AVALON
RARE METALS INC.

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APPENDIX G

SENES RADIOLOGICAL REPORTS

Appendix G.1 Radiation Protection Program in Support of the Thor Lake Project Prepared for Avalon Rare Earth Metals Inc.

Appendix G.2 Preliminary Results of Radiological Pathways Assessment Memorandum.

Appendix G.1

Radiation Protection Program in Support of the Thor Lake Project Prepared for Avalon Rare Earth Metals Inc.

RADIATION PROTECTION PROGRAM IN SUPPORT OF THE THOR LAKE PROJECT

Prepared For:

Avalon Rare Metals Inc.

Prepared By:

SENES Consultants Limited

March 2011

AVALON
RARE METALS INC.

SENES Consultants Limited

Specialists in Energy, Nuclear and Environmental Sciences

Final

RADIATION PROTECTION PROGRAM IN SUPPORT OF THE THOR LAKE PROJECT

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Final

RADIATION PROTECTION PROGRAM IN SUPPORT OF THE THOR LAKE PROJECT

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GLOSSARY

ALARA: An optimization tool in radiation protection used to keep individual, workplace and public dose limits As Low As Reasonably Achievable (ALARA), social and economic factors being taken into account. ALARA is not a dose limit; it means making reasonable efforts to maintain exposures to radiation as far below the dose limits as practical.

alpha particle: An emission of a helium nucleus (two protons and two neutrons) by a radionuclide as it decays. Alpha particles can be stopped by air or by a sheet of paper.

becquerel (Bq): The SI (metric) unit of radioactivity equal to one radioactive decay per second.

beta particle: High energy electrons or positrons that are emitted by a radionuclide as it decays. Beta particles can be stopped by a 1-2 cm of water or the surface of the body.

effective dose: A measure of radiation dose in humans designed to reflect the amount of potential detriment (risk) caused by radiation.

gamma radiation: Penetrating electromagnetic radiation which is emitted by a radionuclide as it decays. Like X-rays, gamma radiation can penetrate into the body; it can be stopped by lead, concrete, or a suitable thickness of soil and comparable materials.

half-life: The time required to decrease the activity of a radioactive substance by half through radioactive decay. A shorter half-life represents a more radioactive substance.

heavy minerals: A mineral which has a density greater than 2.9 g/cm^3.

ionizing radiation: Radiation that is able to produce ion pairs in materials. (In this report, radiation refers to ionizing radiation.)

isotopes: Different forms of an atom of the same element (number of protons is the same) but with different numbers of neutrons. For example, U-238 and U-234 are isotopes of uranium.

millisievert: 1/1000 Sv (see “sievert”).

non-ionizing radiation: Radiation, such as microwaves or radiowaves, that does not have sufficient energy to produce ions.

NORM: Naturally Occurring Radioactive Material consisting of radioactive elements found in the environment. In rocks and soils, NORM primarily comprises natural uranium and thorium and their radioactive decay products.

radioactive decay: The process in which a radionuclide loses energy by spontaneously emitting radiation such as alpha, beta, or gamma radiation.

radioactivity (or activity): The rate at which nuclear disintegrations occur in a radioactive material. The amount of a radionuclide present is measured in units of becquerels (Bq).

radioisotope: An isotope that undergoes spontaneous decay and emits radiation.

radionuclide: A radioactive nuclide.

radon: Radon (Rn-222) is a naturally occurring radioactive noble gas in the radioactive decay series of natural uranium (U-238).

rare earths: Refers to any element from atomic number 57 (La) to 71 (Lu) (also called lanthanides), plus the elements of atomic numbers 39 (Y) and 21 (Sc).

sievert: The SI unit used to measure radiation dose. Typically, millisieverts (mSv = 1/1000 Sv) or microsieverts (μSv = 1/1000000 Sv) are used for measuring occupational or environmental radiation doses.

specific activity: The direct relationship between the mass and the radioactivity of a radionuclide. It is measured in units of Bq/g or Bq/kg. The longer the half-life of a radioactive substance, the smaller is its specific activity.

thermoluminescent dosimeter (TLD): A device worn by workers that measures and records the radiation doses received by the workers. TLDs can also be used to measure environmental doses.

thoron: Thoron (Rn-220) is a naturally occurring radioactive isotope of radon in the radioactive decay series of natural thorium (Th-232).

working level (WL): A historical unit for the concentration in air of the short-lived decay products of radon. One WL is equal to a concentration of radon decay products in equilibrium with 3700 Bq/m^3 of radon.

working level month (WML): A historical unit for exposure to radon decay products. One WLM is equal to exposure to a concentration of 1 WL for one working month (170 hours).

1.0 INTRODUCTION

Avalon Rare Metals Inc. (Avalon) proposes to build facilities to mine, mill and refine a number of rare earth metals from its Nechalacho deposit, located on its Thor Lake Property near the east arm of Great Slave Lake in the Northwest Territories (NT). The operations of the proposed Thor Lake Project (TLP) will occur at two sites: an underground mine and flotation plant, located at the Thor Lake Property, and a hydrometallurgical plant located at the site of the former Pine Point Mine on the south shore of Great Slave Lake. An overview of the TLP is provided below, with further information provided in Chapter 3 of this report. A full description of the TLP is provided in the draft Avalon Developers Assessment Report (Avalon 2011a).

1.1 PROJECT OVERVIEW

The proposed Thor Lake Project is a proposed underground mine and processing plants to recover rare earth products and is comprised of two site locations, the Nechalacho Mine and Flotation Plant located on the Thor Lake Property, and the Hydrometallurgical Plant located at the brownfield site of the former Pine Point Mine near Hay River, NT.

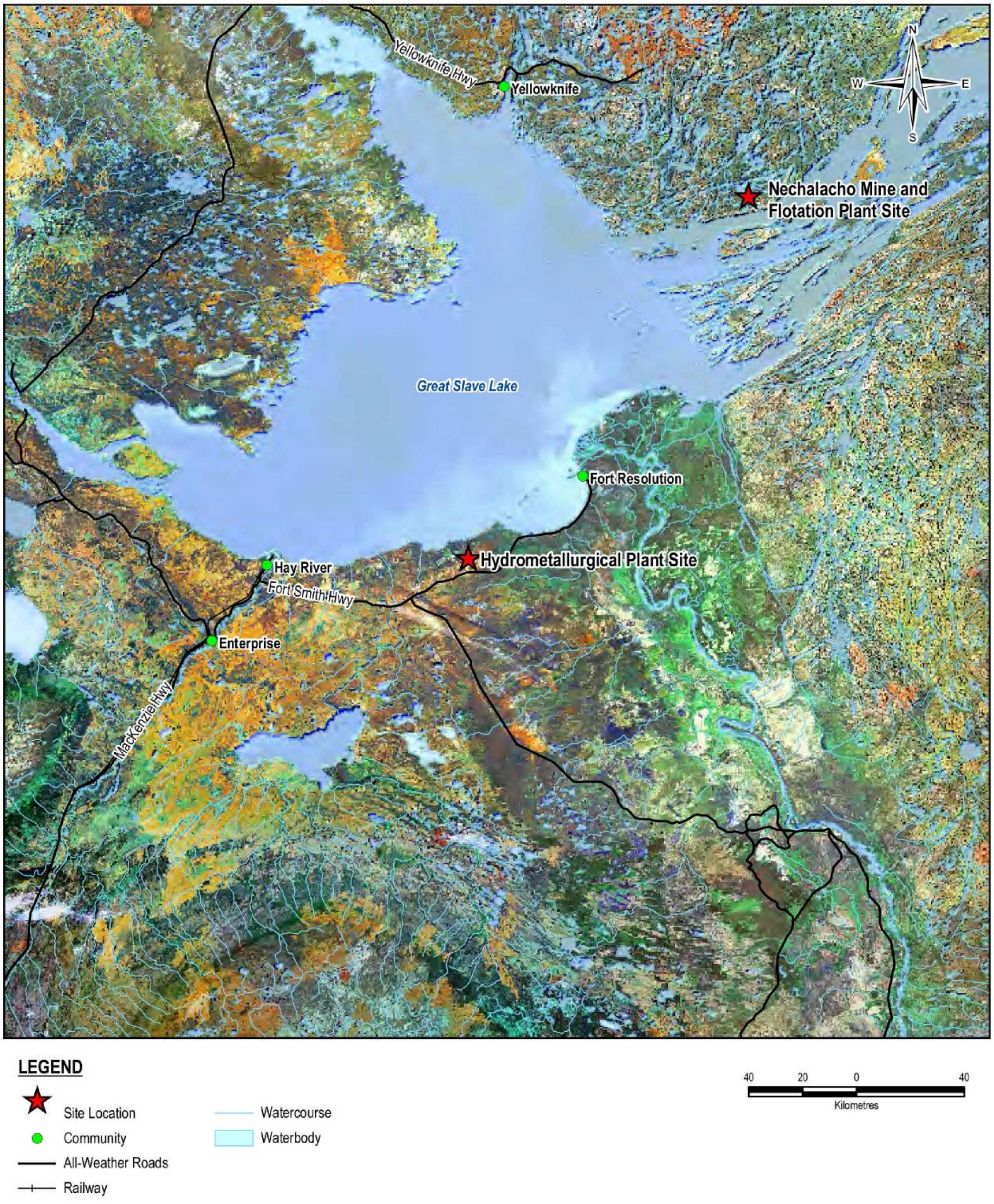
The Nechalacho Mine is located on Thor Lake, 5 km from the northern shore of the Hearne Channel, in the East Arm of Great Slave Lake. 100% owned by Avalon, the property is within the Mackenzie Mining District, approximately 100km southeast of Yellowknife, 100 km southwest of Lutsel K'e, and 225 km northeast of Hay River. The Thor Lake Property hosts a total of six metal bearing mineral deposits, with the Nechalacho deposit the largest covering an approximate area of two square kilometres (Avalon, 2010a). The Property is shown on National Topographic System (NTS) map sheet 85I02 at approximately 62°06'30''N 112°35'30''W. The materials mined in the Nechalacho Mine will be processed into Rare Earth Element (REE) concentrate on-site in the Flotation Plant using conventional grinding, crushing, and flotation techniques. The concentrate is to be shipped by barge to the Hydrometallurgical Plant Site for further processing.

In addition to the rare earth metals and a number of other metals such as niobium, zirconium and tantalum, the Thor Lake ore also contains naturally occurring radioactive material (NORM). The NORM consists of naturally occurring uranium and thorium and associated radioactive decay products. NORM is ubiquitous and is present in all rocks and soils throughout the earth in highly varying concentrations, especially in areas of mineralization, but background concentrations are typically in the order 1 to 10 parts per million (ppm) (e.g. UNSCEAR 2000, U.S. NCRP 1987). The uranium and thorium concentrations in the Thor Lake ore are on average approximately 24 ppm and 130 ppm, respectively, or above typical background levels. For perspective, the uranium concentration at a low grade uranium mine (0.1% grade) is about 1000 ppm.

The Hydrometallurgical Plant Site is situated at the former Pine Point Lead/Zinc mine, approximately 165 km southwest of the Nechalacho Mine and 11 km south of the southern shore of Great Slave Lake. The now decommissioned lead/zinc mine is a brownfield site, and as such was determined to offer the most environmentally and financially viable location for ore processing. Following processing of the Nechalacho Mine ore at the Hydrometallurgical Plant site, the final product will be shipped by rail to southern markets. Centre point coordinates for the site are 60^{o} 53’ 20.1”N 114^{o} 23’ 14.5”W within NTS map sheet 85B16.

Figure 1.1 below provides an overview of the location of the Nechalacho Mine/Flotation Plant and the Hydrometallurgical Plant.

Figure 1.1 Thor Lake Project Sites



Source: Map adapted from Avalon Rare Metals Inc., Figure 1.0-1, April 2010

1.2 REPORT OVERVIEW

The purpose of this report is to identify potential radiological issues associated with mining and processing of the Thor Lake ore arising from the natural radioactivity in the ore (NORM), and to provide a perspective on the magnitude and significance of potential radiation exposures that could possibly result from the activities undertaken in the proposed TLP.

Potential radiation exposures could occur through the inhalation or inadvertent ingestion of various NORM materials, or via exposure to radon gas that is emitted from any uranium-bearing materials. External (to the body) gamma radiation that is emitted from radioactive materials would also be a potential exposure pathway. To help put these exposures in context, regulations relevant to the NORM are also discussed, including potentially applicable regulations for the off-site transport of radioactive materials. An approach to the development of any radiation protection protocols that might be required at the proposed TLP is also provided.

To provide the information noted above, the remainder of this report is subdivided according to the following chapters:

- Chapter 2 – Project Description – outlines the various activities at the proposed TLP and qualitatively identifies potential radiological concerns associated with each activity, from mining and milling through to waste management.
- Chapter 3 – Regulatory Considerations – presents regulations of the Northwest Territories and other jurisdictions and agencies that relate to the NORM. The Canadian guidelines for the management of NORM are also discussed.
- Chapter 4 – Radiation Protection – addresses the potential magnitude of radiation exposures to some workers at the proposed TLP by providing illustrative estimates of doses through various exposure pathways. Radiation management protocols that could be used at various project activities to control and limit exposures are presented.
- Chapter 5 – Summary and Discussion – summarizes the major findings of the report.
- Chapter 6 – References.
- Appendix A – Radiological Issues at Other NORM Facilities – provides a brief overview of the experience at other mineral/rare earth mining and processing facilities in different parts of the world. The major exposure pathways and resultant radiation doses measured are outlined and discussed.

At the outset, because the subject matter of this report is possibly new to some readers, a brief description of some radiological terms is presented in Section 1.3 to assist those unfamiliar with the concepts of radiation and radioactivity. A glossary of primarily radiological terms is also included in this report.

1.3 NATURAL RADIATION AND RADIOACTIVITY

Types of Radiation

There are basically three types of radiation that are emitted from the naturally occurring radioactivity present in all rocks and soils: alpha, beta and gamma. Alpha radiation consists of particles (helium nuclei) that are readily stopped in air or by a sheet of paper. Beta radiation consists of smaller particles (electrons) that travel further in air, but are readily stopped by 1-2 cm of water or by the surface of the body. Gamma radiation is a form of electromagnetic radiation, such as light or radiowaves, and is more penetrating than either alpha or beta radiation. Gamma radiation can be stopped by lead, concrete or suitable thicknesses of soil and comparable materials. Alpha and beta radiation emitters are usually only of concern when they are taken into the body by inhalation or ingestion (internal radiation), while gamma radiation can also be a hazard when outside the body (external radiation). Figure 1.2 illustrates the penetrating power of alpha, beta and gamma radiation.

