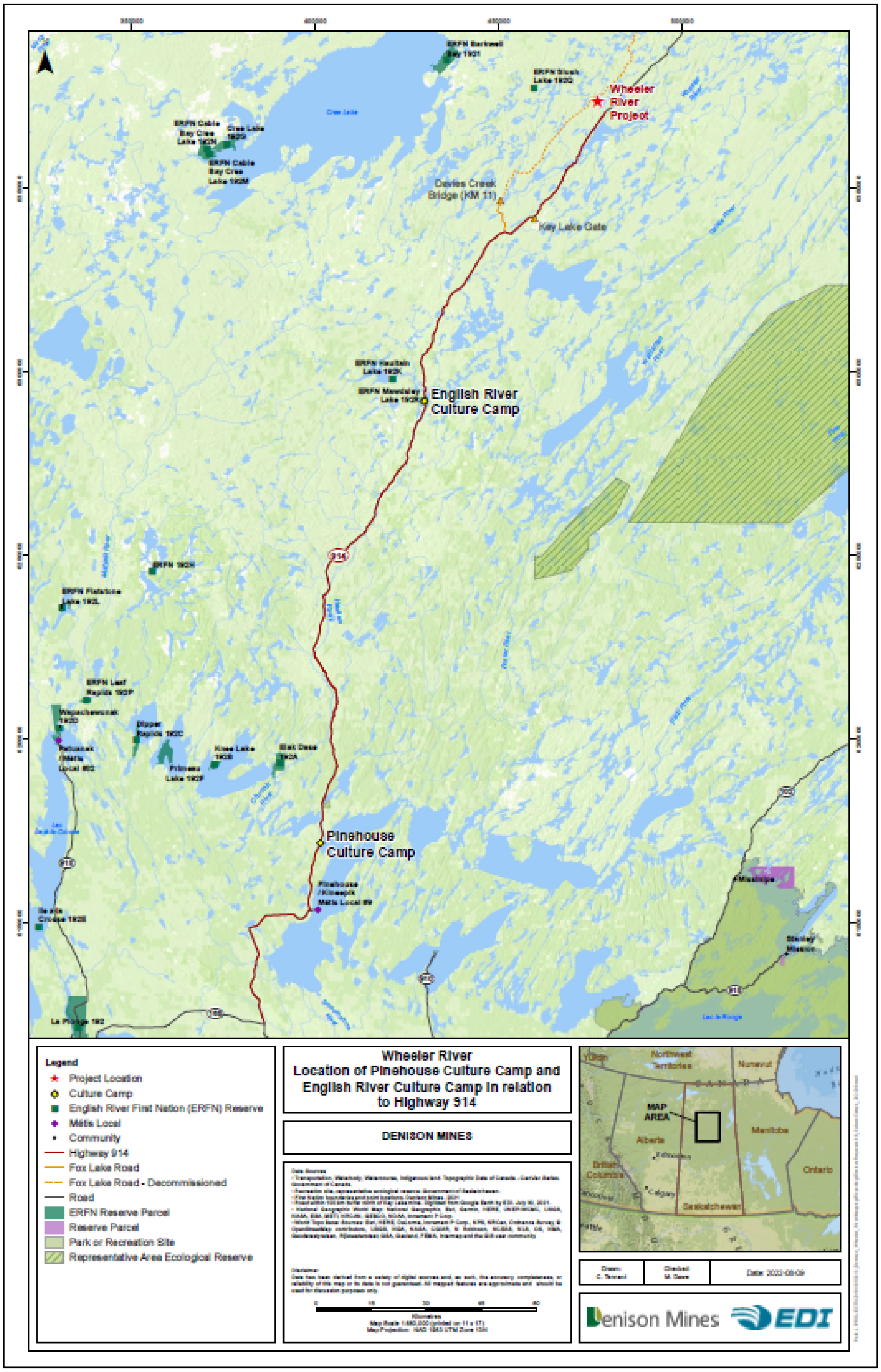
Bounding Scenario 7 is similar to Bounding Scenarios 1and 2 comprising a release of hazardous materials; however, this release is postulated to occur at an off-site location and the release is to ground and not water.

Based on engagement with Interested Parties two release locations have been assumed to provide the scenario some context. Generically, the events can be treated in a similar fashion as the probability and consequence are expected to be the same. The first location corresponds to km 160 of Hwy 914 which is the location of a cultural camp that has been established by the English River First Nations. The second location is at km 67 of Hwy 914 that is a gathering location for the Kineepik Metis Local associated with the Northern Village of Pinehouse. The locations of these camps are shown on **Figure 5-3**.

For reference and as described in **Section 5.2** for such a scenario, it was conservatively assumed that a volume equivalent to the entire cargo of a shipment would be released during an event. The information related to the fuel and chemicals transported to the site is summarized in **Table 5-5**. Based on the available project information, the following is assumed:

- Diesel and Jet Fuel A (30 m^3 or 30,000 L release).
- Gasoline (30 m^3 release).
- Propane (11,000 gallons or 41.58 m^3 release).
- Sulphuric acid (25 m^3 release).
- Sodium hydroxide (25 m^3 release).
- Hydrogen peroxide (~18 m^3 release).

Figure 5-3: Location of Terrestrial Release Along Highway 914



6.0 CHEMICAL, OCCUPATIONAL, AND RADIOLOGICAL BENCHMARKS

The following subsections define relevant benchmarks that are utilized to assess the potential effects of the postulated accident and malfunction scenarios. The benchmarks presented are specific to the bounding scenarios that have been described in **Section 5.0** and are given for the atmospheric and aquatic environments. The benchmarks are specifically selected with consideration of the expected interactions of the bounding scenarios with the environment for the following:

- Uranium
  - atmospheric environment
  - aquatic and terrestrial environment
- Radioactivity
  - aquatic and terrestrial environment
- Radon
  - atmospheric and terrestrial environment
- Sulphuric acid and sodium hydroxide
  - aquatic environment (pH).

6.1 Uranium

6.1.1 Non-Radioactivity

Atmospheric Environment

The Agency for Toxic Substances and Disease Registry (ATSDR) provides evaluations of toxicity for numerous agents, including uranium. In its 2013 report "Toxicological Profile for Uranium" (USHHS 2013), the ATSDR reports that "natural and depleted uranium have the identical chemical effect on your body. The health effects of natural and depleted uranium are due to chemical effects and not to radiation." The 2013 report by ATSDR further notes that "neither the National Toxicology Program, International Agency for Research on Cancer, nor the Environmental Protection Agency have classified natural uranium or depleted uranium with respect to carcinogenicity."

UNSCEAR (2017) indicates that the relative importance of chemical and radiological toxicities of uranium depend on a number of factors – notably, the degree of enrichment of uranium-234 and uranium-235. The chemical toxicity from uranium exposure is mainly associated with damage to the kidneys and is assumed not to occur below a threshold concentration. Thus, while uranium is a radioactive substance, for natural and depleted uranium, the risks from intake of uranium are related to its chemical toxicity, and the potential for such effects are the basis for the hazard and risk assessments described in this report.

Exposure limits for emergency scenarios are defined by a hierarchy of threshold concentrations. These include the Emergency Response Planning Guideline (ERPG), and Temporary Emergency Exposure Limit (TEEL) (USDOE 2016). TEELs are intended for use until ERPGs are adopted for chemicals and have similar definitions as the corresponding ERPG levels.

ERPGs are intended to be a planning tool to help anticipate human adverse effects on the general public caused by toxic chemical exposure. These are only available for a one-hour exposure duration and are not designed for hypersensitive individuals.

- ERPG-1 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing other than mild transient adverse health effects or perceiving a clearly defined, objectionable odour.
- ERPG-2 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing irreversible or other serious health effects or symptoms that could impair an individual's ability to take protective action.
- ERPG-3 The maximum airborne concentration below which it is believed that nearly all individuals could be exposed for up to one hour without experiencing or developing life-threatening health effects.

The most commonly used benchmarks for emergency release scenarios are from ERPG-2. ERPG values developed by the American Industrial Hygiene Association are included in Table 6-1. These values were taken from the Protective Action Criteria (PAC) tables (USDOE 2016).

Table 6-1: Emergency Response Planning Guidelines for Uranium Oxide and Uranium Concentrate

Chemical	ERPG-2	ERPG-3
Uranium oxide	10 mg/m^3	30 mg/m^3
Uranium concentrate	10 mg/m^3	50 mg/m^3

ERPG = Emergency Response Planning Guideline.

Aquatic Environment

A maximum acceptable concentration of 0.02 mg/L (i.e., 20 µg/L) is established for total natural uranium in drinking water. The guideline is based on the chemical toxicity of naturally occurring uranium (Health Canada 2019).

Canadian Water Quality Guidelines for Uranium (total recoverable, unfiltered) for the protection of aquatic life are 15 µg/L and 33 µg/L for long-term exposure and short-term exposure, respectively (CCME 2011).

The water quality guidelines for drinking and protection of aquatic life are not developed for emergency situations; however, they can be conservatively used during transient situations following an accident.

6.1.2 Radioactivity

Aquatic Environment

Radiation Protection Regulations, SOR/2000-203, governs the annual effective dose equivalent limits for individual members of the public exposed to the radioactivity resulting from industrial activities such as uranium mining and process plant buildings. The effective dose limit for the general public is 1 mSv per calendar year (Government of Canada 2021).

The assessment of effects on ecological receptors from exposure to radioactive constituents involves the estimation of the combined (total) dose that a receptor may receive from radionuclides taken into the body as well as from exposure to radiation fields in the external environment. In addition, it is standard practice to take into account differences in the effects of alpha, beta and gamma radiation. Radiation effects on biota depend not only on the absorbed dose, but also on the relative biological effectiveness (RBE) of the particular radiation (i.e., alpha, beta or gamma radiation). For example, alpha particles can produce observable damage at lower absorbed doses than gamma radiation. Thus, in order to estimate the potential harm to non-human biota from a given absorbed dose, the absorbed dose is multiplied by an appropriate radiation weighting factor. This in turn is derived from an experimentally determined RBE. In this assessment, the terms "RBE" and "radiation weighting factor" are used interchangeably. It should be noted that uncertainty remains concerning the most appropriate RBE values for assessing risks to non-human biota. The RBE values depend on the radiation quality, the biota under consideration, the endpoint being considered and the reference photon energies. The RBE values selected to develop protection criteria should correspond to the endpoint being protected (e.g., health of a population). For this assessment, an RBE of 2 was used for "low beta" and an RBE of 10 was used for alpha components, to represent their greater relative effectiveness (CSA Group 2012).

The Canadian Standard N288.6 which addresses Environmental Risk Assessments at Class I Nuclear Facilities and Uranium Mines and Mills (CSA 2012) recommends an RBE of 10 to be applied to the component of internal dose from alpha emitters. This assessment will follow this recommendation. The Standard also recommends that radiation dose benchmarks for quantitative effects assessment should follow UNSCEAR (2008), i.e., 100 µGy/h for terrestrial biota and 400 µGy/h for aquatic biota. Therefore, the benchmarks used in the assessment are 2.4 mGy/d for terrestrial biota and 9.6 mGy/d for aquatic biota. The prescribed limit for the general public is 1 mSv per calendar year.

6.2 Radon

6.2.1 Radioactivity

The maximum amount of radiation people are allowed to receive in the workplace is regulated. The Canadian Nuclear Safety Commission sets a limit of 50 mSv in a single year and 100 mSv over 5 years (a 20 mSv per year average). The limit for a pregnant worker, once pregnancy has been declared, is 4 mSv for the remainder of the pregnancy (CNSC 2021). The prescribed limit for the general public is 1 mSv per calendar year (CNSC 2021).