Radioactive Decay Series

Uranium and thorium are naturally occurring radioactive elements that are widely distributed on earth and are major constituents of NORM. Natural uranium (i.e., uranium with its natural isotopic abundances) consists principally of uranium-238 and uranium-234 in one radioactive decay series headed by U-238 and uranium-235 in another, independent radioactive decay series. [Because of its low abundance in natural uranium, the U-235 series is not usually considered under normal circumstances to be radiologically significant relative to the U-238 series (e.g. Lowe 1997).] On an atomic mass basis, the natural abundances of the uranium radionuclides are U-238 (97.2745%), U-234 (0.0055%) and U-235 (0.72%) (Rosman and Taylor 1998). On a radioactivity basis (nuclear disintegrations per second), the radioactivity of U-235 in natural uranium is 4.6% of the radioactivity of U-238.

Through the radioactive decay of uranium-238 with the emission of alpha, beta and gamma radiation, a series of 14 different radionuclides (including U-234) is formed until stable, non-radioactive lead-206 is reached (Figure 1.3).

Figure 1.2 Penetrating Power of Radiation

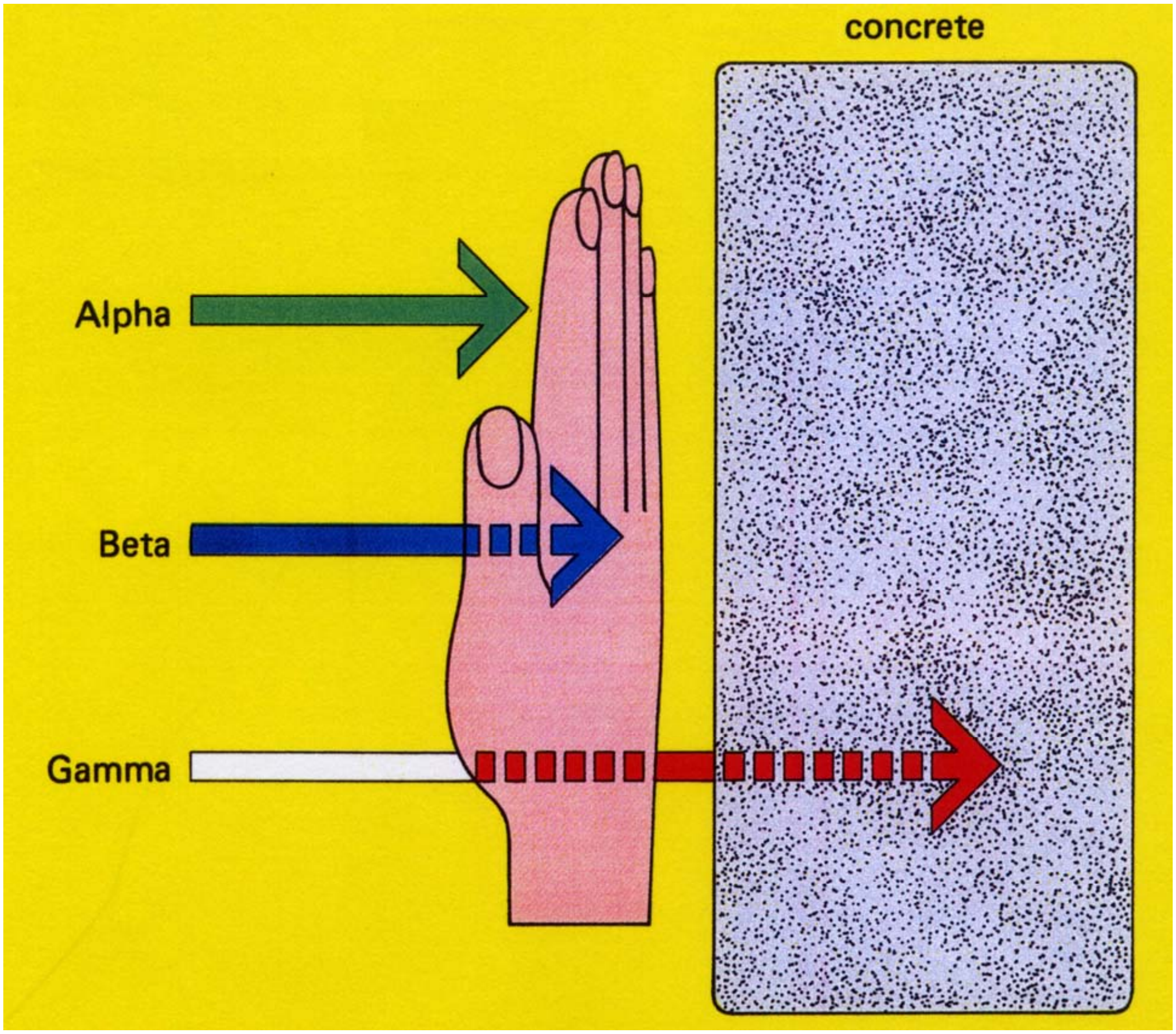
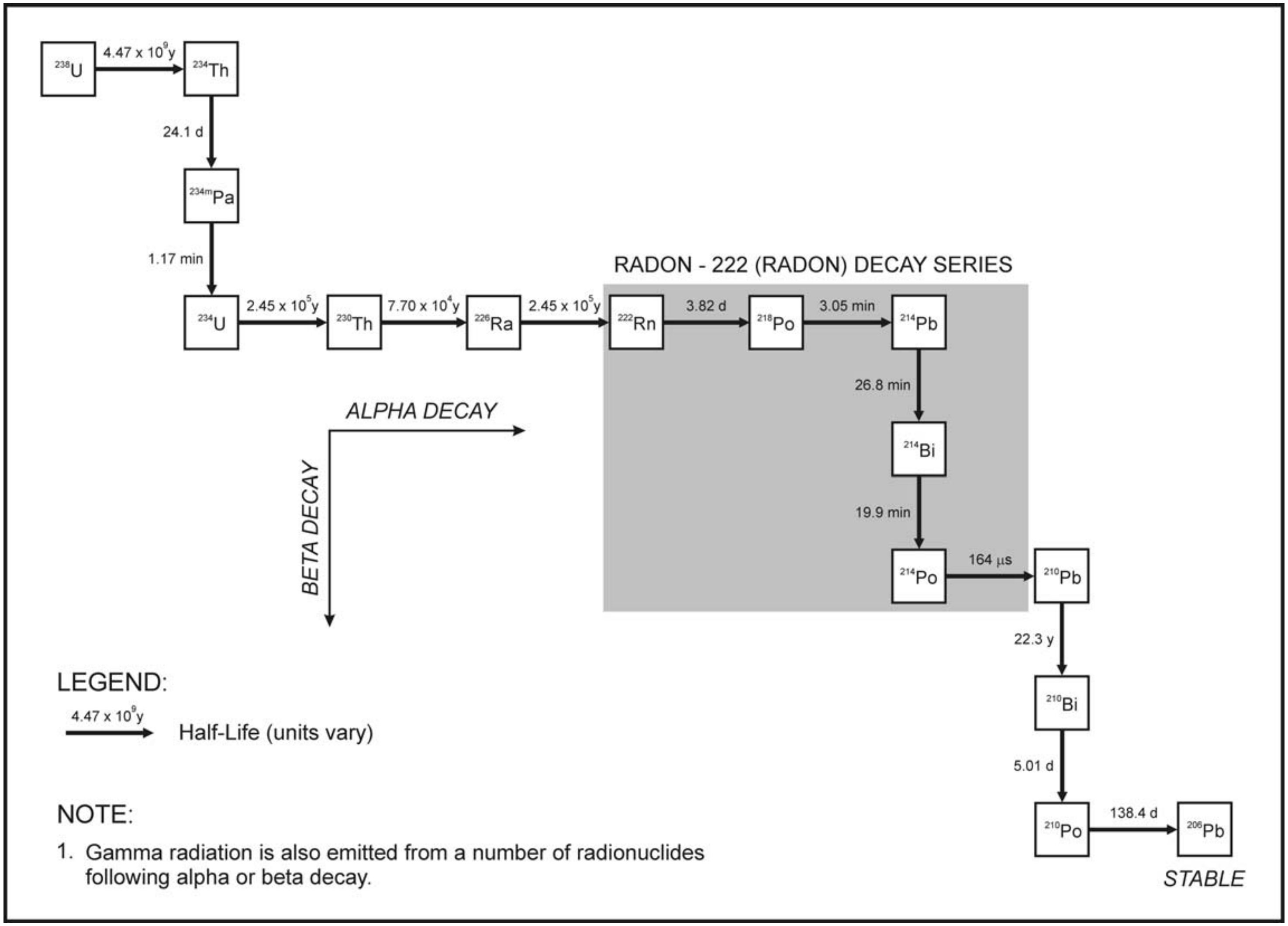


Figure 1.3 The Uranium-238 Decay Series



One important member of the U-238 decay series is radon-222 (radon), which is a gas. It is chemically inert (non-reactive) and if it is formed near the surface of material containing radium-226 (radium), it is free to diffuse and enter the atmosphere. Since all soils contain some uranium and radium, our atmosphere and our homes contain radon. In fact, indoor radon (and its short-lived decay products) causes most of the exposure we receive from background radiation. Because of normal atmospheric dispersion, radon exposure outdoors is not a concern. Similarly, because of the typical high air exchange rates (ventilation) in industrial facilities, radon exposures are usually not an occupational concern in industries associated with NORM. However, radon exposures in underground mining and in enclosed areas can be an issue if appropriate ventilation is not provided.

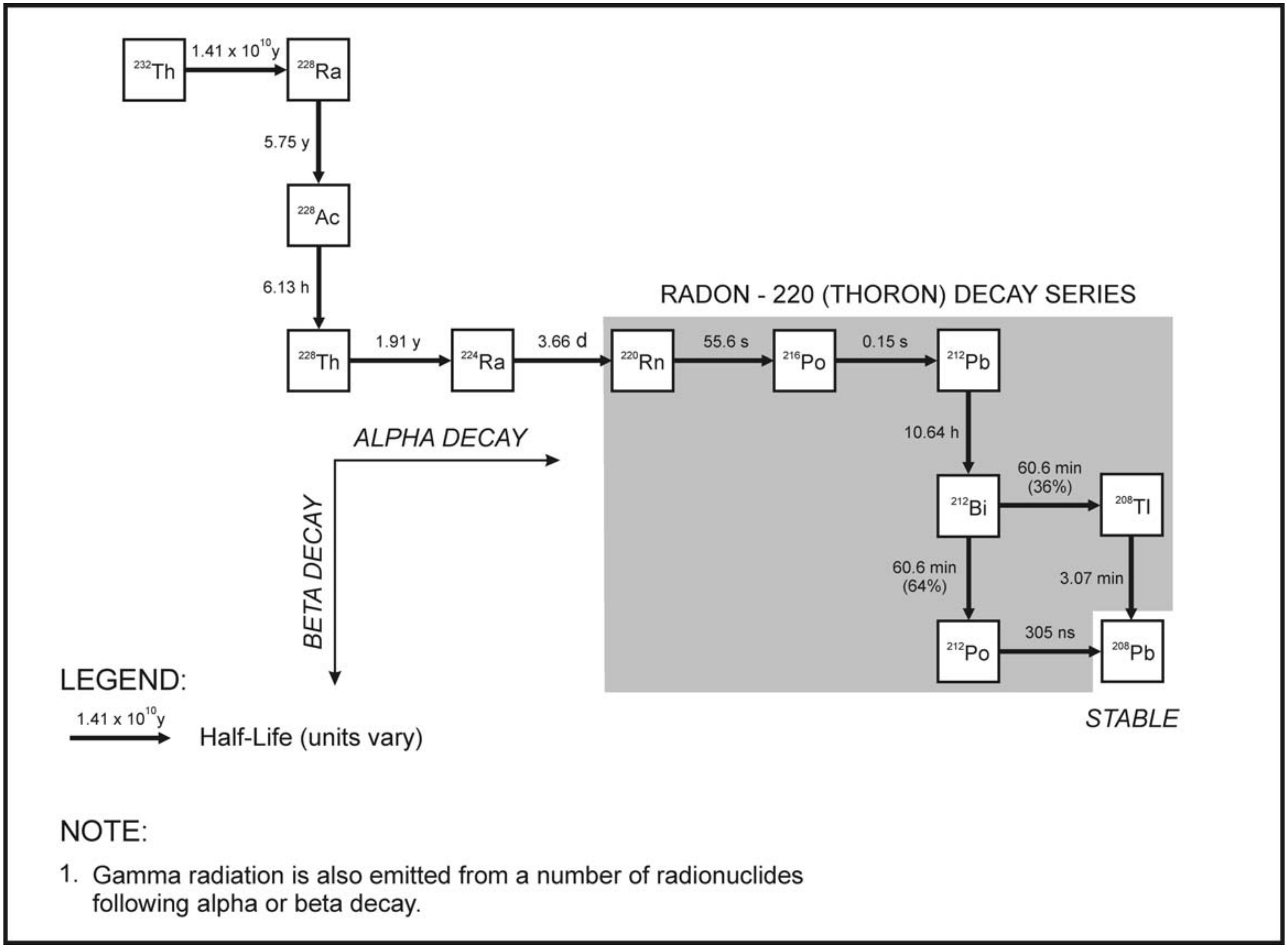
Similar to natural uranium, natural thorium consists of a radioactive decay series, in this case headed by Th-232 (Figure 1.4). There are 11 radionuclides in the series that emit alpha, beta and gamma radiation and end in stable, non-radioactive lead-208. Because of the very long half-life of Th-232 relative to other radionuclides in the Th-232 decay series, essentially 100% of the mass of natural thorium is Th-232. Similar to the U-238 series, another isotope of radon, Rn-220 or thoron by its historical name, is released from thorium-bearing materials. However because of its short half-life (55 s), thoron is not usually considered an occupational or environmental concern.