6.3 Sulphuric Acid Sodium Hydroxide

Aquatic Environment

Canadian Water Quality Guideline for pH for the Protection of Aquatic Life is 6.5-9 for long-term exposure. No guideline for short-term exposure is available (CCME 1987).

7.0 ASSESSMENT OF PROBABILITIES OF THE BOUNDING SCENARIOS

The probabilities of the seven identified bounding scenarios are characterized below.

7.1 Bounding Scenario 1: Traffic Accident and Aquatic Release of Radioactivity

Principal Traffic risk mitigation measures include:

- traffic control measures, such as the speed limit;
- travel management plans;
- spill and emergency response planning; and
- driver training.

Despite these risk control measures, a residual probability of accidents occurring remains. The probability of occurrence of a transportation accident and sequence of events resulting in release of hazardous materials is the key factor for quantifying the transportation risk. Statistical data for transportation accidents are available for general transportation, as well as the transportation of hazardous materials. General transportation accident statistics are commonly presented as the number of accidents per million kilometres or million miles of transport vehicle travelled. Specific hazardous materials transportation accident statistics are commonly presented as the number of accidents per million ton-miles or million tonne-kilometres of materials transported.

Hazardous material transportation accident statistics are generally more relevant for risk assessment studies such as this; however, the statistical datasets for hazardous material transportation are less reliable. Data regarding the total volume and mass transported by various modes of transportation are maintained by shipping companies and in most cases are only available to regulatory agencies such as Transport Canada. Publicly available information is reported on a lump sum basis. In addition, the statistical breakdown for transportation routes is not readily available and the route data, particularly for road transportation, are maintained by road transport companies and are not publicly available. With the above in mind, general transportation accident statistics have been used herein to characterize accident probability.

In Canada, the statistics related to the transportation and road accidents are primarily collected and maintained by federal and provincial government agencies including Transport Canada (2019) and its branches (such as the Canada Transportation Safety Board), the Saskatchewan Ministry of Highways and Infrastructure, and Saskatchewan Government Insurance (SGI 2018). These statistics indicate that average accident rates for Canada and Saskatchewan were 1.2 and

0.89 per one million kilometres travelled, respectively. Statistics more localized to the Project site indicate that average accident rate was1.75 per one million kilometres travelled for Highway 914. This value was used for the calculations.

In the case of the accident scenario envisioned, calcined uranium concentrate would be packed into standard 205 L (45 gal) steel drums for shipping. It is projected that there would be about 100 drums packaged per mill operating day (Wheeler River project description documentation). It was also assumed that a traffic accident on the bridge or within 40 m from either side of the bridge has the potential for release to the Wheeler River.

Using the transportation route lengths and the transportation accident rates estimated above and assuming one trips per day for 330 days per year, the annual probability of traffic accidents involving uranium concentrate along Highway 914 and in the vicinity of the Wheeler River crossing (i.e., considering a 40 m buffer at each side of the bridge, total of 40+40+20=100 m = 0.1 km) are estimated as:

for release to water: $330 \times 1.75 \times 0.1 / 1{,}000{,}000 = 5.78 \times 10^{-05}$

The above probabilities were calculated using Saskatchewan Government Insurance statistics for Highway 914.

According to the probability ratings described in **Section 3.2.2**, the probability that this accident and malfunction scenario would occur is highly unlikely.

7.2 Bounding Scenario 2: Traffic Accident, Aquatic Release of Fuel, and Hazardous Chemicals

Traffic risk mitigation measures for this Bounding Scenario 2 are the same those presented for Bounding Scenario 1. The annual probability of traffic accidents involving fuel or chemicals along Highway 914 and in the vicinity of the Wheeler River crossing (i.e., considering 40 m buffer at each side of the bridge, total of 40+40+20=100 m = 0.1 km), assuming 1,220 trips per year for 330 days per year, are estimated as:

for release to ground: $1{,}220 \times 1.75 \times 0.1 / 1{,}000{,}000 = 2.14 \times 10^{-03}$

The above probabilities were calculated using Saskatchewan Government Insurance statistics for Highway 914.

According to the probability ratings described in **Section 3.2.2**, the probability that this accident and malfunction scenario would occur is unlikely.

7.3 Bounding Scenario 3: Loss of Freeze Capacity

In **Section 5.3** it was argued that a loss of freeze capacity resulting in freeze wall failure and the subsequent release of mining fluids from the mining theatre into the local / regional groundwater environment was very unlikely. Accordingly, and based on professional judgement, a nominal value of $1x10^{-7}$ was assigned as the annual probability of this scenario.

According to the probability ratings described in **Section 3.2.2**, the probability that this accident and malfunction scenario would occur is highly unlikely.

7.4 Bounding Scenario 4: Failure of the Freeze Wall

In **Section 5.4**, it was noted that a strong earthquake with magnitude larger than 6 would have the potential to damage the freeze wall and result in the release of mining fluids from the mining theatre into the local / regional groundwater environment. A review of seismicity at the Wheeler site indicates that the probability of occurrence of an earthquake with this magnitude is very unlikely and is less than 10^{-4} per year.

According to the probability ratings described in **Section 3.2.2**, the probability that this accident and malfunction scenario would occur is highly unlikely.

7.5 Bounding Scenario 5: Process System and Piping Failure

The following principal mitigating measures would be in place to reduce the probability of a release from process piping and vessels:

- visual inspections;
- regular and preventive inspection, testing, and maintenance programs;
- emergency response planning; and
- full containment of processing plant.

A spill of uranium bearing solution and subsequent release of radon gas from the released solution could occur as a result of the following events:

- overflow of storage or process vessels and thickener;
- leaks or rupture in thickener;
- failure of valves or other piping system components.
- failure of the pumps; and

- failure of other process components, such as screens and filters.

Average probabilities of failures for different components in the solvent extraction unit were based on the information provided by the Center for Chemical Process Safety of the American Institute of Chemical Engineers (AIChE-CCPS 1989) and are shown in **Table 7-1**.

Table 7-1: Average Failure Probability for Solvent Extraction Process Equipment

Equipment with Potential for a Major Spill or Fire	Failure Rate (all modes)(per year)
Vessels (i.e., atmospheric and metallic) (assuming 2 thickeners containing uranium rich solvents)	10^{-3}
Piping (i.e., metal; straight section and connection) (assuming 100 sections)	10^{-4} per item
Pumps (e.g., motor driver and pressure-centrifugal) (assuming 2 pumps)	10^{-2}

Source: Center for Chemical Process Safety (AIChE - CCPS 1989)

If it is assumed that the plant is in 8,250 hours per year, this would result in a annual failure probability of 3.2×10^{-02} under this scenario, as shown below.

$$10^{-3}\times2+10^{-4}\times100 + 10^{-2}\times2 = 3.2 \times 10^{-02}$$

According to the probability ratings described in **Section 3.2.2**, the probability that this accident and malfunction scenario would occur is likely.

7.6 Bounding Scenario 6: Facility Fire and / or Explosion

The average annual probability of the occurrence of a furnace explosion, which is used as an analogue for Bounding Scenario 6, as provided by Chemical Process Safety of the American Institute of Chemical Engineers (AIChE-CCPS 1989) is $4\text{x}10^{-4}$.

According to the probability ratings described in **Section 3.2.2**, the probability that this accident and malfunction scenario would occur is highly unlikely.

7.7 Bounding Scenario 7: Traffic Accident, Terrestrial Release of Radioactivity, Fuel, and Hazardous Chemicals

Traffic risk mitigation measures for Bounding Scenario 7 are the same those presented for Bounding Scenarios 1 and 2. The annual probability of traffic accidents involving radioactivity, fuel or chemicals along Highway 914 and within one kilometer near the designated locations assuming 1,220 trips per year for 330 days per year, are estimated as:

$$(1{,}220+330) \text{ x } 1.75 \text{ x } 1 / 1{,}000{,}000 = 2.71 \times 10^{-03}$$

The above probabilities were calculated using Saskatchewan Government Insurance statistics for Highway 914.

According to the probability ratings described in **Section 3.2.2**, the probability that this accident and malfunction scenario would occur is unlikely.

7.8 Summary of Probabilities

The probabilities for the bounding scenarios are summarized below in **Table 7-2**. Recall that the potential effects (i.e., overall risks) associated with the bounding scenarios are a function of both probability and consequence and therefore these probabilities are considered along with scenario consequences to predict effects in **Section 8.0**.

Table 7-2: Probabilities of Bounding Scenarios

No.	Potential Accidents or malfunctions	Project Phase	Potential Effects Pathway	Calculated Annual Probability	Probability Characterization
1	Vehicle accident including rollover, collision, run off road	Op	Aquatic release of radioactivity	5.77×10^{-05}	Highly unlikely
2	Vehicle accident including rollover, collision, run off road	Co / Op / De	Aquatic release of fuel, hazardous chemicals and reagents	2.14×10^{-03}	Unlikely
3	Loss of freeze capacity	Op	Release of mining liquid to the local / regional groundwater environment	$1x10^{-7}$	Highly unlikely
4	Failure of freeze wall	Op	Release of mining liquid to the local / regional groundwater environment	10^{-4}	Highly unlikely
5	Process vessel and piping system failure	Op	Release of radon from storage tank	3×10^{-02}	Likely
6	Facility fire / explosion	Op	Release of radioactivity and uranium concentrate powder to atmosphere	$4x10^{-4}$	Highly unlikely
7	Vehicle accident including rollover, collision, run off road	Co / Op / De	Terrestrial release of radioactivity and chemicals	2.71×10^{-03}	Unlikely

Notes: Co is construction; Op is operations; De is decommissioning.

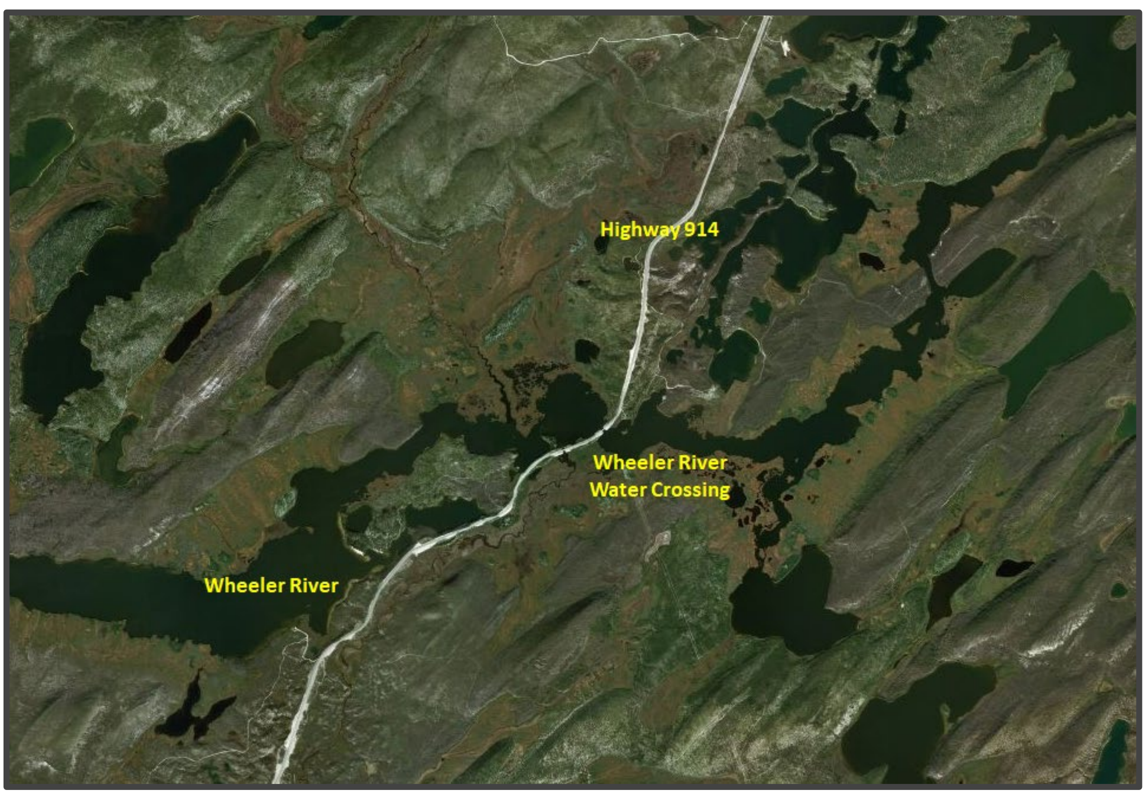
8.0 ASSESSMENT OF POTENTIAL EFFECTS FROM BOUNDING SCENARIOS

The assessment of potential effects associated with each of the identified bounding scenarios is presented below.

8.1 Bounding Scenario 1: Traffic Accident and Aquatic Release of Radioactivity

The Wheeler River runs approximately 10 km south of the Wheeler site from the southwest towards northeast and drains to Russel Lake. Provincial Highway 914 crosses the Wheeler River 10 km southwest of the site access road junction. This is the crossing where it is assumed that a hypothetical truck accident would occur (**Figure 8-1**). The river width at the crossing measures about 20 m. The closest hydrometric gauging station is station number 06DA005 (at Wheeler River South of Russell Lake). The rivers flows considered for this assessment are 5th percentile annual flow of 10.9 m^3/s (minimum flow), the average annual flow of 24.3 m^3/s (average flow), and the 95th percentile annual flow of 24.67 m^3/s (maximum flow). Corresponding river depths for these flow conditions are 0.8, 1.2, and 1.7 m, respectively.

Figure 8-1: The Wheeler River crossing location



Uranium Concentrates Fate and Transport Results

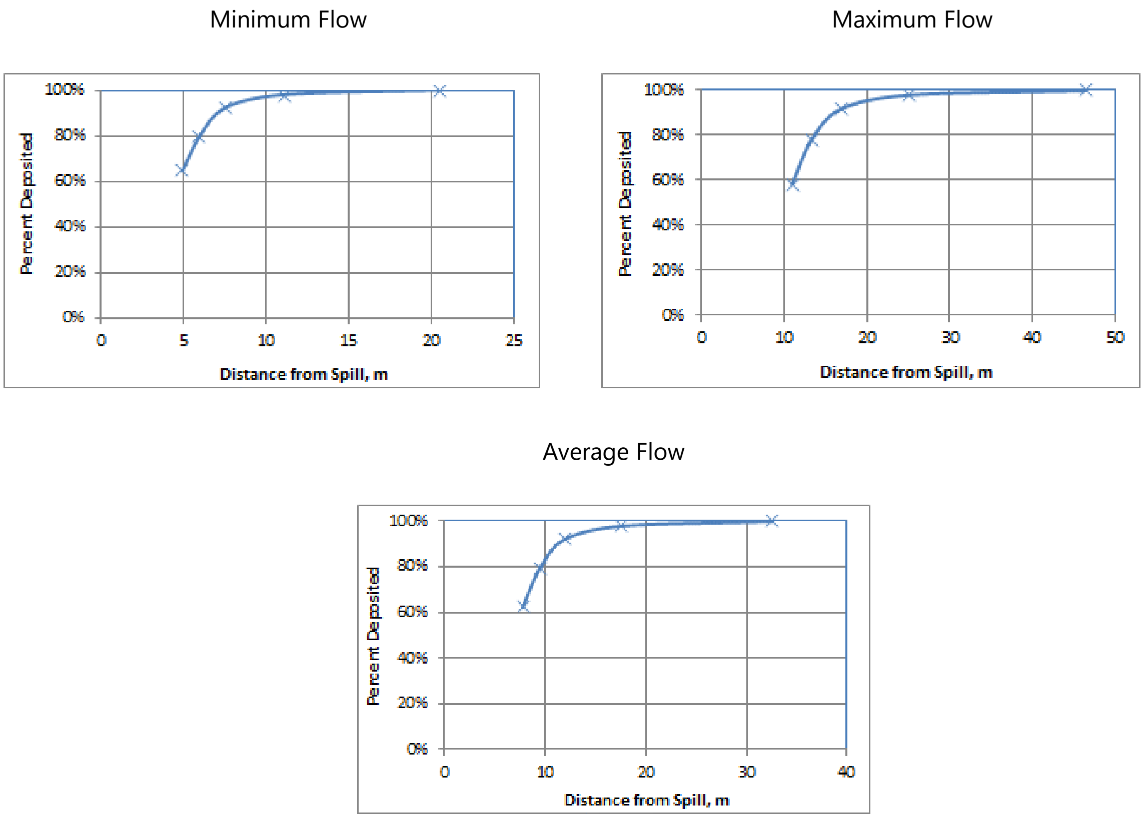
Sediment concentrations were estimated through calculation of the distance travelled by uranium concentrate after a spill, and the area impacted.

Figure 8-2 illustrates the implication of this distribution of uranium concentrate mass for any clean-up planning. The results indicate that most (98% of the mass) of the uranium concentrate will settle within a short distance of the release, even under high flow conditions in the Wheeler River (i.e., within ~20 m of the release point) due to a relatively slow water velocity (<0.8 m/s). This indicates that the hypothetical release would be confined to a small area and it is expected that it could be effectively recovered. Under high flow conditions (i.e., worst-case), the maximum estimated distance for the deposition of particulates <5 μm is approximately 46 m from the crossing.

For the purposes of the current assessment, it was assumed that 95% of the solids that settle within 15 m of the spill site are potentially recoverable through remedial activities. Sediment quality results are shown in **Table 8-1** for post remediation conditions. The results presented in the table are a summary of the three flow conditions for predicted sediment concentrations in the Wheeler River. In general, using the results of the assessment, the minimum predicted uranium concentrates concentrations in the river sediments occurred under high flow conditions, where the smaller particles (<5 μm) are deposited over a larger area.

Porewater quality within the impacted sediment of the Wheeler River was estimated based on weighted-average sediment concentrations and using a sediment-to-water partition coefficient of 3.5 m^3/kg. The results are shown in **Table 8-1**. During minimum flow conditions, the impacted volume is smaller resulting in a higher sediment concentration; whereas, higher flow conditions on the other hand, result in a greater footprint and hence lower concentrations. Concentrations post-cleanup may not follow the same trend since the clean-up is limited to a distance of 15 m and, while higher concentrated sediment in the vicinity of spill will be cleaned, sediments with lower concentrations further downstream will not, resulting in a higher overall concentration in the high flow conditions.

Figure 8-2: Distribution of Deposited Uranium Concentrate by Distance Downstream of the Wheeler River Crossing



Note: The horizontal scale is not the same for all figures.

Table 8-1: Estimated Post-Remediation Sediment and Porewater Quality Downstream of the Wheeler River Crossing

Flow	Affected Distance (m)	Average Sediment Concentration (µg/g)	Porewater Concentration (µg/L)
Minimum	21	3,461	12
Average	33	2,535	9
Maximum	47	3,309	12

Water concentrations for the three flows were estimated for short and long-term concentrations using information on uranium solubility and porewater concentrations, respectively. The results are shown in **Table 8-2**. The short-term period for the Wheeler River is estimated at about a week regardless of whether settling is taken into account.

Table 8-2: Estimated Water Quality Downstream of the Wheeler River crossing (µg/L)

Duration	Mixing in 5% of River Flow			Mixing in 25% of River Flow			Mixing in 100% of River Flow		
	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q	Min Q	Mean Q	Max Q
Short-term†	56,747	37,831	26,705	11,349	7,566	5,341	2,837	1,892	1,335
Long-term*	n/a	n/a	n/a	n/a	n/a	n/a	0.39	0.188	0.173

Notes:

† Estimated at one week

* Post remediation

Q is flow

n/a- mixing in 5% and 25% is not relevant for long-term concentrations

Exposure Assessment

The assessment of effects to ecological receptors is made by comparing exposure estimates to the relevant toxicological / radiological benchmarks. For example, intake (or dose) estimates are compared to non-radiological Toxicity Reference Values (TRVs) and to dose rate guidelines for radionuclides to assess the risks of adverse health effects for each of the ecological receptors. For people, the estimated exposure is compared to the drinking water quality guidelines. The adverse effects on the water quality are transient, and the accumulation of contaminants through the food chain is not expected for the accident scenarios. Therefore, the only credible exposure pathway for the human receptors is drinking water.

It should be noted that for ecological health effects are considered on a population-level as opposed to an individual-level. Estimation of population level impacts is a complex issue and involves some level of scientific judgement.

The results of water and sediment quality predictions were used to assess exposures of ecological species to uranium.

In general, the approach taken for estimating the exposure of radiological and non-radiological contaminants to non-human biota is to model the intake of a contaminant by the biota (in mg/d or Bq/d) and then use a transfer factor or TF (d/kg) to obtain a body or flesh concentration where necessary. Many toxicity values for non-radiological contaminants are expressed as intake rates rather than tissue residues. Therefore, the assessment of non-radiological and radiological contaminants can be carried out in parallel with the flesh concentrations being important for estimating internal radiological dose; and intakes are used for assessment of non-radiological contaminants.

The comparison of intake (or dose) estimates to TRVs or dose rate guidelines is usually undertaken by the calculation of screening index (SI) values, also referred to as hazard quotients or HQs. The SI values provide an integrated description of the potential hazard, the exposure (or dose) response relationship and the exposure evaluation. This approach is widely used as a key line of evidence in ecological assessments, particularly in screening-type assessments (EC, 2012).

The acute exposure to all aquatic species, with the exception of benthic invertebrates was assessed. Since an acute TRV is not available for benthic invertebrates and they are exposed to both sediments and water, benthic invertebrate exposure was considered to be chronic.

In the assessment of population-level effects on benthic invertebrates, one of the key considerations in this predictive assessment is the scale of the impact. As discussed by U.S. EPA (2003), if the area is large, the effects will be diluted. However, if the area is small, the affected population or community may be too insignificant to prompt stakeholder concern or action. For this assessment, population-level impacts are judged to occur if more than 5% of a lake is affected or 0.2 hectares in river systems.

The results of the water quality predictions were used to assess exposures of a human receptor to chemical uranium as well as radionuclides. For a short-term assessment, the estimated uranium concentration in water was compared to the appropriate water quality benchmark and the estimated radiological dose was compared to the reference dose.

For the assessment of the exposure following a spill in a river, the focus is placed on the estimated concentration following mixing in the entire river flow under average conditions.

Table 8-3 provides estimated concentration and intake, calculated SI values for each receptor selected for assessment in the Wheeler River for average flow conditions for exposure to a spill of uranium concentrate. As seen from the table, the SI values for short-term water and sediment concentrations are above the reference value of 1; these are examined further below. The results of the ecological risk assessment indicate short-term ingestion of contaminated water resulting from an accident would not result in potential risks to grouse, vole or deer. No additional exceedance is observed under low or high flow conditions.