Radiation Units

The unit used in the International System of Units (SI) (commonly called the “metric” system) to represent the activity of a radionuclide is the becquerel (Bq) which equals one nuclear disintegration per second. There is a direct relationship between the mass and the radioactivity of a radionuclide, which is called its “specific activity”. The specific activity is determined by the half-life of the radionuclide and is expressed in becquerels per gram (Bq/g). In particular, a concentration of 1 ppm of natural uranium (U-nat) corresponds to 0.01235 Bq of U-238 per gram. A concentration of 1 ppm of natural thorium (Th-nat), which has a half-life about three times longer than U-238, corresponds to 0.00406 Bq of Th-232 per gram. Under conditions of radioactive equilibrium, which is common for most rocks and soils, all the radionuclides in the U-238 series will have the same radioactivity (Bq/g) as that of U-238; similarly, all the radionuclides in the Th-232 series will have the same radioactivity (Bq/g) as that of Th-232 (except for Po-212 and Tl-208 at 64% and 36%, respectively, the radioactivity of Th-232 – see Figure 1.4).

The SI unit of dose to humans is the sievert (Sv) or millisievert (mSv, 10^{-3} Sv). The potential risks of radiation exposure are considered to be proportional to the dose measured in Sv or mSv.

Figure 1.4 The Thorium-232 Decay Series



Background Radiation Levels

People have always been subjected to natural background radiation. (In the present context, "radiation" is assumed to mean ionizing radiation, as opposed to microwaves, radiowaves, ultraviolet radiation and other forms of non-ionizing radiation.) People are exposed to radiation from the sun and outer space. Naturally occurring radioactive materials are present in the earth, in the houses we live in and in the buildings where we work, as well as the food and drink we consume. There are radioactive aerosols and gases in the air we breathe and even our own bodies contain naturally occurring radioactive elements. The level of this inescapable natural "background" radiation exposure varies greatly from place to place. Typical background rocks and soil contain in the order of 1 to 10 ppm each of uranium and thorium although much higher concentrations, especially in areas of mineralization, are not uncommon (UNSCEAR 2000, U.S. NCRP 1987).

People are also exposed to sources of radiation that we ourselves create. X-rays and other kinds of radiation used for medical purposes, fall-out from past nuclear weapons tests and the small quantities of radioactive materials that are allowed to escape to the environment in the course of normal operation of nuclear installations are some examples.

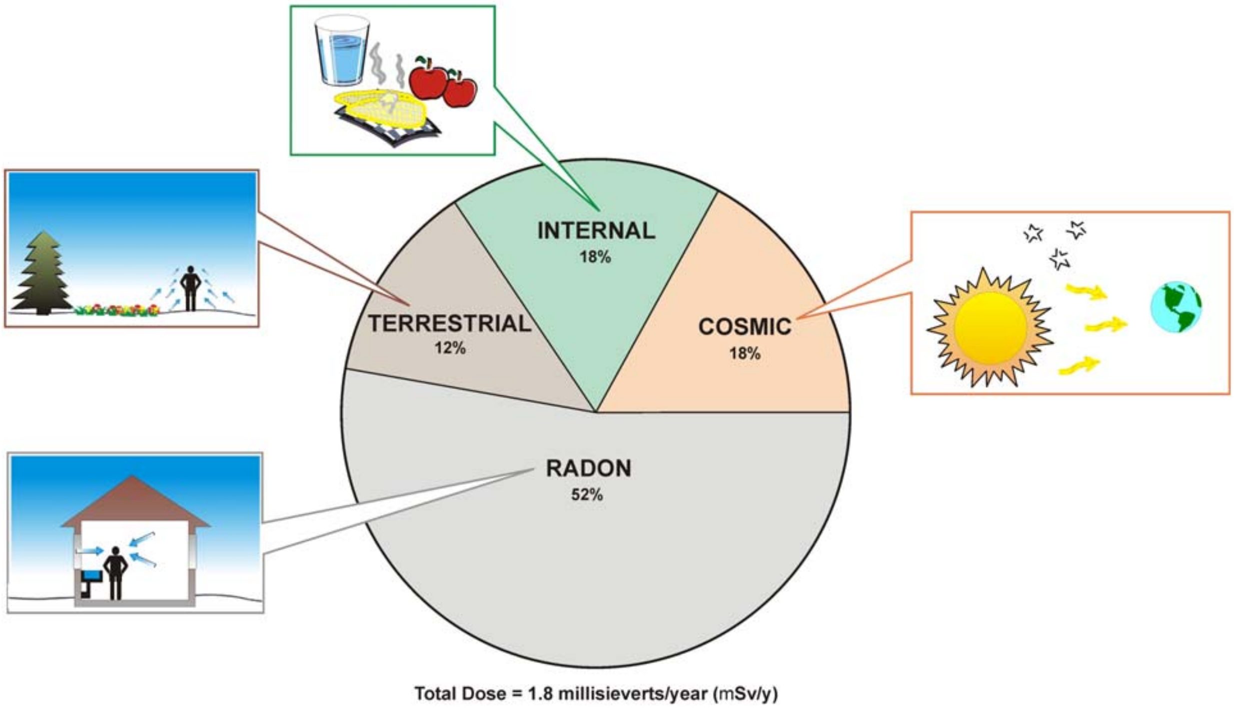
Natural background radiation typically results in a dose rate of about 2 to 3 mSv per year (UNSCEAR 2000), although some places in the world experience much higher exposure rates, i.e. 10 mSv per year and higher. According to Grasty and LaMarre (2004), the average annual exposure from natural background radiation in Canada is as shown in Table 1.1 and Figure 1.5. Exposure to radon, primarily indoors, is responsible for about 50% of the dose from background radiation. Grasty and Lamarre (2004) also indicate that the average dose varies from place to place in Canada depending on factors such as the radioactivity in local soils and rocks. For example, annual doses are about 1.5 mSv/y for someone who lives in Toronto and about 4 mSv/y for someone who lives in Winnipeg, with the difference being primarily due to indoor radon.

Table 1.1 Exposures to Natural Background Radiation

Source of Exposure	Average in Canada (mSv/y)[a]
cosmic radiation	0.32
internal radiation	0.31
inhalation (primarily radon)	0.93
external	0.22
Total	1.8

a. Grasty and LaMarre (2004).

Figure 1.5 Natural Background Radiation in Canada



Radiation dose limits recommended by the International Commission on Radiological Protection (ICRP), which form the basis for radiation protection guidance in most countries, including Canada, are 20 mSv per year for radiation workers (averaged over five years with a maximum in any one year of 50 mSv) and 1 mSv per year for members of the general population (most recently updated in ICRP Publication 103, 2007). These limits are exclusive of the radiation doses from natural background and medical exposures. These limits are promulgated in Canada by the Canadian Nuclear Safety Commission (CNSC) under the Nuclear Safety and Control Act but the CNSC regulations do not apply to NORM that is not associated with nuclear energy. However, identical guidelines for non-radiation workers and member of the public exposed to NORM have been recommended for use in Canada (Health Canada 2000). The Canadian NORM Guidelines were prepared by the Canadian NORM Working Group of the Federal Provincial Territorial Radiation Protection Committee. Therefore, although not legally binding, the Canadian NORM Guidelines are accepted by the provinces and the Northwest Territories.

1.4 RADIOLOGICAL ISSUES AT OTHER RARE EARTH FACILITIES

Naturally Occurring Radioactive Material (NORM) is present in many resource-based industries throughout the world. These include the oil and gas industry, phosphate fertilizer facilities, aluminum wastes, gold and silver mining, and titanium production wastes, to name a few, as well as rare earth facilities (e.g., UNSCEAR 2000, U.S. NCRP 1993, IAEA 2006). The potential radiological issues at the Thor Lake Project (TLP) are not unique. Appendix A provides an overview of some of this experience at other mineral/rare earth mining and processing facilities in different parts of the world. The major exposure pathways and resultant radiation doses measured are briefly discussed. The potential radiation exposures are dependent on the NORM concentrations in the ore and processed materials, and increase with increasing levels of radioactivity. Potential exposures to workers at the proposed TLP are estimated in later sections of this report. In general, recognition of potential radiological issues combined with normal, good industrial hygiene practices have been shown to keep exposures to well within safe levels. Monitoring is performed to confirm that worker exposures to radiation and radioactivity are maintained within recommended limits.

2.0 PROJECT DESCRIPTION

2.1 Overview of Thor Lake Project

Avalon proposes to mine, mill and process rare earth oxides, zirconium, niobium and tantalum oxides from the Nechalacho deposit, located on its Thor Lake property. The Thor Lake Project spans about 20 years, with an estimated 14 million tons of indicated resources to be mined from the Nechalacho deposit alone.

The proposed schedule for major tasks at the Nechalacho Mine/Flotation plant and at the Hydrometallurgical Plant site are provided below (Table 2.1), with the subsequent sections presenting detailed descriptions of infrastructure and activities at the two sites.

Table 2.1 Thor Lake Project Schedule

Activity	Years (2010-2032)																					
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Regulatory Review and Approvals																						
Construction																						
Operations																						
Closure and Reclamation																						

Source: Project Description Report (Avalon, 2010a)

2.1.1 Nechalacho Mine and Flotation Plant Site (Thor Lake Area)

The following section is a summary of the Thor Lake Project as provided within the Project Description Report and draft Developers Assessment Report (Avalon 2010a, 2011a). Figure 2.1 below displays the proposed location of site infrastructure within the Thor Lake property.

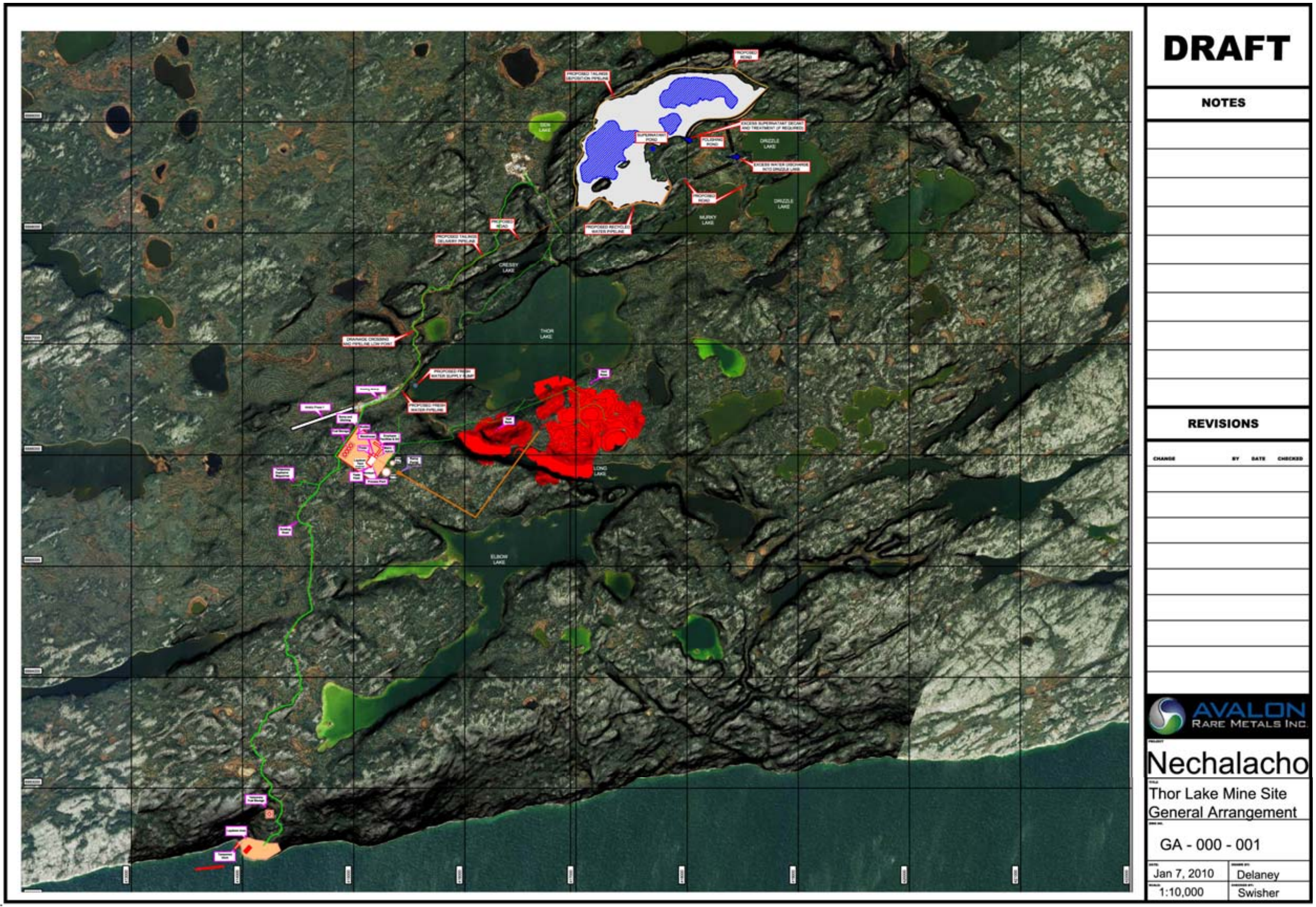
The Nechalacho Mine is a remote site with no road access, and may be reached by boat, helicopter, snowmobile, or plane (float or skis, and wheels with completion of a 300 metre runway).

- *Underground Operations*: The Nechalacho Deposit will be mined underground to an anticipated depth of 200m, using a 1,600 m long decline ramp (15% ramp grade) to access the ore zone. Waste rock generation will be used as surface construction fill, dam construction material for the tailings management facility, extension of the existing 300 metre runway to 1000 metres and existing roadway upgrades. Upon the initiation of normal operating conditions, approximately 2,000 tonnes per day (tpd) of ore will be extracted from the mine, with the underground circuit including screening, primary, secondary and tertiary crushing. The ore will be conveyed from the fine ore bin to the Flotation Plant, and a misting system used to wet the ore material during crushing and surface transport (Avalon, personal communication). Waste rock generated during mining is projected to be minimal, and will be transferred to the open stopes for combination with paste backfill. The Mine ventilation will consist of a fresh air fan atop the fresh air intake raise located to the northeast of the ore body. The intake system will include the mine air fans and direct fired fuel oil air heaters. Compressed air will be fed to the underground operations from a bank of primary compressors located inside the Flotation Plant building.