<u>Sediment:</u> Concentrations in post-remediation conditions (95% cleanup within 15 m of spill) are expected to exceed the benchmark. Spilled uranium concentrate would spread over approximately 10.3 m in the average flow condition, covering an area of approximately 824 m^2 (10.3x80=824 m^2 = 0.084 ha). These results indicate that a spill of uranium concentrate could potentially affect the benthic invertebrate populations following a spill, but the spatial extent would be limited.

Water: In the determination of the evaluation of the potential impact, a comparison was made between the results of the estimated short-term water quality and the guideline. The concentration of 1,892 µg/L is greater than 33 µg/L. This indicates that there may be some aquatic species that are affected, but the effects are transient the water concertation quickly drops to long-term level of 0.19 µg/L.

Table 8-3: Consequences on Ecological Receptors for Average Flow in the Wheeler River

Receptor	Exposure					SI (based on)		
	Concentration, mg/kg	Intake, mg/kg.d	Internal Dose	External Dose	Equivalent Dose, mGy/d	Concentration	Intake	Dose
Water-short term	1.892	-	-	-	-	57.3	-	-
Water-long term	0.00019	-	-	-	-	0.005	-	-
Sediment- dw	8449	-	-	-	-	4	-	-
Grouse	0.076	457	1.95E-05	-	1.95E-05	-	0.86	<0.001
Vole	3.97E-06	0.38	1.88E-06	-	1.88E-06	-	0.033	<0.001
Deer	2.55E-03	0.113	0.0012	-	0.001	-	0.01	0.018

Benchmarks: Water, mg/L: 0.033 (short-term);TRVs: 0.043, 0.17 and 0.73 (95^{th}, 90^{th} and 80^{th} protection levels)
Sediment, mg/kg dw: 2,296 (benthic invertebrates)
Intake, mg/kg.d: 160 (grouse), 11.4 (vole, deer)
Dose, mGy/d: 2.4
Grey shading exceeds benchmark
dw is dry weight

Based on the above assessment, and in consideration of the consequence scale described in **Section 3.2.2**, Process Hazards Analysis, the severity of the consequences of this accident and malfunction scenario is judged to be moderate.

8.2 Bounding Scenario 2: Traffic Accident and Aquatic Release of Fuel and Hazardous Chemicals

Fuel Spill

Amongst the fuels considered for this scenario, the consequences of the release of gasoline and solvents are bounded by the consequences associated with the release of diesel fuel. Both gasoline and solvents are lighter with higher vapour pressure; therefore, they have a shorter half-life in the aquatic environment and have a lesser tendency for adsorption to sediments and suspended solids in the water column.

Diesel fuel is considered a non-persistent oil, as it will lose 40% of its volume due to evaporation within 48 hours of an accidental release, even in cold weather. Small diesel spills (i.e., 2 to 20 m^3) will usually evaporate and disperse within a day or less in the aquatic environment; thus, seldom is there any oil on the surface for responders to recover (NOAA, 2020). With a specific gravity between 0.82 and 0.88, diesel fuel is much lighter than water, so it is not possible for diesel to sink and accumulate on the seafloor as pooled or free oil unless adsorption occurs with sediment. Diesel dispersed in the water column can adhere to fine-grained suspended sediments that can then settle out and get deposited on the seafloor. This process is more likely to occur near river mouths where fine-grained sediment is carried in by rivers. This process is not likely to result in measurable sediment contamination for small spills (NOAA 2020). The residual diesel is completely degraded within one to two months; therefore, surface water cleanup for small-scale diesel spills is not likely feasible.

Nevertheless, the unplanned release of diesel still poses a threat to aquatic organisms and particularly birds if they if they are exposed. Fish, aquatic invertebrates, and aquatic vegetation that come in direct contact with a diesel spill may be killed. However, small spills in open water are so rapidly diluted that fish kills are unlikely events unless the spill is in confined, shallow water. Diesel spills can affect water-associated birds by direct contact. Mortality is caused by ingestion during preening.

The theoretical maximum size of 1 µm diesel fuel sheen that can be created by a 30 m^3 spill is $3 \times 10^{+07}$ m^2; however, due to evaporation and dissolution of the majority of the spilled diesel, the size the affected area is much smaller, particularly in a slow-moving surface waterbody. The average water flow rate in the Icelander at station SA-5 is approximately 0.917 m^3/s and when considering the width of the river (i.e., 10 m) and the depth of less than 1 m, the average water velocity is less than 9 cm/s. The spill would quickly reach downstream water bodies (an unnamed lake and Whitefish Lake) where the water velocity would dramatically decrease. At this point, a spill would travel less than 1 km in a day. Considering the lifetime of diesel fuel, the diesel sheen cannot travel beyond 2 km from the bridge on the access road. Thus, the affected areas would be limited to areas downstream to Whitefish Lake. McGowan Lake, to the south of Whitefish Lake, would not be affected in long term (beyond 2 or 3 days). The effects under this scenario are transient, and some adverse effects to aquatic biota and birds may be expected; however, irreversible population level effects are not expected.

Based on the above, and in consideration of the consequence scale described in **Section 3.2.2**, Process Hazards Analysis, the severity of the consequences of this accident and malfunction scenario is judged to be moderate.

8.3 Bounding Scenario 3: Loss of Freeze Capacity

In **Section 7.3**, it was indicated that the probability of groundwater contamination due to the loss of freeze capacity is highly unlikely. In a very unlikely case of groundwater contamination, establishing an exposure pathway from deep contaminated groundwater to a surface water is associated with a large uncertainty. In addition, fate and transport of mine fluids cannot be easily quantified. However, it is recognized that, in a very unlikely case of contamination, remediation at the depth of mining horizon is very difficult and spread of contamination could potentially result in effects severity that can be characterized as major per the consequence scale described in **Section 3.2.2**, Process Hazards Analysis. Accordingly, Denison has put great effort into ensure that the structural stability of freeze wall is maintained, and the freeze plant is maintained in good working order.

8.4 Bounding Scenario 4: Failure of the Freeze Wall

In **Section 5.4**, it was indicated that the failure of the freeze wall is only possible due to a large magnitude (6+) earthquake which is a very low probability event at the Wheeler site. In addition, it was discussed that a small fracture in freeze wall may be sealed due to freezing of the intruding groundwater or mining fluid. In this case only small amount of contaminated fluid may leave the mining horizon.

Similar to the previous scenario discussed in **Section 8.3**, establishing an exposure pathway from deep contaminated groundwater to a surface water is associated with a large uncertainty. In addition, fate and transport of mine fluids cannot be easily quantified. It is also noted that the groundwater monitoring and freeze wall thickness monitoring would help detecting the loss of freeze capacity. In a very unlikely event of failure of freeze wall, mitigation measures including pumping both within the freeze wall/CSW and outside the freeze wall could be employed. However, it is recognized that, in a very unlikely case of contamination, remediation at the depth of mining horizon is very difficult and spread of contamination could potentially result in effects severity that can be characterized as major per the consequence scale described in **Section 3.2.2**, Process Hazards Analysis.

8.5 Bounding Scenario 5: Process System and Piping Failure

The assessment of the accidental release of uranium-rich solution in a processing plant was completed by US NRC (2009). The analysis considered the source terms similar to the source term calculated in **Section 5.5**. The analysis was conducted for a number of wind speeds, stability classes, release durations, and receptor distances. For receptor distances of 100 and 500 m, doses from this scenario were calculated to be less than 0.25 and 0.01 mSv, respectively (US NRC 2009). Both of these doses are less than 25 percent of the annual dose limit for the public of 1 mSv.

There could be external doses from the spill to workers exposed to the released radon, but offsite receptors further than 500 m would be too far away to experience any effects. The assessment also indicated that the dose to the unprotected worker staying inside the processing plant during the spill could exceed the 50 mSv dose limit specified by CNSC if workers did not leave the area quickly after the spill. Denison ensures that the process designed to include control measures to reduce the exposure to both workers and members of the public as low as achievable. The measures would ensure that the processing plant is adequately ventilated, and that spills or leaks are detected by loss of system pressure, observation, or flow imbalance. Emergency response and spill response plans will include procedure for workers protection, personnel protection equipment, and procedures to evaluate exposures during a spill.

Based on the above, and in consideration of the consequence scale described in **Section 3.2.2**, Process Hazards Analysis, the severity of the consequences of this accident and malfunction scenario is judged to be minor.

8.6 Bounding Scenario 6: Facility Fire and / or Explosion

The assessment of the accidental release of uranium powder in the processing plant due to dryer explosion was completed by US NRC (2009). The analysis considered the source terms similar to the source term calculated in **Section 5.6**. Using the release amount of 1 kg inside the processing plant, the dose to offsite receptor at 200 m was calculated to be less than CNSC public dose limit of 1 mSv. The analyses also indicated that the dose to a worker in a full-face-piece powered air-purifying respirator who stays in the area would be 88 mSv, which exceeds the annual worker dose limit of 50 mSv.

Denison would ensure that the design of the plant includes control measures to reduce the exposure to both workers and members of the public to levels that are as low as achievable. The measures would ensure that the processing plant is adequately ventilated. Emergency response and spill response plans will include procedures for worker protection, personnel protection equipment (particularly respiratory equipment), as well as procedure to evaluate exposures during a release of uranium powder.

In the unlikely event of an unmitigated accidental release of uranium due to a dryer explosion, doses to the workers could have a moderate effect, but doses to members of the public would have only a minor effect.

Based on the above, and in consideration of the consequence scale described in **Section 3.2.2**, Process Hazards Analysis, the severity of the consequences of this accident and malfunction scenario is predicted to be moderate.

8.7 Bounding Scenario 7: Traffic Accident, Terrestrial Release of Radioactivity, Fuel, and Hazardous Chemicals

Compared with release to surface water, terrestrial release of hazardous materials are easier to manage due to less mobility of the released materials with the soil and potentially groundwater.

There are several provisions considered to ensure that the effects of terrestrial release of hazardous materials are as low as practicable. In additions to transportation mitigations listed for Scenarios 1 and 2, additional provisions include:

- The Transportation of Dangerous Goods (TDG) Act (Government of Canada 1992) outlines the requirements for entities that transport dangerous goods to establish Emergency Response Assistance Plans (ERAP). ERAPs list specialized personnel and equipment needed for responding to an incident. It is expected that the contractor who is responsible for transportation of uranium concentrate, fuel, and hazardous chemicals develop the ERAP.
- Transport Canada CANUTEC which is the Canadian Transport Emergency Centre operated by the Transportation of Dangerous Goods (TDG) Directorate of Transport Canada serves as a national advisory service that assists emergency response personnel in handling dangerous goods emergencies on a 24/7 basis.
- Limiting the wildlife access to the spill location.
- Speedy clean up to a pre-determined level.
- Preventing runoff and release to surface water.
- Preventing penetration to groundwater.

In a series of experiments during a study contracted by the USDOE, Simmons and Keller (2005) showed that the penetration rate of spilled liquid into soil depends on many factors, including slope, soil permeability, soil wettability, surface roughness, and initial moisture content of soil. In this study, experimental results were fitted into the Green-Ampt model (Simmons and Keller 2005). The results showed that, for most cases, the penetration rates ranged from 0.07 centimetres per second (cm/s) to 0.1 cm/s for silt loam and sandy soils (air porosity of 30% to 45%) with slopes of 2.4% and 4.8%. In most experiments, the final moisture content of 60% was reached after the front head of the spills disappeared. Given that the porosity of the areas around the transportation route are likely to be greater in consideration of regional soil conditions, this penetration rate of 0.1 cm/s is expected to be a conservative value for this assessment. At this penetration rate, a pool of released liquid with a depth of 30 cm would have penetrated the ground surface in 300 s (i.e., 5 minutes).