- *Flotation Plant*: The Flotation Plant will process the ore using traditional methods of ore concentration, incorporating: rod mill/ball mill grinding, desliming, magnetic separation, rougher/cleaner flotation to recover a flotation concentrate gravity separation including gravity tails regrind, thickening, and pressure filtration of the gravity concentrate. Processing approximately 2,000 tpd of ore, it is expected the flotation plant will produce 360 tpd of concentrate. Concentrate will be barged off-site for further processing at the Hydrometallurgical Plant and tailings will be discharged to the tailings management facility and, starting in year five, used as paste backfill.
- *Tailings Management Facility*: A total of 3.5 to 4 million tonnes of tailings are expected be discharged to the Nechalacho Mine Tailings Management Facility during mining operations. The TMA will be located up slope from the Flotation Plant and northeast of Thor Lake, within the local catchment of Ring and Buck lakes. The tailings will be discharged to a number of locations around the perimeter of the facility, developing a relatively flat tailings beach and centralized supernatant pond to maximize tailings storage efficiency. Discharge from the supernatant pond is first treated in a polishing pond and then naturally fed into Thor Lake via Drizzle and Murky Lakes.
- *Dock and Concentrate Transport*: Concentrate is to be containerized into half-height intermodal containers, and transported from the Flotation Plant to the dock area for barging to the Hydrometallurgical Plant, or for winter storage in a designated stacking area to be located near the dock facility. During the seasonal barging season, a single low-keel barge secured to the shoreline will be used as a seasonal dock facility with a low angle ramp for loading and offloading. To avoid permanent dock facilities or damage from freezing, the low-keel barge will be returned to the barging company and the access ramp will be stored onshore during winter.
- *Airstrip*: Constructed in the summer of 2010, the airstrip will be extended to a total length of 1000 m, permitting larger aircraft (e.g. Dash 8 and Buffalo), and will serve as the primary transport mechanism for employees.

- *Roadways*: Access roads throughout the mine area, and leading to the dock area, will be upgraded for transport of concentrate, supplies, and staff. These roadways are expected to be composed of aggregate (likely wasterock).
- *Power and Fuel*: Power requirements for the Nechalacho Mine and Flotation Plant are estimated to be an average of 8.4 MW during full production. Owing to the remote nature of the site, all power generation is to be by diesel powered generators. Fuel will be shipped to the site from sources on the southern shore of Great Slave Lake, and transferred to an approved fuel storage facility with a 4.5 ML capacity. Distribution throughout the Nechalacho Mine will be by fuel truck.
- *Camp*: Camp facilities are planned to support staff of approximately 150. The camp is currently planned to be located beside the Flotation Plant and near to the airstrip. The mine is expected to operate on a 24/7 schedule throughout the year with individual employees working a 12 hour shifts on a 1 week in/1 week out rotation.
- *Water Supply*: Fresh and process water for camp and mine purposes will be supplied from Thor Lake. Tailings water will pass from the tailings management facility (TMF), to the polishing ponds, Drizzle and Murky Lakes and finally back into Thor Lake. A system of valves and pumps is planned to permit water management within the lakes.

Figure 2.1 Proposed Nechalacho Mine/Flotation Plant Site



2.1.2 Hydrometallurgical Plant Site

The proposed Hydrometallurgical Plant will further process the REE concentrates produced at the Nechalacho Mine/Flotation Plant site. The Hydrometallurgical Plant will be located at the former Pine Point Mine, now classified as a brownfield site. Pine Point Mine was a large scale lead-zinc mine operating from 1964 to 1986. The operation was largely open-pit, with approximately 40 pits mined during the project lifespan. A railway was constructed from Alberta, in addition to a town site to support approximately 1,200 workers. The Pine Point Abandonment and Remediation Plan was completed in 1991, including the removal of the townsite and railway (GNWT 2007), however, the site is still accessible by a maintained four-season Territorial roadway and transport of concentrate would be by road.

The following section is a summary of the Thor Lake Project Hydrometallurgical Plant Site provided within the Project Description Report and draft Developers Assessment Report (Avalon 2010a and 2011a), the Updated Development Description for Avalon's Proposed Hydrometallurgical Plant Tailings Management Facility at Pine Point (Knight Piésold 2011a), and the Hydrometallurgical Plant Tailings Management Facility Clarification Memorandum (Knight Piésold 2011b). The proposed plan is graphically displayed in Figure 2.2 below.

Hydrometallurgical Plant

The proposed Hydrometallurgical Plant will further process the REE concentrates from the Nechalacho Mine and Flotation Plant. The process will include a thaw shed and dump system, sulphuric acid plant, acid baking, water washing, filtration, bulk concentrate loadout, neutralization, product drying and mixed light rare earth packaging facilities to produce direct ship products to Avalon's separation plant.

Water Supply

Potable and process water will be obtained from an existing nearby open pit lake known as T-37N and treated on-site as necessary for its intended uses.

Hydrometallurgical Tailings Facility

The proposed hydrometallurgical tailings facility will be an engineered facility located 2.5 kilometres south of the proposed plant in an existing historic open pit (L-37) which remains from the historic Pine Point Mines mining operation. Using this location presents significant environmental and operational benefits for the overall Project. Any water decanted from the tailings facility will be discharged in compliance with MVLWB Water License discharge criteria into an adjacent existing historic open pit (N-42) which is located 1.5 kilometres southwest of the L-37 pit.

Figure 2.2 Proposed Hydrometallurgical Plant Site

Concentrate Storage and Loading

Upon arrival at the Hydrometallurgical Plant, the concentrate storage containers will be unloaded from the trucks and placed into a secure storage area. As required, the containers will be moved into a heated thaw shed. Once in the thaw shed, the concentrate will be removed from the containers. The containers will be cleaned prior to shipment back to the Nechalacho Mine.

Power Supply

Average power consumption for the Hydrometallurgical Plant during start-up and throughout the life of operations is estimated at 3.0 MW demand. This power will be provided through the existing Northwest Territories Hydro Corporation (NTHC) power grid and substation located at the former Pine Point Mine site. Due to the Taltson dam's inability to provide guaranteed and continuous supply, additional diesel generation of 1.3 MW will be required for backup and safety control systems only.

Limestone Storage

The limestone used to neutralize the Hydrometallurgical Plant's waste stream prior to discharge to the tailings management facility will be obtained from local supply sources and stockpiled in a designated area that is in close proximity to the Hydrometallurgical Plant. Because the limestone is a neutralizing product, no special stockpile considerations will be necessary.

Haul Road

An existing access road remaining from historical mine activities will be upgraded to safely transport the concentrate offloaded from barges on the south shore of Great Slave Lake to the Hydrometallurgical Plant located at the former Pine Point Mine site. The haul road will be approximately 8.6 km long. It will be aligned directly north-south along an existing drainage ditch for approximately 4.9 km prior to connecting to an existing haul road from a former mine pit located north of the main Pine Point Mine area.

Dock Facility

A seasonal dock facility consisting of two low keel barges connected together to create a temporary floating dock and a marshalling yard will be installed on the south shore of Great Slave Lake approximately 8.6 km from the Hydrometallurgical Plant. The seasonal dock facility will permit the berthing and offloading of Thor Lake REE concentrates onto flatbed trucks for transportation to the Hydrometallurgical Plant. This facility will also be used for the annual shipment of major mining consumables, including fuel, to the Nechalacho Mine site.

Product Transportation to Railhead

The Hydrometallurgical Plant will produce approximately 418 tpd of concentrate and light rare earth products. The concentrate not processed makes up 330 tpd while the light rare earth produced is 88 tpd. Both concentrate and light rare earth products will be dried to approximately 10-12% moisture content and prepared for shipment to Avalon's separation plant. The value of the products will be very high.

- Concentrate residue from the acid bake process will be dried and loaded into 20 tonne trucks and pub trailers with covers for direct shipment to the railhead facilities operated by CN rail. The final light rare earth products will be packaged in either sealed drums or sealed bulk bags for shipment to ensure that product is not lost during the handling and/or transportation process. The packaged products will be hauled 85 km from the Hydrometallurgical Plant to the Hay River railhead on flatbed trucks. Truck shipments are expected to occur daily during one twelve hour shift. The concentrates and rare earth products will be direct-shipped south from the railhead to Avalon's separation plant.
- *Accommodations*: The Hydrometallurgical Plant is scheduled to operate on a schedule of 351 days per year, 24 hours per day, 7 days per week, and with an annual 14 day maintenance shut-down. Staffing requirements are estimated to be 100-200 during construction, and 88 during Plant operation. Workers will be bussed daily from either Hay River or Fort Resolution, and thus no camp facilities are required.

2.1.3 Barging

Concentrate extracted and processed at the Nechalacho Mine/Flotation Plant is to be transported by barge 165 km southwest to the Hydrometallurgical Plant. Barges will also be required to transport the consumables and fuel required at the remote Nechalacho Mine site.

Barging activities are projected to occur over a 60 day period during the normal 120 day summer barge season, with all barging limited to periods of open water. Upon arrival at the Nechalacho Mine, fuel will be offloaded to an upland fuel storage facility near to Great Slave Lake, for subsequent transfer by tanker truck to the main fuel storage facility (adjacent to the diesel generator at Thor Lake). Consumables for the mine (e.g. food) as well as mine equipment will also be transferred by barge (Avalon 2010a).

The concentrate from the Nechalacho Mine/Flotation Plant will be barged to the seasonal Hydrometallurgical Plant dock facility in enclosed 40 tonne intermodal containers. Each barge may haul up to about 40 containers (a total of 1710 tonnes) of concentrate, indicating a total of 78 barge trips are required each year to transport the concentrate produced. The projected barge schedule will involve the operation of two tugs, with each tug towing three barges. Assuming a two day round trip, 60 days will be required to complete the ore shipments each summer (Avalon 2010b).

The concentrate will be unloaded from the barges and trucked 8.6 km to a secure storage area located on the west side of the Hydrometallurgical Plant. Once in the thaw shed, the concentrate will be removed from the containers and transferred to the Hydrometallurgical Plant and the empty containers will be cleaned for barging back to the Nechalacho Mine/ Flotation Plant site (Avalon 2010a).

2.2 PROCESS FLOW

The Thor Lake Project may be roughly categorized into three ore processing activities: underground ore mining and crushing at the Nechalacho Mine, flotation at the Thor Lake Flotation Plant, and final concentration at the Hydrometallurgical Plant on the southern shore of Great Slave Lake. The following sections detail the processes involved in each stage of the operation, as extracted from the draft Developers Assessment Report (Avalon 2011a).

2.2.1 Nechalacho Mine Process Flow

The majority of the Nechalacho deposit's Mineral Resources are located directly beneath and to the north of Long Lake, approximately 200 m below surface. The deposit will be accessed via a decline ramp collared to the southwest of Long Lake. The main access decline ramp will be driven from a location near the Flotation Plant at a grade of -15% and will be approximately 1,600 m in length. The development decline ramp and stope access headings will be driven as 5 m by 6 m headings and decline ramp grades will be approximately 15%.

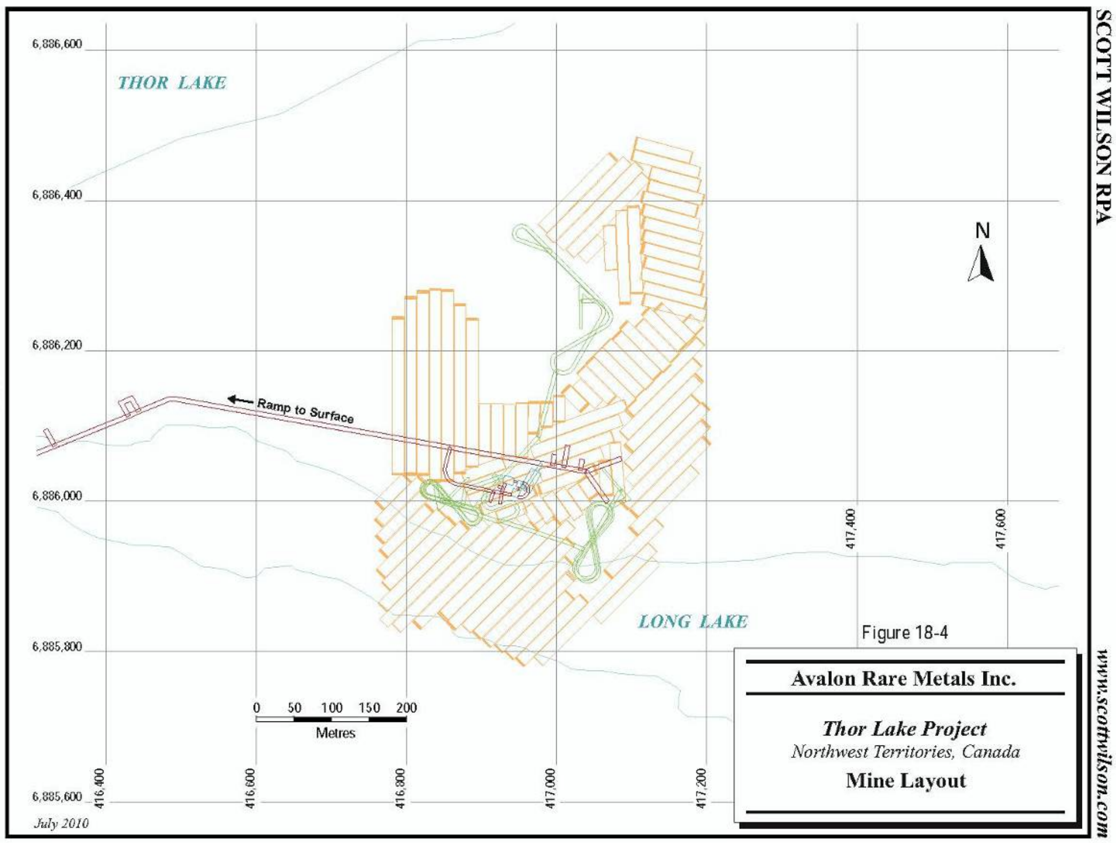
Mining Method
The Nechalacho Mine plan will utilize underground methods to access the higher grade resources at the base of the deposit and to minimize surface disturbance. Ground conditions have been studied and identified as being very competent. In light of the high value of the resources in the Basal Zone, the use of backfill is planned beginning in year five of operations.

Mining will be conducted with a first pass of primary stopes, followed by pillar extraction after the primary stopes have been backfilled. The primary stopes are expected to be stable at widths of up to 15 metres. Only primary stopes will be mined in the first 4 years in a retreat type fashion with stope lengths up to 50-75 m long. Due to the expanse of the basal zone, and the ability to leave solid rock support pillars, backfill will not be required until year 5 of operations.

Access to the stopes will be through a single access ramp located outside the Indicated Resource in the Basal Zone. The location of the ramp is shown in Figure 2.3. The access ramp would connect to a centrally located ore pass and two ventilation raises to surface. Mining will be carried out with rubber-tired mechanized equipment to provide maximum flexibility. The modeled Mine design is shown in Figure 2.4 (based on SWRPA prefeasibility study June 2010).

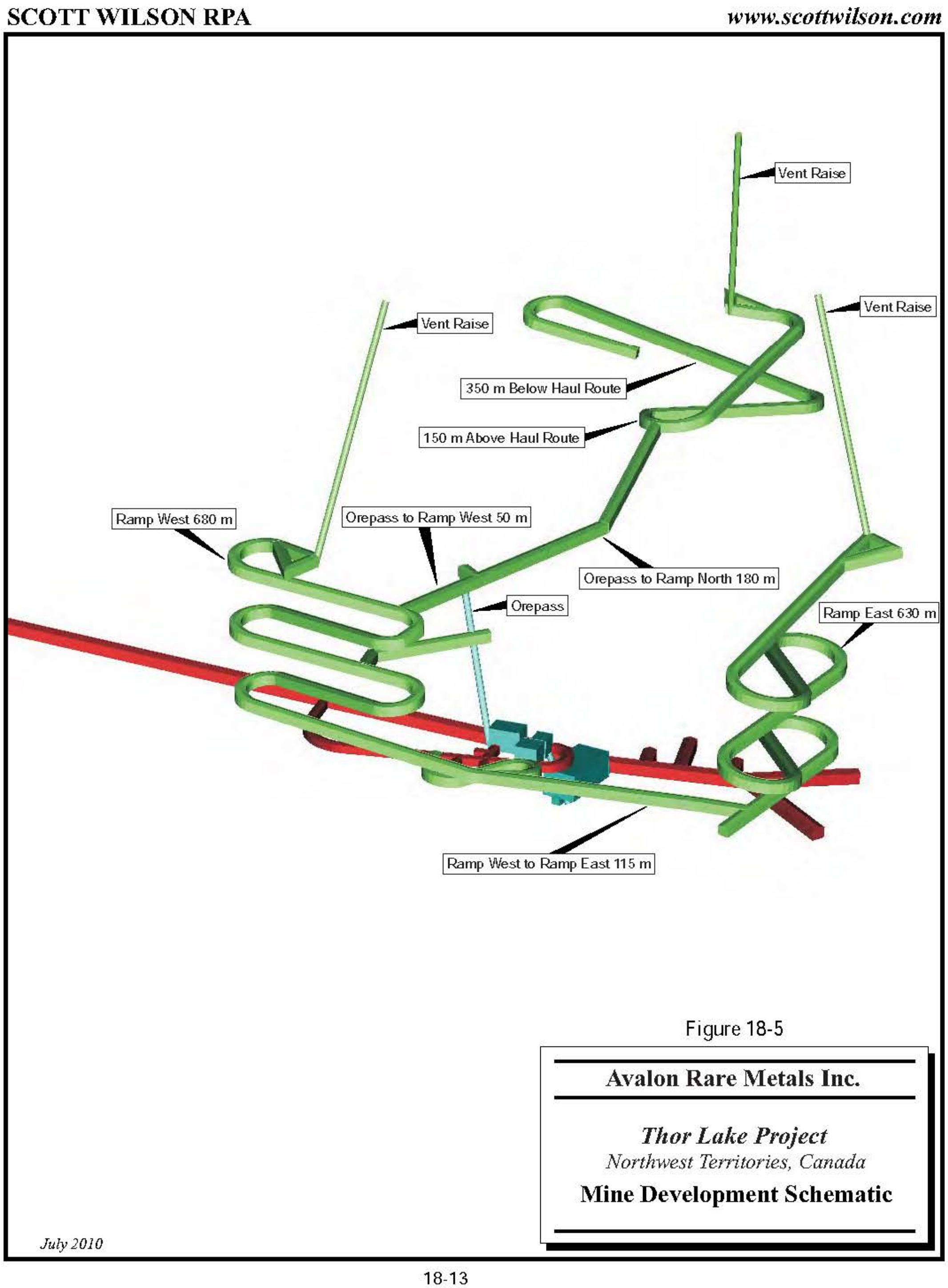
Transport of Ore and Waste
During development, waste and ore materials will be hauled to the surface using underground haul trucks and segregated in a temporary storage area. Once the underground crusher and conveyor are in place, broken rock will be hauled and deposited in an ore pass leading to the underground crushing chamber. The underground crushing circuit will include primary, secondary and tertiary crushing as well as screening. From the crushing plant, the -15 mm fine ore will be stored in a 1,000 tonne fine ore bin excavated in the rock. The ore will be conveyed from the fine ore bin to the Flotation Plant along the main decline access. During operations, waste from ongoing development activities will be diverted to mined stopes for use as fill, combined with planned paste backfill.

Figure 2.3 Nechlacho Mine Layout



Source: SWRPA (2010).

Figure 2.4 Nechalacho Mine Development Schematic



Source: SWRPA (2010).

Temporary Waste and Ore Stockpiles

Decline ramp development activities will generate approximately 400,000 tonnes of waste, plus low grade and ore grade material. This material will be hauled to the surface and segregated in a temporary storage area. Over 375,000 tonnes of waste rock will be used for surface construction activities, specifically for dam building for the tailings management facility, extension of the existing airstrip and road upgrading. The minimal amount of ore produced from development will be temporarily stockpiled on the surface and utilized for the flotation plant feed during start-up operations.

During operations, ore will be stockpiled underground in the 500 tonne ore bin prior to crushing.

Paste Backfill

Paste backfill will be utilized to maximize the extraction recoveries of the higher grade resources in the Basal Zone. It will be distributed via a pipeline installed in the main decline ramp. The paste fill pipeline's location in the main decline ramp will be advantageous because it will be exhaust ventilated, in a warm environment and more accessible for maintenance.

The paste plant will be installed as a component of the Flotation Plant, and will operate as part of the mill operations. The plant will be constructed in year 5 of operations. Once commissioned, it will operate on a continuous basis to progressively fill the voids created by the mined primary stopes and to allow full extraction of secondary stopes. Use of the paste plant will also reduce the mass of tailings placed in the tailings management facility.

Avalon intends to utilize a deep cone thickener during normal operations to increase the amount of reclaim water for processing. This will allow less water to report to the tailings management facility. Because of this, infrastructure required for the pastefill plant is limited to the addition of a pug mill and two silos for cement and fly ash additions.

Mine Services/Supplies

Mine services/supplies include ventilation and Mine air heating, compressed air, electric power, communications, water supply, water discharge, explosives, warning system, primary and secondary escapeways and refuge stations.

2.2.2 Flotation Plant Process Flow

The following description is extracted from the draft Developers Assessment Report (Avalon 2011a).

The Flotation Plant design is based on a throughput of 2,000 tpd, the specified production capacity for the current life of mine.

The Flotation Plant process will be comprised of several unit operations including underground crushing and fine ore storage, delivery of mill feed to a surface Flotation Plant incorporating rod mill/ball mill grinding, desliming, magnetic separation and regrinding to recover coarse non-magnetics, dewatering of flotation feed, rougher/cleaner flotation to recover a flotation concentrate for further processing through gravity separation including gravity tails regrind, thickening, and pressure filtration of the gravity concentrate.

The upgraded concentrate will be shipped off-site for further processing at the Hydrometallurgical Plant and tailings will be discharged to the tailings management facility. A figure drawing of the Plant layout and summary flow sheet are found in Figures 2.5 and 2.6.

Underground Crushing

The crushing circuit, including coarse and fine ore storage facilities, will be located underground in a purpose-built excavation area. Run of mine (ROM) ore will be fed to a 500 tonne coarse ore pocket via a grizzly fitted with a rock breaker. The 700 mm (28") rock will be fed directly to the primary jaw crusher located beneath the coarse ore bin. The discharge from the jaw crusher will be fed to a double deck screen located in a separate screening chamber. The combined undersize and crushed material will then pass through a second vibratory screen in which undersize will by-pass the secondary crusher. A final, tertiary crusher will receive the oversized material from a third vibratory screen that will allow the undersize to by-pass this crusher. The -9 mm (⅜") screened and crushed material will be stored in a fine ore bin where slot feeders will direct the material onto an overhead conveyor for delivery to the Flotation Plant.

The fine ore bin will discharge crushed product via slot feeders to a fine ore transport conveyor suspended from the back of the underground decline ramp. One transfer point approximately half way up the ramp has been included in the underground design. NWT mine regulations require the spraying of all muck piles after each shot therefore, ore reporting to the crushing station will be wet however, water sprays will be used at key points in the crushing station to dampen any dust that may form. Runoff water collected from dust control efforts will be diverted to the main mine sump for eventual reporting to the tailings management facility.

Figure 2.5 Simplified Flotation Plant Layout for 2000 tpd

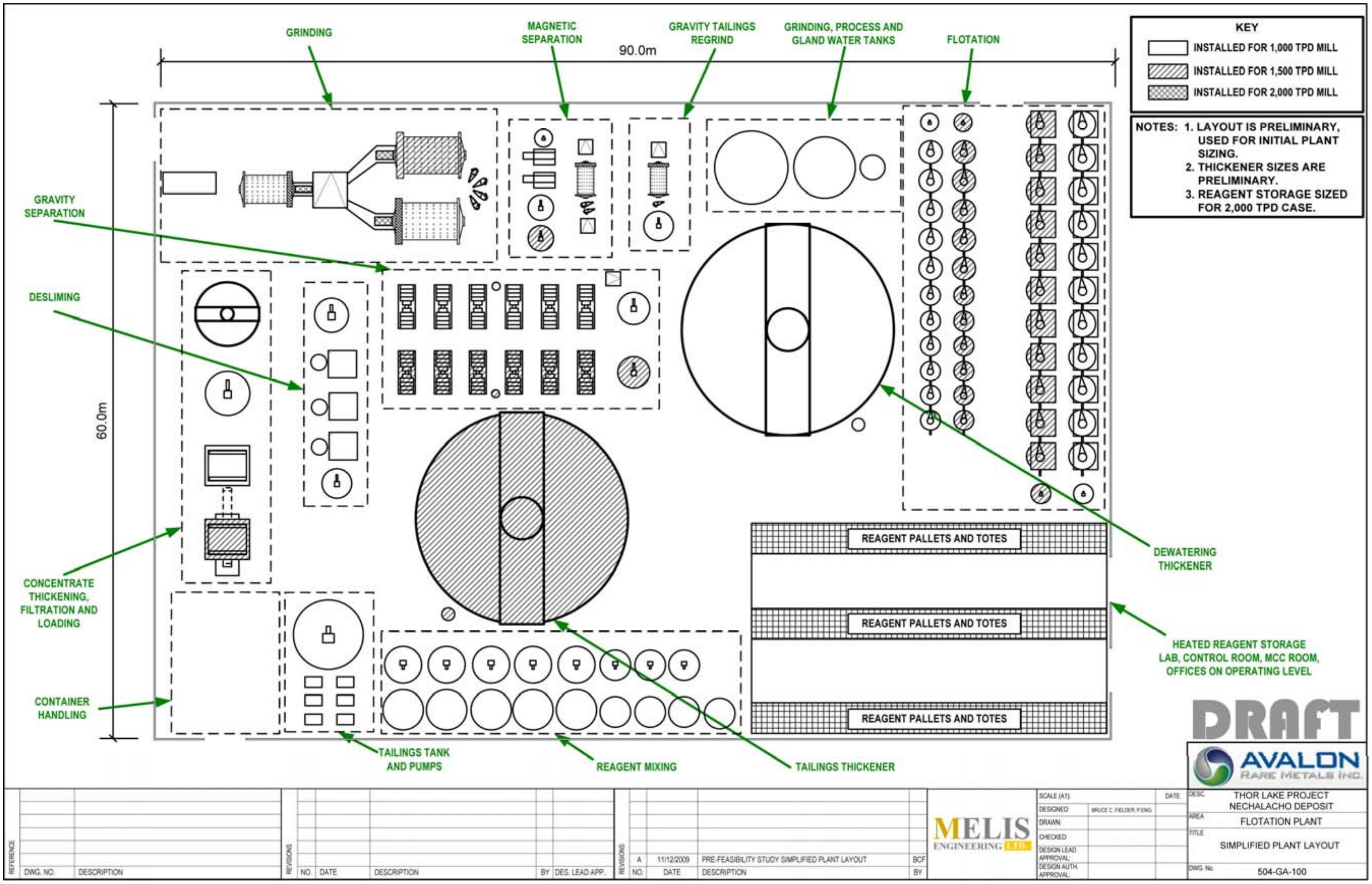
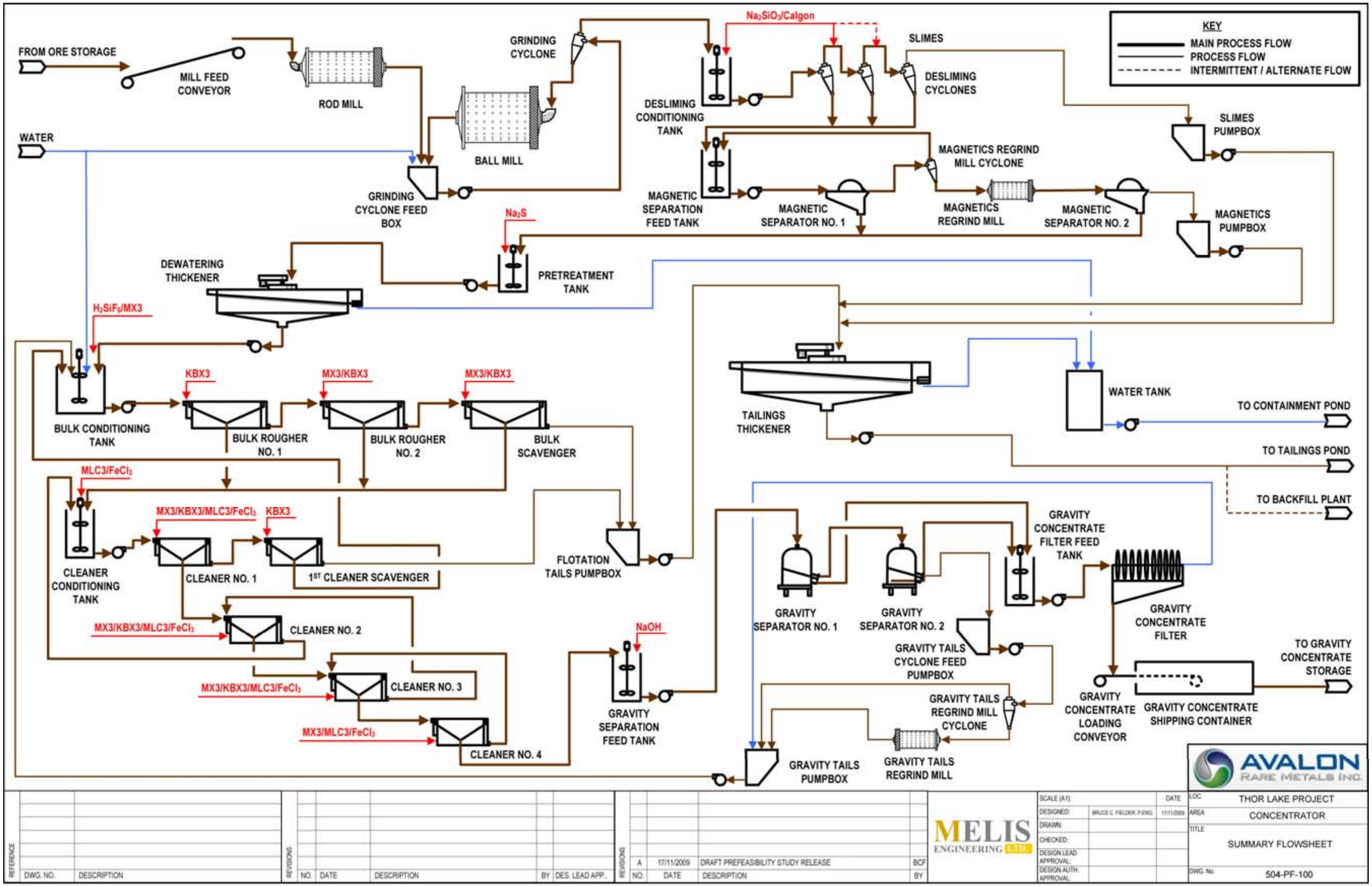