Assuming that the liquid content of the soil (water + diesel) increases from 20% to 60% for the maximum diesel release of 30 m3, approximately 75 m3 of the soil could be contaminated, as calculated below:

- 60% – 20% = 40% of additional liquid; and
- 30 m^3 / 0.4 = 75 m^3 of soil.

If the soil is completely saturated following the spill (from 20% to 100% liquid content), for the maximum diesel release of 30 m^3, 37.5 m^3 of the soil could be contaminated:

- 100% – 20% = 80% of additional liquid; and
- 30 m^3 / 0.8 = 37.5 m^3 of soil.

Based on the above discussion on water penetration rate, a conservative penetration time of 15 minutes was made. Based on this assumption, the maximum depth of contamination could be 90 cm (for penetration rate of 0.1 cm/s):

- depth = 900 s × 0.1 cm/s = 90 cm = 0.9 m.

For the penetration rate of 0.07 cm/s over 15 min, the depth of contamination could be 63 cm:

- depth = 900 s × 0.07 cm/s = 63 cm = 0.63 m.

The surface area affected by the spill can be calculated as follows:

- area = 75 m^3 / 0.9 m= 83 m^2, (60% saturation and depth of 0.9 m);
- area = 37.5 m^3 / 0.63 m = 60 m^2, (100% saturation and depth of 0.63 m);
- area = 75 m^3 / 0.63 m = 119 m^2, (60% saturation and depth of 0.63 m); and
- area = 37.5 m^3 / 0.9 m = 42 m^2, (100% saturation and depth of 0.9 m).

From the above calculation, the size of affected area would range from about 42 m^2 to 119 m^2. Shallow groundwater flow is generally affected by local-scale topography, which is represented by level to gently rolling plains around the transportation route. There is a potential for groundwater contamination within the area of soil contamination.

The velocity of groundwater at this location can be calculated as follows:

- V= K × I/n, where V is groundwater velocity, K is horizontal hydraulic conductivity, I is the horizontal hydraulic gradient, and n is the effective porosity.

Assuming that porosity is 0.45, hydraulic conductivity ranges from 7 × 10^{-5} m/s to 1 × 10^{-7} m/s, and hydraulic gradient ranges from 0.02 to 0.1, a range of groundwater velocity can be calculated as follows:

- Vmax = 7 × 10-5 m/s × 0.1 / 0.45 = 1.5 × 10-5 m/s.
- Vmin = 1 × 10-7 m/s × 0.02 / 0.45 = 4.4 × 10-9 m/s.

The wide range of the calculated velocities is a result of variation of soil conditions and the slope of the surface. The distance that the groundwater can travel under these extreme (i.e., conservative) conditions ranges from 0.15 m to 100 m. During this time period, no major migration of groundwater is expected. Thus, the contamination of soil and shallow groundwater is expected to be limited to a small area near the release location.

During the cold season when the soil is frozen, no penetration of spilled material is expected. Therefore, no soil or groundwater contamination is expected. However, due to large spread of the released materials, the remediation is expected to take longer.

Based on the provisions in place and in consideration of the consequence scale described in **Section 3.2.2**, Process Hazards Analysis, the severity of the consequences of this accident and malfunction scenario is judged to be minor.

8.8 Summary of Consequence Severity

The severity of consequences for the bounding scenarios are summarized below in **Table 8-4**.

Table 8-4: Probabilities of Bounding Scenarios

No.	Potential Accidents or malfunctions	Project Phase	Potential Effects Pathway	Consequence Severity Characterization
1	Vehicle accident including rollover, collision, run off road	Op	Aquatic release of radioactivity	Moderate
2	Vehicle accident including rollover, collision, run off road	Co / Op / De	Aquatic release of fuel, hazardous chemicals and reagents	Moderate
3	Loss of freeze capacity	Op	Release of mining liquid to the local / regional groundwater environment	Major
4	Failure of freeze wall	Op	Release of mining liquid to the local / regional groundwater environment	Major
5	Process vessel and piping system failure	Op	Release of radon from storage tank	Minor
6	Facility fire / explosion	Op	Release of radioactivity and uranium concentrate powder to atmosphere	Moderate
7	Vehicle accident including rollover, collision, run off road	Co / Op / De	Terrestrial release of radioactivity and chemicals	Minor

Notes: Co is construction; Op is operations; De is decommissioning.

9.0 RISK ESTIMATION - SUMMARY

The results of the risk assessment of the bounding accident and malfunction scenarios are summarized in **Table 9-1**. As described in **Section 3.0**, the more in-depth risk evaluation for the bounding scenarios has been provided as this process results in more a representative characterization of the risk of these scenarios. The preliminary screening level assessment (see **Appendix A**) had deemed these scenarios as potentially posing a higher level of risk to the environment and a more detailed assessment was undertaken.

As can be seen, the more rigorous assessment has shown that the risk of the selected bounding scenarios is low to moderate. No high-risk scenarios have been identified.

The results combine the analysis of both probability (**Section 7.0**) and consequence of effect (**Section 8.0**) for each bounding scenario to identify an overall risk rating according to the risk ranking framework presented in **Section 3.2.2**, **Figure 3-1**. The difference between the risk ranking presented below and the original risk screening process (**Section 3.0**, **Appendix A**) is that the risk ratings below were assigned based on the quantitative assessment of these accident and malfunction scenarios.

The overall risk ratings indicate that the traffic accident scenarios releasing uranium concentrate (Scenario 1) and chemicals (Scenario 2), failure of process vessel and piping systems (Scenario 5), a facility fire or explosion (Scenario 6) and a terrestrial release of radioactivity and chemicals have a low risk (Scenario 7).

The overall risk associated with the loss of freeze capacity and the failure of the freeze wall (Scenarios 3 and 3) have been determined to be major; though, highly unlikely from solely a probability perspective.

Overall, low to moderate risk scenarios are deemed to represent a tolerable level of risk in consideration of proposed safeguards and design features that reduce the risk level to ALARP.

Table 9-1 Bounding Scenarios Probability, Consequence, and Overall Risk Rating

No.	Potential Accident /or Malfunction	Potential Effect pathway	Probability	Effect Severity	Overall Risk Rating[1]
1	Vehicle accident including rollover, collision, run off road	Aquatic release of radioactivity	Highly unlikely	Moderate	Low
2	Vehicle accident including rollover, collision, run off road	Aquatic release of fuel, hazardous chemicals and reagents	Unlikely	Moderate	Low
3	Loss of freeze capacity	Loss of freeze wall and secondary underground containment	Highly unlikely	Major	Moderate
4	Failure of freeze wall	Loss secondary underground containment and groundwater contamination	Highly unlikely	Major	Moderate
5	Process vessel and piping system failure	Release of radon from storage tank	Likely	Minor	Low
6	Facility fire / explosion	Release of radioactivity and uranium concentrate powder to atmosphere	Highly unlikely	Moderate	Low
7	Vehicle accident including rollover, collision, run off road	Terrestrial release of radioactivity and chemicals	Unlikely	Minor	Low

[1] Based on Figure 3-1.

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APPENDIX A - HAZARD IDENTIFICATION FOR THE ACCIDENTS AND MALFUNCTIONS ASSESSMENT – WHEELER RIVER PROJECT

WHEELER RIVER ISR PROJECT - HAZARD IDENTIFICATION REPORT

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Ref. 20-2065
23 August 2021

Ecometrix | Environmental INTELLIGENCE

WHEELER RIVER ISR PROJECT - HAZARD IDENTIFICATION REPORT

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FOREWORD

EcoMetrix Incorporated (EcoMetrix) was retained by Denison Mines Corp. (Denison) to complete the accidents and malfunctions assessment for the Wheeler River Project (Wheeler or the Project) as part of the environmental assessment process. The Project is a proposed in-situ recovery (ISR) uranium operation in Saskatchewan. This current memorandum details the initial Hazard Identification (HI) process that has been completed to support that assessment. The HI is used to identify potential hazard scenarios, screen those scenarios as to potential environmental risks and, based on this screening, recommend scenarios that should be carried forward for more detailed consideration.

This HI informed an accidents and malfunctions (A&M) workshop that was completed on March 18, 2021, with representatives of Denison to gain further insights regarding potential scenarios, mitigation strategies and screening outcomes. This current report incorporates information provided in that workshop.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION

The Denison Wheeler River Project (Wheeler or the Project) is a proposed uranium mine and processing plant in northern Saskatchewan, Canada. The Project is located in a relatively undisturbed area of the boreal forest about 4 km off of Highway 914 and approximately 35 km north-northeast of the Key Lake uranium operation. The deposit will be mined via ISR that involves injecting a low-pH mining solution into the uranium deposit through a series of cased drill holes (injection wells) and subsequently pumping the uranium-rich solution to surface through recovery wells. Once on surface, the uranium rich mining solution recovered from the wellfield will be pumped to the on-site processing plant. Inside the processing plant a relatively simple precipitation process will be used to separate the uranium from the mining solution. Once separated, the uranium will be dried, packaged and trucked off site, destined for eventual use in a nuclear power plant. The main phases of the Project are construction, operation, decommissioning, and post-decommissioning. Construction would last for approximately three years; production activities would commence following commissioning of the facilities and would last 15 years with a production rate of up to 12 M lbs U3O8 per year. Decommissioning is expected to last for five years and post-decommissioning a further 15 years.

EcoMetrix Incorporated (EcoMetrix) was retained by Denison to complete the accidents and malfunctions (A&M) assessment for the Wheeler River Project as part of the environmental assessment process. The Project is a proposed in-situ recovery (ISR) uranium operation in Saskatchewan. This current memorandum details the initial Hazard Identification (HI) process that has been completed to support that assessment. The HI is used to identify potential hazard scenarios, screen those scenarios as to potential environmental risks and, based on this screening, recommend scenarios that should be carried forward for more detailed consideration.

This HI informed an accidents and malfunctions workshop that was completed om March 18, 2021 with representatives of Denison to gain further insights regarding potential scenarios, mitigation strategies and screening outcomes. This current report incorporates information provided in that workshop.

1.1 Scope and Applicability of the Hazard Identification

The regulations governing the Environmental Impact Statement (EIS) requires that the impacts of A&M related to the various project components be assessed. As a step towards the assessment of A&M, an HI needs to be completed. The objective of HI is to identify those A&M scenarios that have the potential to present a risk to the biophysical environment. The HI also includes a screening assessment that determines those scenarios that require more detailed quantitative assessment as to their probabilities and severity of consequences. This detailed quantitative assessment is documented in a stand-alone A&M Assessment Report, that is an appendix to the main Environmental Impact Statement (EIS).

The scope of the HI included consideration of all project phases: construction; operation; decommissioning and post-decommissioning. The spatial extent of the evaluation included the

Project site and the site access road to its junction with Highway 914, as well as at locations of interest to Interested Parties along the mine-related transportation route.

Generally, the evaluation focused on potential human health or biophysical environmental risks associated with Project components and activities. It is noted that some hazards related to worker safety were identified; however, worker safety (risks and consequences) is beyond the scope of this assessment.

1.2 Information Sources

Project related information that has been used to complete this evaluation is the most recent information available as provided by Denison, as of the publication of this report.

2.0 HAZARD ANALYSIS

The HI evaluation was performed to identify hazard scenarios associated with the Project that may result in consequences to human health or the biophysical environment. The hazard scenarios were subsequently assessed at a screening level as to potential risks to human health or the biophysical environment, and to identify scenarios that should be carried forward for more detailed evaluation.