Figure 2.6 Flotation Plant Summary Flowsheet



Grinding
Ore will be metered from the fine ore bin via slot feeders and discharged onto the fine ore transport conveyor. The conveyor will discharge to the mill feed conveyor feeding the rod mill. During start-up activities, A small feed hopper will discharge temporary stockpiled ore on the surface onto the mill feed conveyor until all material is removed.

Slurry from the rod mill will discharge into a pumpbox feeding the grinding cyclones. Cyclone underflow, made up of coarse slurry, will be ground further in a ball mill. The ball mill will discharge into the cyclone feed pumpbox with the rod mill discharge. Cyclone overflow, with an 80% passing size of 38 microns, will be the grinding circuit product forwarded to the desliming conditioning tank.

Desliming
Cyclone overflow will be treated with a mixture of sodium silicate and sodium metaphosphate that will act as a slimes dispersant. Desliming will occur in three stages of small diameter cyclones: a first stage using 102 mm cyclones, a second stage using 51 mm cyclones and a third stage using 10 mm cyclones. The third stage overflow will be discharged to the tailings tank and the underflows from the three sets of cyclones will be forwarded to magnetic separation for further processing.

Magnetic Separation
The cyclone underflow from the desliming cyclones will be fed to a magnetic separator. The magnetics collected from the magnetic separator will be fed to 102 mm cyclones. The underflow will be reground in a small ball mill to 80% passing 37 micron and fed to a second stage magnetic separator along with the cyclone overflow. The magnetics from the second magnetic separator will be discharged to the tailings tank.

The non-magnetics from both magnetic separators will be collected and treated with sodium sulphide in a pre-treatment tank prior to reporting to the dewatering thickener.

Dewatering and Bulk Conditioning
The non-magnetics will be dewatered and thickened to approximately 62% solids (w/w) prior to being discharged to the bulk conditioning tank. The thickener overflow will then be discharged to the tailings tank.

The thickened non-magnetics, along with some recycle streams, will be treated with fluorosilicic acid and conditioned with the MX3 reagent mix depressant. The conditioned pulp, at a re-adjusted density of 25% solids (w/w), will be forwarded to bulk rougher flotation.

Bulk Flotation

The conditioned pulp from the dewatering circuit will be processed through rougher/scavenger flotation using the KBX3 reagent mix as a collector and the MX3 reagent mix as a gangue depressant.

The bulk rougher concentrate and the bulk scavenger concentrate will be collected and discharged by gravity to the cleaner conditioning tank where they will be conditioned with the MLC3 reagent mix acting as a dispersant/depressant ahead of cleaner flotation.

The bulk scavenger tailings will be discharged to the tailings tank.

Cleaner Flotation

Four cleaning stages will be used to upgrade the rare earths concentrate with upstream recycle of cleaner tails. A scavenger float on the first cleaner tails will recover some metal values which will be returned to the bulk conditioning tank ahead of bulk flotation. Reagents used will include the MX3 depressant reagent mix, the KBX3 collector reagent mix, the MLC3 dispersant/depressant reagent mix and ferric chloride.

The fourth cleaner concentrate will be fed to gravity separation.

Gravity Separation

The fourth cleaner concentrate will be conditioned with sodium hydroxide to raise the pH to 12 to disperse the froth contained in the concentrate ahead of gravity separation.

Recovery of gravity concentrate will be accomplished in Mozley C902 multi-gravity separators. The gravity tails will be cycloned and the cyclone underflow will be reground to 80% passing 37 micron prior to being forwarded to the bulk conditioning tank along with the cyclone overflow. The upgraded gravity concentrate will be collected and forwarded to the concentrate thickener.

Concentrate Dewatering and Loadout

The concentrate thickener underflow will be held in a surge tank and fed to a pressure filter for dewatering to approximately 10% moisture. The filtered concentrate, the final product from the Flotation Plant, representing 18% of the mill feed, will be transferred to concentrate intermodal storage containers for barging to the off-site Hydrometallurgical Plant for further refining.

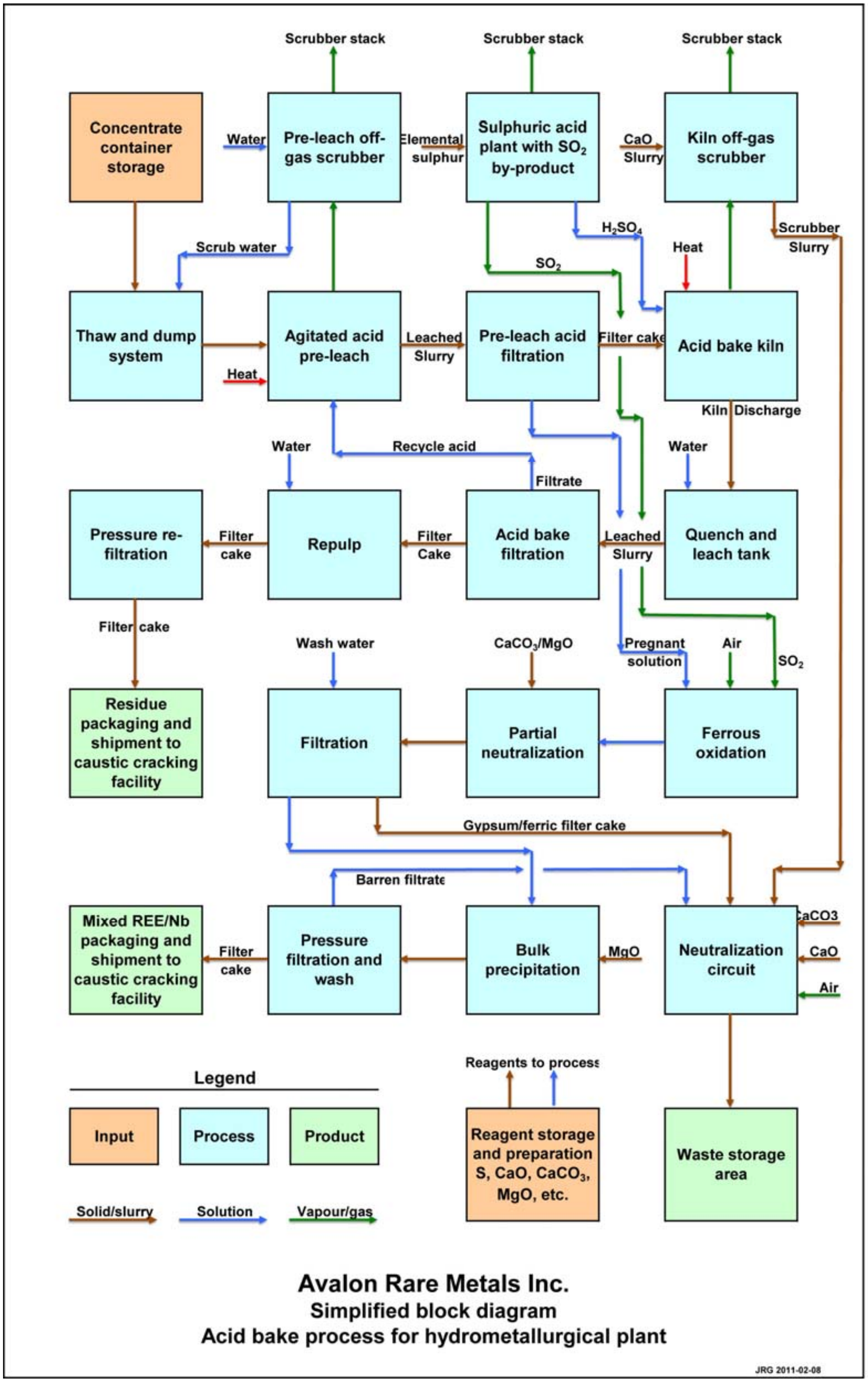
2.2.3 Hydrometallurgical Plant Process Flow

For 2000 tpd ore extraction, the Hydrometallurgical Plant will process up to 416 tpd, operating 351 days per year. The process flow is taken from the draft Developers Assessment Report (2011a) and shown schematically in Figure 2.7. The main steps of the Hydrometallurgical Plant process flow include:

- *Acid Bake:* Concentrate will be mixed with concentrated sulphuric acid, heated to a temperature of about 200ºC, quenched with water and the resulting slurry will be pumped to automatic filter presses. The washed and blow-dried acid bake residue will be repulped and refiltered then conveyed to the acid bake residue handling system.
- *Light Rare Earth Precipitation:* The pregnant solution from the acid bake process will be oxidized, ferric iron and excess acid removed, then precipitated as mixed oxides. These will be filtered from the mixed solution, partially dried and packed as a LREE product.
- *Product Transportation to Railhead:* The Hydrometallurgical Plant will produce approximately 418 tpd of acid baked residue and light rare earth products. The acid bake residue makes up 330 tpd while the light rare earth produced is 88 tpd. Both concentrate and light rare earth products will be dried to approximately 10-12% moisture content prior to shipment.

  Concentrate residue from the acid bake process will be dried and loaded into 20 tonne trucks and pup trailers with covers for direct shipment to the railhead facilities operated by CN rail. The final light rare earth products will be packed into inter-modal containers to ensure that product is not lost during the handling and/or transportation process. The products will be hauled 85 km from the Hydrometallurgical Plant to the Hay River railhead on flatbed trucks. Truck shipments are expected to occur daily during one twelve hour shift. The acid baked residue and rare earth products will be direct-shipped south from the railhead to Avalon’s process and separations plant.

Figure 2.7 Hydrometallurgical Plant Process Flow Schematic for Whole Plant



2.3 ORE AND CONCENTRATE GRADES

Three ore phases are produced by the Thor Lake Project: mined ore from the Nechalacho deposit, an intermediate concentrate from the Thor Lake Flotation Plant, and a final concentrate produced in the Hydrometallurgical Plant.

2.3.1 Nechalacho Deposit Ore

Mineral resources in the Basal Zone form the basis of the mineral reserves for the Thor Lake Project. January 2011 Indicated Mineral Resources in the zone are estimated to be 57.49 million tonnes, at an average grade of 1.56% Total Rare Earth Oxides (TREO), including 0.33% Heavy Rare Earth Oxides (HREO), 2.993.38% ZrO_2, 0.44% Nb_2O_5 and 0.043% Ta_2O_5 (Avalon 2011b).

Mass concentrations of U and Th in ore had been determined in a number of analyses, summarized in Table 2.2. The basal zone mineralization and data from the Saskatchewan Research Council (SRC) were based on individual core samples (Mercer, 2010a) while the other available data were based on composite samples (SGS, 2010). The average U was relatively consistent through the three programs; however, an individual SRC sample exceeded 1,000 ppm (0.1% U) which, it should be noted, exceeds the average content in some low-grade uranium mines. The statistics for the SRC samples are shown in the table with and without this sample. The values in the table demonstrate that there is a range (about an order of magnitude) in the ratio between Th and U mass concentrations in the various samples. A more complete set of data on the analysis of core samples for uranium, thorium and total rare earth oxides (TREO) was subsequently provided by Mercer (2010b). The mean uranium and thorium concentrations in this date set were similar to the other samples (SENES 2010). Finally, the results from a very large numbers of samples (> 4000) were provided by Avalon as discussed in Section 3.4.2, and as shown in Table 3.3. The resulting mean values of 130 ppm thorium and 24 ppm uranium were as shown in Table 2.2

Table 2.2 Mass Concentrations of Uranium and Thorium in Nechalacho Ore

Samples	Mean U (ppm)	Mean Th(ppm)	Th/U Ratio	Range U(ppm)	Range Th(ppm)
Nechalacho Basal Zone mineralization	29	160	-	1 - 269	2 – 1060
SRC (4 sample)	32	254	1 to 10	19 - 46	23 – 419
SRC (5 sample)	260	207	<1 to 10	19 - 1172	20 – 419
SGS (rock)	37	109	1.8 to 4.5	22-51	81-140
Multiple Ore Samples (Mercer, 2010b)	41	190	0.2-95	4.7-1,400	25-2000
Avalon (pers. comm., Feb 2011 – see Table 3.3)	24	130	-	-	-

Notes:
Nechalacho and SRC results from Mercer (2010a)
SRC (4 sample) excludes one elevated sample (>1000ppm U)
SGS from SGS (2010, Table 11)

2.3.2 Flotation Plant Concentrates

Mineral processing test work indicates that the TREO, ZrO_2, Nb_2O_5 and Ta_2O_5 can be recovered in a flotation circuit after crushing and grinding to 80% minus 38 μ with recoveries of 80% of the TREO, 90% of the zirconium oxide, 69% of the niobium oxide and 63% of the tantalum oxide to a flotation concentrate. The processing circuit also includes magnetic and gravity separation stages (SWRPA 2010).