2.1 Methodology

The hazard identification process is a systematic approach to identify possible hazards in a work process. A hazard can be defined as a physical condition that has the potential for causing damage to people, property, or the environment (e.g., fire, explosion, release of chemicals, or radioactivity). Potential nodes for hazard identification are selected through the review of the Project-related components. A node is a Project component that represents a physical system or activity with the potential to present a risk to the human health or biophysical environment. Hazard scenarios are developed on consideration of these nodes.

The hazard identification for each node involves the consideration of the sources of hazard (e.g., presence of hazardous materials), hazardous situations (e.g., height or extreme heat), and initiating events (e.g., natural causes, technical failure, or human error) that in combination present a risk to the human health or biophysical environment. A screening evaluation is applied to a given scenario by qualitatively evaluating consequence severity and probability to determine a risk level.

While there are standards and regulatory documents (e.g., REGDOC-2.4.2, Safety Analysis, Probabilistic Safety Assessment (PSA) for Reactor Facilities (CNSC 2014)) that govern the assessment of the probability of the hazard scenarios for nuclear reactors, no such documents exist for non-reactor facilities. The focus of these documents is design-basis and beyond design-basis accidents that affect the integrity of the reactor core. The annual probability of releases from these accidents can be $1x10^{-6}$ and lower, while the consequence of these accidents could be very severe. In contrast, the probability of accidents and malfunctions at non-reactor facilities such as mines and process plants can be higher, as derived from the operating experience of similar installations. The International Atomic Energy Agency's TECDOC-1267 (IAEA 2002) states that while a plant-specific qualitative risk analysis should be conducted for a nuclear reactor facility, for non-nuclear facilities hazard identification and screening, evaluation of selected accident scenarios, and a combination of qualitative and quantitative analysis should be conducted. This document does not prescribe what probabilities should be considered.

On a scale of increasing likelihood, scenarios are categorized as highly unlikely, unlikely, likely, very likely, and almost certain as follows:

1. highly unlikely: ≤ 1 occurrence in 1,000 years;

2. unlikely: ≤ 1 occurrence in 100 years and > 1 occurrence in 1,000 years;
3. likely: ≤ 1 occurrence in 10 years and > 1 occurrence in 100 years;
4. very likely: ≤ 1 occurrence in 1 year and > 1 occurrence in 10 years; and
5. almost certain: > 1 occurrence in 1 year.

On a scale of increasing severity, scenarios are categorized as none, minor, moderate, major, and catastrophic as follows:

1. none: no human health or biophysical environmental consequences;
2. minor: short-term (less than one month) minor effect on small area or minor first aid injuries with no lost time;
3. moderate: reversible or repairable effect (less than one year) off site or reversible injuries with lost time;
4. major: extended-range, long-term effect off site (e.g., 10 years) or severe injuries with long lasting effects and/or disability; and
5. catastrophic: long-lasting with long-lasting or irreversible environmental effects, fatalities or multiple disabilities.

The resulting risk levels are defined according to the matrix shown in **Figure 2-1**.

For the purpose of the assessment, risks are identified as being low (coloured green in the matrix) where the screening evaluation considers the risk as generally being acceptable, as the likelihood of these scenarios can be effectively managed through application of planned controls and/or the consequence would be low in magnitude. Low-risk scenarios have none to moderate severity with likelihood ranging from highly unlikely to almost certain.

Risks are identified as being moderate (coloured yellow in the matrix) where the screening evaluation considers the risk as generally being tolerable. Moderate-risk scenarios have minor to catastrophic severity with likelihood ranging from highly unlikely to almost certain. In many cases, risk reduction activities will reduce the risk associated with these scenarios to As Low as Reasonably Practicable (ALARP) and therefore these scenarios are characterized as tolerable.

Risks are identified as being high (coloured red in the matrix) where the screening evaluation considers the risk as generally being unacceptable. High-risk scenarios have major to catastrophic severity with likelihood ranging from unlikely to almost certain. As the evaluation of the risk at this hazard identification stage is qualitative and is associated with some uncertainty, the hazard scenarios identified as high risk are advanced for further detailed assessment so that a more fulsome evaluation of risk and potential management activities can be considered.

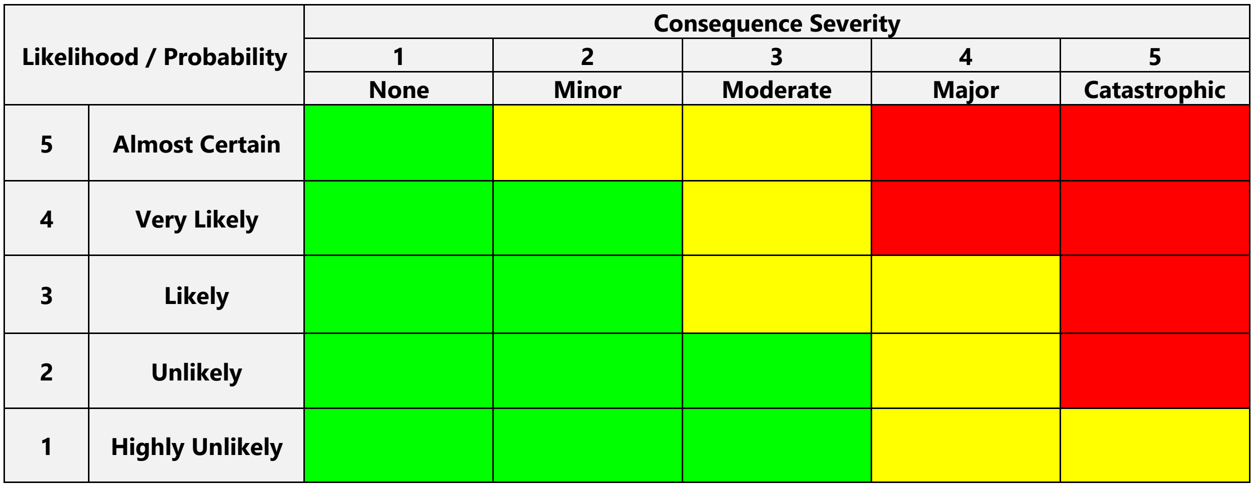

Figure 2-1: Hazard Analysis Risk Matrix

2.2 Evaluation of Project Components and Activities (Process Nodes)

The following nodes were considered in the HI evaluation:

1. Site works, including
    - Site preperation.
    - Road construction.
    - Istallation of piping.
    - Building construction.
    - Constrution of ponds and pads.
    - Installtion of process equipment.
    - Constrution of utility systems.
    - Batch plnt operation.
    - Decomissioning of wells.
    - Demlition of buildings.
    - Removal of rocess equipment.
    - Closure of landfill.
2. Drilling of wells.
3. Access road / land transportation.
4. Air strip / air transportation.
5. Operation of the freeze plant.
6. Maintenace of the freeze wall.

7. Production facility (operation of the processing plant).
8. Clean waste rock pads.
9. Special and mineralized waste rock pads.
10. Precipitates disposal area.
11. Wastewater treatment system.
12. Ponds and retention berms.
13. Electrical system and power plant.
14. Fire protection system.
15. Hazardous waste management system.

3.0 EVALUATION OF PROJECT COMPONENTS AND ACTIVITIES (PROCESS NODES)

For each of the identified process nodes, hazard identification evaluations are shown in **Table 3-1** through **Table 3-16**. In each case, the evaluation considers consequence(s), existing safeguards and design features, and the qualitative evaluation of likelihood and severity of consequences.

The following notations are provided in support of the HI tables:

- As it pertains to Project phase:
  - "Co" is Construction;
  - "Op" is Operations;
  - "De" is Active Decommissioning; and
  - "PD" is Post-Active Decommissioning.
- "L" is Likelihood;
- "S" is Severity of the consequences; and,
- "RR" is Risk Ranking.

With consideration of the sources of hazard and initiating events, a total of 69 hazard scenarios were identified and evaluated.

Five of the hazard scenarios characterized as high-risk, three of which are recommended for further assessment. An addition four moderate / ALARP-moderate scenarios require further detailed assessment for more accurate characterization of the risk. The two high-risk scenarios that were not recommended for further detailed assessment are associated with occupational fatalities for the site preparation activities. These scenarios have not been advanced since it is assumed that the Denison health and safety program will be "best practice" and therefore in these cases the risk is considered ALARP.

Twenty-three of the scenarios evaluated were characterized as moderate-risk scenarios. Generally, the moderate-risk scenarios were deemed to represent a tolerable level of risk in consideration of proposed safeguards and design features that reduce the risk level to ALARP. As indicated above, four moderate / ALARP-moderate scenarios require further detailed assessment for more accurate characterization of the risk.

The balance of the scenarios evaluated, 41, were characterized as low-risk scenarios, based on low likelihood of occurrence and/or consequence in consideration planned existing safeguards and design features.

Site Works - Summary – Nine potential scenarios have been identified. Risks have been characterized as low to moderate as it concerns environmental risks. No scenarios carried forward for quantitative assessment.

Table 3-1: Hazard Identification Evaluation – Site Works

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
1.1	Fall / slip	Co / Op / De	Occupational major injuries	Occupational health and safety plan Personnel training and orientation Personal protection equipment	5	2	ALARP, moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
1.2	Fall / slip	Co / Op / De	Occupational fatalities	Occupational health and safety plan Personnel training and orientation Personal protection equipment	2	5	ALARP, High	Best practice in worker health and safety program resulting in high but ALARP, no further assessment
1.3	Refuelling accident	Co / Op / De	Hydrocarbon release	Occupational health and safety plan Personnel training and orientation Personal protection equipment Spill management and response Secondary containment	4	2	Low	Risk level is low, low consequence event, no further assessment
1.4	Fuel storage failure	Co / Op / De	Hydrocarbon release	Occupational health and safety plan Personnel training and orientation Personal protection equipment Spill management and response Secondary containment	1	3	Low	Risk level is low, highly unlikely event, no further assessment
1.5	Fuel storage and transfer fire and explosion	Co / Op / De	Occupational major injuries	Occupational health and safety plan Personnel training and orientation Personal protection equipment Fire safety plan and firefighting system	2	2	Low	Risk level is low, highly unlikely event, no further assessment
1.6	Fuel storage and transfer fire and explosion	Co / Op / De	Occupational fatalities	Occupational health and safety plan Personnel training and orientation Personal protection equipment Fire safety plan and firefighting system	1	5	ALARP, moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
1.7	Vehicle and construction equipment accident	Co / Op / De	Occupational major injuries	Occupational health and safety plan Personnel training and orientation Preventive and routine maintenance Onsite traffic control (speed limits, signage)	4	2	ALARP, moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
1.8	Vehicle and construction equipment accident	Co / Op / De	Occupational fatalities	Occupational health and safety plan Personnel training and orientation Preventive and routine maintenance Onsite traffic control	2	5	ALARP, High	Best practice in worker health and safety program resulting in high but ALARP, no further assessment
1.9	Vehicle accident	Co / Op / De	Hazardous materials spill	Occupational health and safety plan Personnel training and orientation Preventive and routine maintenance Onsite traffic control (speed limits, signage) Spill management and response	4	2	Low	Risk level is low, minor consequences, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Wellfield - Summary – Three potential scenarios have been identified. Risks have been characterized as low to moderate as it concerns environmental risks. No scenarios carried forward for quantitative assessment.