The uranium and thorium are expected to follow the Rare Earth Elements (REE) to the heavier fraction resulting in higher concentrations in the concentrate and lower concentrations in the flotation tailings when compared to the ore. Measured values in some test concentrate samples are shown in Table 2.3. It was estimated that U and Th concentrations in flotation concentration would be about 3 to 5 times the rock concentration. (Chapter 4 discusses transport regulations for radioactive material.) Given the variability in rock concentrations, some concentrate may have concentrations above those indicated and there is a probability of exceeding transport exemption limits for concentrate shipped offsite. This is discussed further in Section 3.4.

Table 2.3 Uranium and Thorium Potential Concentrations in Flotation Plant Concentrate and Tailings

SAMPLES	Mass Concentration (ppm) (rounded)	
	U	Th
Measured Values in Concentrate and Tailings		
SGS (concentrate)	153	333
SGS (tailings)	10	66
Goode (concentrate)	131	979

Note:
SGS is from SGS (2010), and Goode data are from J. Goode (2010, personal communication, May)

2.3.3 Hydrometallurgical Plant Concentrates

Metallurgical process test work for the extraction of the TREO, zirconium oxide, niobium oxide and tantalum oxide from the flotation concentrate was carried out and the recoveries of 96% of the TREO, 93% of the zirconium oxide, 82% of the niobium oxide and 60% of the tantalum oxide were demonstrated in the laboratory (SWRPA 2010).

In the course of processing the concentrate, a high proportion of the thorium and uranium (as well as Th and U daughters) will be dissolved. They could be isolated as crude products (up to 50% ThO_2 and 75% U_3O_8) and blended back into the hydrometallurgical plant residues. (SENES 2010). Due to the absence of laboratory results on Hydrometallurgical concentrate samples, projections of radiological constituents of concern were conducted by SENES. Original predictions of U and Th concentrations in hydrometallurgical residue based on preliminary ore data were estimated at 36 ppm U_3O_8, and 247 ppm ThO_2 (SENES, 2009). These are generally low concentrations partly due to addition of chemicals added for REE recovery and lime for neutralization of leach residue and SX raffinate. Predictions using the most recently date, with lower mean U and Th concentrations in the ore and floatation concentrate, would result in even lower concentrations in the hydrometallurgical plant concentrates.

3.0 REGULATORY CONSIDERATIONS

3.1 INTRODUCTION

The presence of NORM in the Thor Lake ore and in subsequent process materials and wastes requires that potential radiation exposures be addressed. Such requirements are specifically noted in the NWT Mines Act. In addition, although the NWT regulations refer to the CNSC regulations, the CNSC regulations do not apply to NORM (see section 4.4). The Canadian NORM guidelines (Health Canada 2000) are intended to apply to occupational radiation exposures at locations and facilities not licensed by the CNSC.

Previous communications by SENES with the NWT WSIB in 2010 indicated that the WSIB may be reviewing regulations and potentially may revise the regulations based on government/industry agreements. It is unclear how the NWT regulations will be revised. It may be possible that strict interpretation of NORM guidelines, or CNSC regulations, might be required in the revised Mine and Safety Act. Finally, transport regulations apply to any radioactive materials, irrespective of the source of the material. The NWT, Canadian NORM guidelines and the transport regulations are outlined below.

3.2 NWT MINES ACT

The NWT Mine Health and Safety Act [Mine Health and Safety Act: Consolidation of Mine Health and Safety Regulations R-125-95, MHSA 2011] covers radiation hazards; specifically as follows for exposure to radon progeny:

> ***9.90.*** *The manager shall inform any person in writing of the amount of the exposure of the employee to radon daughters when that exposure reaches*
> *(a) 0.75 WLM in any one month;*
> *(b) 1.5 WLM in any period of three consecutive months; or*
> *(c) 2 WLM in any period of 12 consecutive months.*

Note that these regulations allow variability from month to month: the limit for one month of 0.75 WLM is more than 1/12 of the annual limit evenly distributed over every month (i.e. 2 WLM/y would be 0.17 WLM/m). The WLM (working level month) is a unit of exposure to radon progeny equal to exposure to a concentration of radon progeny of 1 WL (working level) for 1 working month (170 hours). One WL is equivalent to a radon concentration of 3700 Bq/m^3 in equilibrium with its progeny. The degree of equilibrium is dependent on the "age" of the air, and consequently the degree of ventilation in any workplace. Although predictions of radon levels can be made, such as in underground locations, direct measurements are required to confirm the exposures.

The NWT regulations following the A.E.C.B (now the CNSC) limits for allowable dose and radon progeny levels. Current regulations specify that radon concentrations are multiplied by a dose conversion factor (DCF) of 5 mSv per WLM. Limits on total dose are 50 mSv in any one year and 100 mSv over five years (equivalent to 20 mSv/y) or equivalently, 4 WLM/y

3.3 CANADIAN NORM GUIDELINES

The Canadian Guidelines for the Management of Naturally Occurring Radioactive Materials (NORM) (Health Canada 2000) were developed to address situations where the exposure to NORM is not regulated. The CNSC regulations do not apply to NORM, and therefore jurisdiction over the use and radiation exposure to NORM rests with each Canadian province and territory.

As noted in the Guidelines, the basic principle of the Guidelines is that persons exposed to NORM should be subject to the same regulations as those exposed to CNSC-regulated radioactive materials. The NORM radiation dose limits in the Guidelines are:

- For occupationally exposed workers, 100 mSv in any five years, or an average of 20 mSv/y, with a maximum of 50 mSv/y in any single year;

- For incidentally exposed workers or members of the public, 1 mSv/y.

<u>Occupationally exposed workers</u> are employees who are exposed to NORM sources of radiation as a result of their regular duties. <u>Incidentally exposed workers</u> are employees whose regular duties do not include exposure to NORM sources of radiation. They are considered as members of the public in terms of their dose limits

The NORM guidelines provide dose limits and management practices for three categories of anticipated dose above a dose rate threshold of 0.3 mSv/y. Table 3.1 shows the dose ranges and threshold dose for various NORM radiation protection programs along with the average radon concentration corresponding to these levels which serves as Derived Working Limits. Average concentrations at, an above, these limits would meet the threshold for dose. For underground locations where the relationship between radon and radon progeny differs from the surface, the conversion of dose and concentration to units of WLM and WL is appropriate. This conversion is based on the dose range and assumptions of 2,000 hours per year and a dose coefficient of

5 mSv/WLM. An average workplace WLM above 0.06 would require a NORM Management Program and this would correspond to an average radon progeny of 0.005 WL.

Table 3.1 Dose Ranges for NORM Radiation Management Programs and Derived Working Limits

Program	Unrestricted	NORM Management	Dose Management	Radiation Protection Management
Dose Range (mSv/y)	0 to 0.3	0.3 to 1	1 to 5	>5
Threshold (mSv/y)	0	0.3	1	5
Derived Working Limit - Radon (Bq/m^3)	Unspecified	Unspecified	150	800
Calculation from NORM dose and radon				
WLM/y	0	0.06	0.2	1
Derived Working Level -Mean WL	0	0.005	0.017	0.085

Note:
Conversion assumes 2,000 hours per year and a dose conversion factor of 5 mSv/WLM.
The conversion from radon concentration to WLM or WL from concentration is slightly different than the conversions from dose.

Table 3.2 summarizes the actions which would arise from adoption of the NORM guidelines. A column for unrestricted use is not included; however, the conditions are provided for NORM Management since these will also apply. Three broad categories include access and restriction (e.g. training and signage), dose estimation (and reporting) and control of radon doses (through work practices or engineering controls).

Table 3.2 NORM Management Programs and Corresponding Requirements

Action	NORM Management	Dose Management	Radiation Protection Management
Access and Restriction			
Public Access	Restricted	Restricted	Restricted
Worker Access	Unrestricted; however potential for incidentally exposed worker restrictions	training	Radiation signage for locations with high dose rate. The guidelines suggest 25 µSv/h which is roughly equivalent to 0.85 WL.
Dose Assessment			
Worker Notification	not required	Training	Notification of dose
Dose Estimation	not required	Required	Meets S106* requirement
NDR Reporting	not required	Required	Meets S106* requirement
Dose Reduction (ALARA)			
Engineering	- work practices	engineering controls (e.g. ventilation)	

Notes:
* Technical and Quality Assurance Standards for Dosimetry Services in Canada, S-106, A Joint Federal-Provincial Standard, Published by the Atomic Energy Control Board, March 20, 1998.

3.4 REGULATIONS ON THE TRANSPORT OF RADIOACTIVE MATERIALS

3.4.1 Regulations

Naturally occurring radioactive materials (NORM), such as the rare earths ore and concentrate from the Thor Lake project, are specifically excluded from the mandate of the Canadian Nuclear Safety Commission (CNSC), except for the transport and import/export regulations[1] which govern all radioactive materials. This is stated in section 10 of the General Nuclear Safety and Control Regulations (CNSC 2000a):

> *Naturally occurring nuclear substances, other than those that are or have been associated with the development, production or use of nuclear energy, are exempt from the application of all provisions of the Act and the regulations made under the Act except the following:*
>
> *(a) in the case of a nuclear substance having a specific activity greater than 70 kBq/kg, the provisions that govern the transport of nuclear substances;*
> *(b) in the case of a nuclear substance listed in the schedule to the Nuclear Non-proliferation Import and Export Control Regulations, the provisions that govern the import and export of nuclear substances.*

The 70 kBq/kg specific activity limit is based on a now superseded limit found in previous IAEA transport regulations that referred to the total radioactivity of the material. This applied to all radionuclides, i.e. it was not radionuclide-specific. Based on secular equilibrium, equivalent mass concentrations corresponding to a 70 Bq/g specific activity (from all radionuclides in the U-238 and Th-232 series in natural uranium and natural thorium) are 405 and 1720 ppm for uranium and thorium, respectively.

The CNSC regulates the packaging and transport of nuclear substances in Canada in cooperation with Transport Canada. The latest Canadian Packaging and Transport of Nuclear Substances Regulations (PTNSR 2000), under the Transport of Dangerous Goods Regulations (TDGR), now refer to the IAEA 1996 Edition (revised) TS-R-1 transport regulations (IAEA 2000), which have radionuclide-specific exemption limits, including revised exemption limits specific to NORM. Section 2 of the PTNSR (2000) states that the Regulations do not apply to the packaging and transport of a nuclear substance:

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[1] The import/export regulations for transporting materials across international borders are not a subject of this report. Relative to nuclear substances and NORM, only materials exceeding 0.05% by mass (500 ppm) of uranium and thorium are subject to the regulations (CNSC 2000b). However, export permits are not required for most controlled goods or technology destined to a final consignee in the United States. An export controls handbook on the regulations is available from the Department Foreign Affairs and International Trade (DFAIT 2011).

> *(j) consisting of natural material and ores containing naturally-occurring radionuclides that either are in their natural state, or have been processed only for purposes other than for extraction of those radionuclides, and that is not intended to be processed for use of those radionuclides, provided the activity concentration of the material does not exceed 10 times the "activity concentration for an exempt material" values specified in paragraphs 401 to 406 of the IAEA Regulations.*

The above refers to exemption limits for the transport of NORM. Although these Canadian regulations apply to the 1996 version (revised) of the IAEA regulations, the values referenced have not changed in the most recent version of the IAEA regulations (IAEA 2009), and thus apply to Canadian and international transport.

For U-nat, the IAEA transport exemption limit for NORM is 10 kBq/kg (10 Bq/g) of U-238, or 140 Bq/g if all 14 radionuclides in equilibrium in the U-238 series are included. The equivalent total concentration for Th-nat (Th-232 series with 10 radionuclides), also with an IAEA transport exemption limit of 10 Bq/g (of Th-232), is 100 Bq/g. (These exemption limits refer only to the transport of NORM. Exemption limits for the transport of materials associated with the nuclear fuel cycle (e.g. uranium ore) are a factor of 10 lower.)

3.4.2 Potential Application to Thor Lake Materials

The equivalent mass concentrations corresponding to the transport exemption limits of 10 Bq/g of U-238 or Th-232 in radioactive equilibrium are 810 ppm and 2460 ppm for U-nat and Th-nat, respectively[2]. For mixtures of radionuclides, a "sum rule" applies to the exemption limits. In the case of U-nat and Th-nat, the sum rule requires that:

$$\frac{\text{U}-\text{nat (ppm)}}{810} + \frac{\text{Th}-\text{nat (ppm)}}{2460} < 1$$

The radioactivity data on the Thor Lake materials was previously reviewed and the concentrations of U and Th in the Nechalacho deposit were estimated (SENES 2010). Subsequent to this, Avalon released an updated resource estimate (Avalon 2011b).

According to Avalon (personal communication, February 2011), based on current economic mine planning, the mine plan would include mining ore with an average of 2.19% TREO over the life of the mine. Under present conditions, the mean Th and U in the mined ore is estimated

[2] Based on 0.01235 Bq U-238/g per ppm of natural uranium and 0.00406 Bq Th-232/g per ppm of natural thorium.

to be 130 ppm and 24 ppm, respectively as indicated in Table 3.3 from individual uranium and thorium assays based on 2 m intervals.

The ore would not be transported off site but the flotation concentrate would be barged to the hydrometallurgical facility. Avalon estimates that the concentrations of uranium and thorium in the ore would be increased in the flotation concentrate by a factor in the order of 3 to 5 (Avalon personal communication, February 2011). The corresponding estimated concentrations in the individual samples are as summarized in Table 3.3.