Table 3-2: Hazard Identification Evaluation – Drilling

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
2.1	Drilling mud spill	Co / Op	Material spill to ground, including contaminated drill muds	Occupational health and safety plan Personnel training and orientation Personal protection equipment Spill management and response Primary and secondary containment for drilling mud	4	2	Low	Risk level is low, low consequence event (assumes containment and clean up), no further assessment
2.2	Piping failure in the well field	Co / Op	Loss of lixiviant, UBS, and/or regents to ground	Occupational health and safety plan Personnel training and orientation Personal protection equipment Spill management and response Secondary containment via freeze wall	2	3	Low	Risk level is low, moderate consequence event (assume localized event to ground where clean up is possible prior to groundwater contamination), no further assessment
2.3	Surface flood	Co / Op	Potential for groundwater contamination	Lined collection points Site grading to collection areas Collection pond sized to accommodate PMP	2	2	Low	Risk level is low, low consequence event, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Access Road / Land Transportation - Summary – Eight potential scenarios have been identified. Risks have been characterized as low to high as it concerns environmental risks. Two scenarios carried forward for quantitative assessment.

Table 3-3: Hazard Identification Evaluation – Access Road / Land Transportation (shaded rows are those recommended for further assessment)

ID#	Accident / Malfunction	Phase	Consequences	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
3.1	Vehicle accident including rollover, collision, run off road	Op	Aquatic release of radioactivity	Occupational health and safety plan Personnel training and orientation Traffic control measures Travel management plan Spill management and emergency response plan	3	5	High	Further Assessment Recommended
3.2	Vehicle accident including rollover, collision, run off road	Co / Op / De	Terrestrial release of radioactivity	Occupational health and safety plan Personnel training and orientation Traffic control measures Travel management plan Spill management and emergency response plan	3	4	ALARP, moderate	Best practice in terrestrial spill containment and cleanup resulting in ALARP, no further assessment
3.3	Vehicle accident including rollover, collision, run off road	Co / Op / De	Aquatic release of fuel, hazardous chemicals and reagents	Occupational health and safety plan Personnel training and orientation Traffic control measures Travel management plan Spill management and emergency response plan	3	5	High	Further Assessment Recommended
3.4	Vehicle accident including rollover, collision, run off road	Co / Op / De	Terrestrial release of fuel, hazardous chemicals and reagents	Occupational health and safety plan Personnel training and orientation Traffic control measures Travel management plan Spill management and emergency response plan	3	4	ALARP, moderate	Best practice in terrestrial spill containment and cleanup resulting in ALARP; Further Assessment Recommended to address interested party concerns (includes consideration of radioactivity)
3.5	Vehicle fire	Co / Op / De	Terrestrial release of hydrocarbons and fuel	Occupational health and safety plan Personnel training and orientation Travel management plan Spill and emergency response plan Spill management and emergency response plan	1	4	ALARP, moderate	Best practice in terrestrial spill containment and cleanup resulting in ALARP, no further assessment
3.6	Vehicle fire	Co / Op / De	Release of radioactivity to air	Occupational health and safety plan Personnel training and orientation Travel management plan Spill and emergency response plan Spill management and emergency response plan	1	4	ALARP, moderate	Low risk, low probability event. Reversible and transient effect. No further assessment
3.7	Vehicle fire	Co / Op / De	Atmospheric release of particulate and combustion by-products	Occupational health and safety plan Personnel training and orientation Travel management plan Spill management and emergency response plan Fire safety plan and firefighting systems Ambient air monitoring	1	3	Low	Low risk, low probability event. Reversible and transient effect. No further assessment
3.8	Vehicle – Wildlife collision	Co / Op / De	Wildlife fatality	Occupational health and safety plan Personnel training and orientation Traffic control measures Travel management plan	4	2	Low	Individual level effect, reversible and nonsignificant effect, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Airstrip - Summary – Four potential scenarios have been identified. Risks have been characterized as low to moderate as it concerns environmental risks. No scenarios carried forward for quantitative assessment.

Table 3-4: Hazard Identification Evaluation – Airstrip

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
4.1	Fuel storage failure	Co / Op / De	Hydrocarbon release	Occupational health and safety plan Personnel training and orientation Storage inspection, maintenance Secondary containment Spill and emergency response plan	1	3	Low	Risk level is low, highly unlikely event, no further assessment
4.2	Refuelling accident	Co / Op / De	Hydrocarbon release	Occupational health and safety plan Personnel training and orientation Secondary containment Spill and emergency response plan	4	2	Low	Risk level is low, low consequence event, no further assessment
4.3	Plane de-icing chemical release	Co / Op / De	Terrestrial release of reagent; possible aquatic release of reagent	Personnel training Containment Spill and emergency response plan	3	2	Low	Risk level is low, low consequence event, no further assessment
4.4	Air plane crash	Co / Op / De	Occupational major injuries / fatality Atmospheric release of particulate and combustion by-products Release of hydrocarbons and fuel Damage to mine infrastructure structure	Travel management plan Air traffic control Spill and emergency response plan Fire safety plan and firefighting systems Personnel training	1	5	ALARP, moderate	Low likelihood event, best practice in air traffic control resulting in ALARP, no further assessment
4.5	Ground vehicle – air plane collision	Co / Op / De	Occupational major injuries / fatality Atmospheric release of particulate and combustion by-products Release of hydrocarbons and fuel Damage to mine infrastructure structure	Travel management plan Air traffic control Ground traffic control Spill and emergency response plan Fire safety plan and firefighting systems Personnel training	1	5	ALARP, moderate	Low likelihood event, best practice in air / ground traffic control resulting in ALARP, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Freeze plant - Summary – Five potential scenarios have been identified. Risks have been characterized as low to high as it concerns environmental risks. One scenario is carried forward for quantitative assessment.

Table 3-5: Hazard Identification Evaluation – Freeze plant (shaded rows are those recommended for further assessment)

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
5.1	Ammonia storage and piping failure	Co / Op	Material spill	Occupational health and safety plan Personnel training and orientation Storage inspection, maintenance Secondary containment Spill and emergency response plan	3	2	Low	Risk level is low, low consequence event, no further assessment
5.2	Loss of freeze capacity	Op	Loss of freeze wall and secondary underground containment	Freeze wall monitoring Monitoring wells outside of the freeze wall – temp, pressure Back up gensets	1	5	Moderate	Loss of containment of lixiviant outside mining chamber - Further Assessment Recommended. Denison does not believe a leak would occur however public perception of a loss of containment is of high concern and should assessed. In practice, the mechanical failure of refrigeration system can be addressed and mitigated well before the thawing of the freeze wall which would take months.
5.3	Cooling line break	Co / Op	Release of brine below ground and potential for groundwater contamination	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Remote monitoring system Spill and emergency response plan	2	4	ALARP, moderate	Low likelihood event, best practice resulting in ALARP, no further assessment
5.4	Cooling line break	Co / Op	Release of brine on surface - potential for ground and groundwater contamination	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Remote monitoring system Pipes in trenches and secondary containment Spill and emergency response plan	2	2	Low	Risk level is low, low consequence event with appropriate response and mitigation, no further assessment
5.5	Pumps failure	Co / Op	Release of brine on surface - potential for surface and groundwater contamination	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Remote monitoring system No open drain from pumphouse Spill and emergency response plan	2	2	Low	Risk level is low, low consequence event with appropriate response and mitigation, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Freeze wall - Summary – One potential scenario has been identified. Risks have been characterized as high as it concerns environmental risks. One scenario is carried forward for quantitative assessment.

Table 3-6: Hazard Identification Evaluation – Freeze wall

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
6.1	Failure of freeze wall due to seismic event / geotechnical instability	Op	Loss secondary underground containment and groundwater contamination	Freeze wall monitoring Redundancy in design Control of pump and injection wells	2	4	Moderate	Loss of containment of lixiviant outside mining chamber - Further Assessment Recommended

Notes: “Co” is construction
“Op” is operations
“De” is Decommissioning
“L” is likelihood
“S” is severity
“RR” is risk ranking

Production Plant - Summary – Seven potential scenarios have been identified. Risks have been characterized as low to high as it concerns environmental risks. Two scenarios are carried forward for quantitative assessment.

Table 3-7: Hazard Identification Evaluation – Production Plant (shaded rows are those recommended for further assessment)

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
7.1	Process vessel and piping system failure	Op	Release of sulphuric acid	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Spill and emergency response plan Secondary containment Process sumps Production building is contained	3	2	Low	Moderate risk, low consequence event, no further assessment
7.2	Process vessel and piping system failure	Op	Release of hydrogen peroxide and potential for fire	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Spill and emergency response plan Secondary containment Process sumps Production building is contained	3	2	Low	Moderate risk, low consequence event, no further assessment
7.3	Process vessel and piping system failure	Op	Release of magnesium hydroxide	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Spill and emergency response plan Secondary containment Process sumps Production building is contained	3	2	Low	Moderate risk, low consequence event, no further assessment
7.4	Process vessel and piping system failure, Thickener overflow	Op	Release of aqueous solution	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Spill and emergency response plan Secondary containment Process sumps Production building is contained Detectable signs of exposure e.g., irritation	3	2	Low	Moderate risk, low consequence event, no further assessment. ALARP
7.5	Process vessel and piping system failure	Op	Release of acidic fume from storage tank	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Availability of respirators Emergency response plan will implement medical response to acute exposure to acidic fumes. Ambient monitoring Building ventilation	3	2	Low	Moderate risk, low consequence event, no further assessment
7.6	Process vessel and piping system failure	Op	Release of radon from storage tank	Occupational health and safety plan Personnel training and orientation Inspection and maintenance	3	3	Moderate	Moderate risk, moderate consequence event - Further Assessment Recommended

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
				Emergency response plan Ambient monitoring Building ventilation				
7.7	Facility fire / explosion	Op	Release of radioactivity and yellowcake powder to atmosphere	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Fire safety plan and firefighting systems Emergency response plan Ambient air monitoring	2	5	High	Further Assessment Recommended. It is also noted that this scenario could eb an outcome of many initiating events – the specific details associated with the event will be determined based on the most current inventory of combustible and flammable materials associated with the production plant when the analysis is completed.
7.8	Process containment and gas cleaning and filtration system failure	Op	Release of yellowcake powder to atmosphere	Inspection, testing, and maintenance program Ambient air monitoring	3	4	ALARP, moderate	The consequence is bounded by scenario 7.7.

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Clean Waste Rock Pads - Summary – Four potential scenarios have been identified. Risks have been characterized as low as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-8: Hazard Identification Evaluation – Clean Waste Rock Pads

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
8.1	Stockpile slope failure	Co / Op /De	Release of material into surrounding environment	Personnel training and orientation Inspection and maintenance	2	2	Low	Low risk, unlikely event due to small extent of stockpiles, no further assessment
8.2	Stockpile erosion	Co / Op /De	Release of materials into the environment	Personnel training and orientation Inspection and maintenance Single-lined pad Inspection and maintenance	1	3	Low	Low risk, unlikely event, no further assessment
8.3	Uncontrolled leachate / seepage release through runoff	Co / Op /De	Release of materials into the surface water	Personnel training and orientation Single-lined pad Inspection and maintenance Ambient monitoring Surface water management Spill management	1	2	Low	Low risk, unlikely event, no further assessment
8.4	Uncontrolled leachate / seepage release through lining failure	Co / Op /De	Release of materials into the groundwater	Personnel training and orientation Single-lined pad Inspection and maintenance Groundwater monitoring Spill response plan	2	3	Low	Low risk, unlikely event, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Special / Specialized Waste Containment - Summary – Two potential scenarios have been identified. Risks have been characterized as low to moderate as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-9: Hazard Identification Evaluation –Special / Specialized Waste Rock Pads

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
9.1	Loss of containment from storage vessels (barrels) resulting in uncontrolled leachate release	Co / Op /De	Release of contaminants into the surface water	Personnel training and orientation Double lined with leak detection/collection Inspection and maintenance Ambient monitoring Surface water management Spill management	1	3	Low	Low risk, unlikely event, no further assessment
9.2	Loss of containment from storage vessels (barrels)resulting in uncontrolled leachate release	Co / Op /De	Release of contaminants into the groundwater	Personnel training and orientation Double lined with leak detection/collection Inspection and maintenance Groundwater monitoring Spill response plan	1	4	ALARP, moderate	Best management practice results in ALARP, highly unlikely event, no further assessment

Notes: “Co” is construction
“Op” is operations
“De” is Decommissioning
“L” is likelihood
“S” is severity
“RR” is risk ranking

Gypsum (clean) Precipitates Disposal Area - Summary – Five potential scenarios have been identified. Risks have been characterized as low as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-10: Hazard Identification Evaluation – Gypsum (clean) Precipitates Disposal Area

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
10.1	Precipitates erosion	Co / Op /De	Release of contaminants into surrounding environment	Personnel training and orientation Single-lined pad Inspection and maintenance	1	2	Low	Low risk, unlikely event, no further assessment
10.2	Uncontrolled leachate / seepage release through runoff	Co / Op /De	Release of contaminants into the environment	Personnel training and orientation Single-lined pad Inspection and maintenance Surface water monitoring Surface water management Spill management and response plan	1	2	Low	Low risk, unlikely event, no further assessment
10.3	Uncontrolled leachate / seepage release through lining failure	Co / Op /De	Release of contaminants into the surface water	Personnel training and orientation Single-lined pad Inspection and maintenance Surface water monitoring Surface water management Spill management and response plan	1	2	Low	Low risk, unlikely event, no further assessment
10.4	Uncontrolled leachate / seepage release through lining failure	Co / Op /De	Release of contaminants into the groundwater	Personnel training and orientation Single-lined pad Inspection and maintenance Groundwater monitoring Spill management and response plan	1	3	Low	Low risk, unlikely event, no further assessment
10.5	Wind erosion	Co / Op /De	Atmospheric release of contaminants	Personnel training and orientation Erosion control measures Inspection and maintenance Ambient air monitoring Response plan	1	3	Low	Low risk, unlikely event, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Iron (contaminated) Precipitates Disposal Area - Summary – Five potential scenarios have been identified. Risks have been characterized as low to moderate as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-11: Hazard Identification Evaluation – Iron (contaminated) Precipitates Disposal Area

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
11.1	Precipitates erosion	Co / Op /De	Release of contaminants into surrounding environment	Personnel training and orientation Double lined with leak detection/collection Inspection and maintenance	1	3	Low	Low risk, unlikely event, no further assessment
11.2	Uncontrolled leachate / seepage release through runoff	Co / Op /De	Release of contaminants into the environment	Personnel training and orientation Double lined with leak detection/collection Inspection and maintenance Surface water monitoring Surface water management Spill management and response plan	1	5	ALARP, moderate	Best management practice results in ALARP, highly unlikely event, no further assessment
11.3	Uncontrolled leachate / seepage release through lining failure	Co / Op /De	Release of contaminants into the surface water	Personnel training and orientation Double lined with leak detection/collection Inspection and maintenance Surface water monitoring Surface water management Spill management and response plan	1	5	ALARP, moderate	Best management practice results in ALARP, highly unlikely event, no further assessment
11.4	Uncontrolled leachate / seepage release through lining failure	Co / Op /De	Release of contaminants into the groundwater	Personnel training and orientation Double lined with leak detection/collection Inspection and maintenance Groundwater monitoring Spill management and response plan	1	5	ALARP, moderate	Best management practice results in ALARP, highly unlikely event, no further assessment
11.5	Wind erosion	Co / Op /De	Atmospheric release of contaminants	Personnel training and orientation Erosion control measures Inspection and maintenance Ambient air monitoring Response plan	1	3	Low	Low risk, unlikely event, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Wastewater Treatment System - Summary – Three potential scenarios have been identified. Risks have been characterized as low to moderate as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-12: Hazard Identification Evaluation – Wastewater Treatment System

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
12.1	Equipment / piping failure	Op / De	Contaminant and radioactivity release	Occupational health and safety plan Personnel training and orientation Piping design pressure higher than pumps shutoff pressure Inspection and maintenance Process monitoring Spill management and response	2	3	ALARP, moderate	Best management practice results in ALARP, containment of the piping within the ditches indicates no further assessment
12.2	Effluent clarifier overflow	Op / De	Contaminant and radioactivity release	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Process monitoring Secondary containment Spill management and response	2	3	ALARP, moderate	Best management practice results in ALARP, no further assessment
12.3	Equipment and control system failure	Op / De	Release of reagents, Environmental contamination	Occupational health and safety plan Personnel training and orientation Inspection and maintenance Process monitoring Recirculation of off-spec water to the process Spill management and response	2	3	Low	Low risk, unlikely event, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Ponds and Retention Berms - Summary – Five potential scenarios have been identified. Risks have been characterized as low to moderate as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-13: Hazard Identification Evaluation – Ponds and Retention Berms

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
13.1	Pond overtopping	Op / De	Contaminant and radioactivity release	Personnel training and orientation Inspection and maintenance Surface water management Ponds designed for PMP/PMF Spill and emergency response plan Monitoring	2	3	Low	Low risk, low probability event, no further assessment
13.2	Ponds containment or embankment failure	Op / De	Contaminant and radioactivity release	Personnel training and orientation Inspection and maintenance Surface water management Ponds designed for PMP/PMF Spill and emergency response plan Monitoring	1	5	ALARP, moderate	Best engineering practice in maintenance and inspection of the containment systems and berms. No further assessment
13.3	Ponds lining failure and leakage	Op / De	Contaminant and radioactivity release to groundwater	Personnel training and orientation Inspection and maintenance Groundwater monitoring Response plan	2	3	Low	Low risk, low probability event, no further assessment
13.4	Surface flooding	Op / De	Contaminant and radioactivity release	Personnel training and orientation Inspection and maintenance Surface water management Ponds designed for PMP/PMF Spill and emergency response plan Monitoring	1	3	Low	Low risk, low probability event, no further assessment
13.5	Wildlife entering pond	Op/De	Exposure to contaminants, drowning	Wildlife management plan Inspection Fencing	1	2	Low	Low risk, low probability event, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Electrical System and Power Plant - Summary – Three potential scenarios have been identified. Risks have been characterized as low to moderate as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-14: Hazard Identification Evaluation – Electrical System and Power Plant

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
14.1	Substation transformer leak	Co / Op / De	Release of mineral oil and potential for groundwater contamination	Personnel training and orientation Inspection and maintenance Spill and emergency response plan Secondary containment	3	2	Low	Low risk, low consequence event, no further assessment
14.2	Transformer, turbine, generator fire / explosion	Co / Op / De	Occupational major injuries	Personnel training and orientation Occupational health and safety program Personal protection equipment Inspection and maintenance Emergency response plan Fire safety plan and firefighting systems	2	2	ALARP, moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment
14.3	Transformer, turbine, generator fire / explosion	Co / Op / De	Occupational fatalities	Personnel training and orientation Occupational health and safety program Personal protection equipment Inspection and maintenance Emergency response plan Fire safety plan and firefighting systems	1	5	ALARP, moderate	Best practice in worker health and safety program resulting in ALARP, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Fire Protection System - Summary – Two potential scenarios have been identified. Risks have been characterized as low as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-15: Hazard Identification Evaluation – Fire Protection System

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
15.1	Failure of fire pump	Co / Op / De	Loss of firefighting capacity	Personnel training and orientation Occupational health and safety program Personal protection equipment Inspection and maintenance Redundancy Fire safety plan and firefighting systems (including and elevated fire water tank, and a gas-powered pump for at a groundwater well) Emergency response plan	1	3	Low	Low risk, highly unlikely event, no further assessment
15.2	Loss or lack of fire water	Co / Op / De	Loss of firefighting capacity	Personnel training and orientation Occupational health and safety program Personal protection equipment Inspection and maintenance Fire safety plan and firefighting systems Emergency response plan	1	3	Low	Low risk, highly unlikely event, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

Hazardous Waste Management System - Summary – One potential scenario has been identified. Risks have been characterized as low as it concerns environmental risks. No scenarios are carried forward for quantitative assessment.

Table 3-16: Hazard Identification Evaluation – Hazardous Waste Management System

ID#	Accident / Malfunction	Phase	Consequence	Existing Safeguards / Design Features	L	S	RR / Significance	Screening Decision / Rationale
16.1	Hazardous waste spill	Co / Op / De	Potential for surface water and soil contamination	Personnel training and orientation Occupational health and safety program Personal protection equipment Inspection and maintenance Waste management plan Emergency response plan Onsite monitoring	2	2	Low	Low risk, low consequence event, no further assessment

Notes: "Co" is construction
"Op" is operations
"De" is Decommissioning
"L" is likelihood
"S" is severity
"RR" is risk ranking

4.0 SCENARIOS ADVANCED FOR FURTHER ASSESSMENT

Based on the HI process presented in the previous section, seven hazard scenarios have been selected for more detailed risk analysis (**Table 4-1**). This further assessment will include the calculation of the probability, and consequences of each of these selected scenarios. This will result in more in-depth and representative characterization of the risk of these scenarios, as the estimation of the risk in this current report was preliminary and at the screening level.

Table 4-1: Accident and Malfunction Scenarios Advanced for Further Quantitative Assessment

Potential Accident or Malfunction	Project Phase	Potential Effect Pathway	Environmental Interactions	Initial Risk Characterization
Vehicle accident, including rollover, collision, run off road	O	Aquatic release of radioactivity	Potential effects on surface water quality, aquatic environment VCs, wildlife VCs and human health	High Risk
Vehicle accident, including rollover, collision, run off road	C/O/D	Aquatic release of fuel, hazardous chemicals, and reagents	Potential effects on surface water quality, aquatic environment VCs, wildlife VCs and human health	High Risk
Loss of freeze capacity	O	Loss of freeze wall and secondary underground containment	Potential effects on the groundwater VCs	High Risk
Failure of freeze wall	O	Loss of secondary underground containment and groundwater contamination	Potential effects on the groundwater VCs	Moderate Risk
Process vessel and piping system failure	O	Release of radon from storage tank	Potential effects on groundwater, soils, vegetation, wildlife VCs and human health	Moderate Risk
Facility fire/explosion	O	Release of radioactivity and uranium concentrate powder to atmosphere	Potential effects on air quality and human health	Moderate Risk
Vehicle accident, including rollover, collision, run off road	C/ O/D	Terrestrial release of radioactivity and chemicals	Potential effects on groundwater, soils, vegetation, wildlife VCs and human health	Moderate Risk

Red are high risks scenarios; yellow are moderate risk scenarios

5.0 REFERENCES

CNSC (Canadian Nuclear regulatory Commission). 2014. REGDOC-2.4.2, Safety Analysis Probabilistic Safety Assessment (PSA) for Reactor Facilities, Version 2. Available at **https://www.nuclearsafety.gc.ca/eng/pdfs/regulatory-documents/regdoc2-4-2/REGDOC-2.4.2_Probabilistic_Safety_Assessment_(PSA)_for_Reactor_Facilities_Version_2.pdf**

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