Table 3.3 Estimated Thorium and Uranium Concentrations (ppm) in Thor Lake Flotation Concentrate

Constituent	Number of Obs	Median (ppm)	Mean (ppm)	95th Percentile (ppm)	Maximum (ppm)	TDGR Exempt Limit (ppm)
			Raw Ore Data			
Th	4391	95	130	355	1013	2460
U	4391	21	24	55	65	810
			Enrichment Factor of 3 from Ore to Flotation Concentrate			
Th	4391	285	390	1065	3039	2460
U	4391	63	72	165	194	810
sum rule		0.19	0.25	0.64	**1.47**	
			Enrichment Factor of 5 from Ore to Flotation Concentrate			
Th	4391	475	650	1775	5065	2460
U	4391	105	120	275	324	810
sum rule		0.32	0.41	**1.06**	**2.46**	

Notes:
1. Actual number of assays is less than shown (the mine site splits assays at survey points).
2. Entire basal ore zone was used since there are numerous low grade intervals within the cut-offs.
3. Sum rule for 95^{th} and maximum values conservatively estimated by assuming perfect correlation in uranium and thorium.

Also shown in the table is how the predicted concentrations in the flotation concentrate compare to the TDGR exemption limits, based on the sum rule derived using statistics on individual ore sample. The mean estimates are appropriate but the percentiles (95th and maximum) for a bulk shipment of concentrate will be overestimated for two reasons. Firstly, there is not perfect correlation between the uranium and thorium concentrations and therefore the sum rule for the 95th percentile and maximum will be overestimated. Secondly, the results will be less variable and closer to the mean due to blending of multiple ore fragments from a stope. In addition, ore from multiple stopes may be present in a shipment of the flotation concentrate thereby further reducing the variability.

Values above 1.0 from the sum rule are shown in bold. Depending on the assumed concentrate/ore ratios for uranium and thorium, some small fraction of the flotation concentrate (based on the analysis of the ore samples) could exceed the sum rule, and possibly be subject to the transport regulations for radioactive material. Due to the conservatism of perfect correlation and no blending, the chance of exceeding the TDGR exemption limit in a shipment of concentrate is however less than that suggested by the statistics on individual samples in Table 3.3. Periodic analysis of the concentrate would be used to determine if transport regulations would apply.

If material requiring off-site transport were to be produced at the mine at concentrations exceeding the TDGR exemption limits, the material would be classified as Low Specific Activity (LSA-1) material. The transport requirements for such material are relatively straightforward. The material could be shipped in standard steel drums, or even in bulk in shipping containers. The containers would have to labelled as LSA-1.

4.0 RADIATION PROTECTION

4.1 GENERAL CONSIDERATIONS

This Section is intended to provide an overview of the kinds and magnitudes of potential radiological issues associated with the proposed Thor Lake Project (TLP). At this stage of design, specific estimates of worker exposures to radiation and radioactivity are not available; nonetheless, although the anticipated levels of NORM are quite low, there is some potential for some workers to receive more than 1 mSv in a year. Hence, some comments are provided on the likely range of anticipated exposures and general considerations for a radiation protection program are discussed.

As previously indicated, radiation exposure can occur as the result of being exposed to gamma radiation from sources outside of the body and also through radiation that is taken into the body through inhalation or ingestion. The following general comments apply with respect to possible pathways of exposure.

<u>For Mining and Processing:</u>

- External gamma radiation arises from gamma emitting radionuclides present in both the uranium and thorium decay series. In general terms, the gamma radiation fields increase with increasing amounts of uranium and/or thorium in the ore or process line and decrease with increasing distance from the source. Where external gamma levels are elevated, doses can be reduced through a combination of administrative controls (time management), distance and, if necessary, shielding.
- Inhalation of dust containing radionuclides of the uranium and thorium series provides another exposure pathway radiation. At the Thor Lake mine, dust levels will be controlled with the use of water sprays to help control dust generation and ventilation. Although the ventilation design has not been developed at this time, experience on other mining projects indicates that the ventilation required for underground diesel equipment will very often also provide adequate ventilation to manage potential radiological exposures.
- Inhalation of radon (and thoron) and their short-lived decay products is another potentially important source of radiation exposure to workers. Again, good workplace ventilation is used to control workplace radon decay products levels. As for dust, experience suggests that ventilation provided for diesel and potential non- radiological exposures is often adequate for radiation protection purposes.
- Another potential exposure pathway is the ingestion of dust containing uranium or thorium and their decay products. In the mine, exposure via this route of exposure is

controlled by prohibiting smoking (hand to mouth) in the workplace and providing a clean lunch/refuge area for eating. Similarly clean areas and contamination control to prevent spread of contamination

- Similarly, in the process plants, contamination control will be important in managing the spread of contamination from the process plant areas to clean areas (change rooms, lunch rooms, engineering, etc.)

Transportation

- During normal transport, gamma radiation is the only source of radiation exposure to workers. Here, proper labelling is important as is careful handling.

The following provide some general observations concerning potential ranges of radiation doses and also an outline of a radiation protection program for the TLP.

4.2 POTENTIAL WORKER EXPOSURES – ILLUSTRATIVE CALCULATIONS

The workers at the proposed Thor Lake project will be exposed to the NORM in the Thor Lake ore and in other materials at the various work locations. The potential exposures will depend on the radioactivity concentrations in the materials being mined and/or processed. For these illustrative calculations, the nominal average uranium and thorium concentrations in the ore were used, namely 24 ppm uranium (= 0.30 Bq/g of U-238 and decay products) and 130 ppm thorium (0.53 Bq/g Th-232 and decay products). The materials were also assumed to be in radioactive equilibrium. This is a reasonable assumption for ore but not necessarily for materials that have undergone chemical and other processing, such as in the hydrometallurgical facility. The resulting doses are proportional to the assumed concentrations.

The calculation of potential exposures required factors to convert intakes of radioactivity via inhalation and ingestion to radiation dose. In addition, an estimate of the gamma exposure rate was required. These items are addressed in the following sections.

4.2.1 Radioactivity Dose Coefficients

As previously indicated, potential exposures to the NORM could result from external exposure to gamma radiation and from intakes of NORM radioactivity via ingestion and inhalation.

External Exposure

For external exposures to large sources of NORM such as might occur at the mining or refining sites, coefficients derived for U-238 and Th-232 series radionuclides in large, planar sources (e.g. the ground surface, proximity to large vessel containing ore or a concentrate e.t.c.) were used (UNSCEAR 2000).

Internal Exposure

To estimate radiation dose from radionuclides taken into the body by inhalation or ingestion, internationally accepted dose coefficients (DCs) of the International Commission on Radiological Protection (ICRP) were used. The ICRP DCs are also used in the Canadian NORM guidelines (Health Canada 2000). The DCs used in the calculations for workers are shown in Table 4.1.

To illustrate, a worker inhaling 1 Bq of Th-232 (and all associated decay radionuclides) would receive a dose of 4.8 x 10^{-5} Sv (0.048 mSv). For inhalation, the default particle sizes recommended by the ICRP were used. Radionuclides in the U-238 and Th-232 series with insignificant inhalation and ingestion DCs were not included in Table 4.1. The small contributions from the U-235 series were also not included for these illustrative calculations.

Table 4.1 Radiation Doses Coefficients (DCs) for Workers

	Worker DCs[a]	
Radionuclide	**Inhalation (Sv/Bq)**	**Ingestion (Sv/Bq)**
uranium		
U-238	5.7E-06	4.4E-08
U-234	6.8E-06	4.9E-08
Th-230	7.2E-06	2.1E-07
Ra-226	2.2E-06	2.8E-07
Pb-210	1.1E-06	6.8E-07
Po-210	2.2E-06	2.4E-07
U-238 series	**2.5E-05**	**1.5E-06**
thorium		
Th-232	1.2E-05	2.2E-07
Ra-228	1.7E-06	6.7E-07
Ac-228	1.2E-08	4.3E-10
Th-228	3.2E-05	7.0E-08
Ra-224	2.4E-06	6.5E-08
Pb-212	3.3E-08	5.9E-09
Bi-212	3.9E-08	2.6E-10
Th-232 series	**4.8E-05**	**1.0E-06**

a. Worker DCs (for least soluble form) from ICRP 68 (1994a) except for revised Ra-226 inhalation DC from ICRP 72 (1996). ICRP default 5 um particle size for airborne dust for workers assumed.
b. Small contributions from U-235 series neglected.

4.2.2 Potential Worker Exposures

The potential radiation exposure pathways of the workers are direct gamma radiation, and inhalation and accidental ingestion of any radioactive dust.

Direct Gamma Radiation

The gamma radiation exposure rate when working near radioactive material is directly dependent on the radioactivity of the material. According to UNSCEAR (2000, Annex A), the dose rate at 1 m above ground containing U-238 series radionuclides in equilibrium is 0.31 microsieverts per hour (µSv/h) per Bq U-238/g. For NORM such as Thor Lake ore at 24 ppm uranium, the concentration would be 0.30 Bq/g each of U-238 and decay products. For the Th-232 series, the dose rate would is 0.42 µSv/h per Bq Th-232/g. For NORM such as Thor Lake ore at 130 ppm thorium, the concentration would be 0.53 Bq/g each of Th-232 and decay products.

The most exposed workers would be those who stand directly next to the radioactive material. For these illustrative calculations, it was assumed that such workers would spend all their working time (2000 h/y) in near contact with the NORM, e.g. miners working in an underground drift assumed to be in ore with no shielding provided by equipment. The miners were assumed to be working in a drift in ore[3]. The resulting dose to those miners was calculated as follows:

Gamma dose (U-series) = 2000 h/y x (0.31 (µSv/h) per Bq U-238/g x 2 x 0.30 Bq U-238/g) x 0.001 mSv/µSv

= 0.37 mSv/y

A similar calculation for Th-232 series radionuclides resulted in a dose of 0.89 mSv/y.

The total external dose rate for a miner, working in ore at the average grade, would thus be in the order of 1.3 mSv/y. Miners working in ores of higher grade would be exposed to higher levels of gamma radiation.

Exposures to those not exposed from all directions (i.e. non-miners) would be lower. Also, gamma radiation exposures to workers not directly exposed to NORM (e.g. those in trucks or other vehicles) would be lower through a combination of source-receptor geometry (i.e., the size of the source and the distance to the receptor) and intrinsic shielding provided by the vehicles.

[3] That is, the miners are "surrounded" by ore. This scenario is approximated by assuming the dose rates are twice (x2) the dose rate from a plane source of ore.

Ingestion

Workers could inadvertently ingest contaminated dirt containing radionuclides and other materials. The U.S. EPA (1991, 1997) has recommended 50 mg/day as a standard default value for adult soil ingestion in commercial/industrial settings or exposures at contaminated sites. For preliminary conservative assessments of exposures to workers, Health Canada (2004) recommends a dirt ingestion rate of 100 mg/day (0.1 g/day). These rates are considered independent of normal variations in a work day (e.g., 8 to 10 hours/day).

For these illustrative calculations, it was assumed that the workers would ingest NORM-bearing dirt at a rate of 0.1 g/day throughout the working year (2000 h/y) or 250 working days/y. It was also conservatively assumed that 100% of the ingested material would be ore. Using the ingestion DC (dose coefficients) of 1.5×10^{-6} Sv/Bq from Table 4.1, the annual worker dose via ingestion of ore at an average ore grade of 24 ppm U (0.30 Bq/g) would be:

$$\text{Ingestion dose (U-series)} = 0.1 \text{ g/d} \times 250 \text{ d/y} \times 0.30 \text{ Bq/g} \times (1.5 \times 10^{-6}) \text{ Sv/Bq} \times 10^{3} \text{ mSv/Sv} = 0.011 \text{ mSv/y}$$

A similar calculation for Th-series at 130 ppm (0.53 Bq/g) resulted in an ingestion dose of 0.013 mSv/y.

Inhalation

The inhalation dose would necessarily depend on the dust concentration in the work environment. The nuisance dust limit is 10 mg/m^3. For these calculations, an annual average dust concentration of 1 mg/m^3 of ore was assumed For an occupational inhalation rate of 1.2 m^3/h (ICRP 1994b) or 2400 m^3/y, assuming that 100% of this dust is respirable (a conservative assumption as only a fraction of the total dust would actually be respirable) at a U-238 concentration of 24 ppm (0.30 Bq/g), and using the inhalation DC of 2.5×10^{-5} Sv/Bq (Table 4.1), results in an dose from inhalation of:

$$\text{Inhalation dose (U)} = 0.001 \text{ g/m}^3 \times 0.30 \text{ Bq/g} \times 2400 \text{ m}^3\text{/y} \times 2.5 \times 10^{-5} \text{ Sv/Bq} \times 10^{3} \text{ mSv/Sv}$$

$$= 0.018 \text{ mSv/y}$$

A similar calculation for Th-series results in a dose of 0.061 mSv/y.

Total Radiation Dose to Workers

Under the assumptions noted above, the total dose to workers exposed to the levels of NORM anticipated at the proposed TLP, was estimated at 1.4 mSv/y (Table 4.2), with the largest contributor (>90%) being direct gamma radiation. For perspective, this is below the average dose of 1.8 mSv/y that Canadians receive from natural background radiation (see section 1.3).

The Th-232 series radionuclides were estimated to contribute most, about 70%, of the total dose under the assumptions of the calculations. The calculations were based on radioactive equilibrium, a good assumption for ore. This would not likely be the case for all the NORM materials at the hydrometallurgical plant, where radioactive concentrations in the various workplaces and the relative contributions of the exposure pathways would differ.

Additionally, underground miners would also be exposed to radon and its short-lived decay products. Source control and standard mine ventilation practices developed for conventional pollutants, such as diesel exhaust, are expected to control radon and its decay products to acceptable levels.

The total dose of 1.4 mSv/y is well below the 20 mSv/y dose limit for NORM workers, but is above the 1 mSv/y limit for incidentally exposed workers (Health Canada 2000). It is also above the 0.3 mSv/y dose constraint that is considered “unrestricted” in terms of radiological protection requirements. The potential implications of these workplace exposures are discussed in Section 4.3.

Table 4.2 Potential Radiation Doses to Workers – Illustrative Calculations

Input parameters:

duration:	direct exposure to ore (h/y)	2000	
	(d/y)	250	
duration:	exposure to ore dust (h/y):	2000	
	inhalation rate (m^3/h)	1.2	
	ingestion rate (mg/day)	100	
	average dust conc (mg/m^3)	1	
		U-series	Th-series
	radioactivity of ore (ppm)	24	130
	(Bq/g)	0.30	0.53
	ingestion DC [a] (Sv/Bq U-238 or Th-232 series)	1.5E-06	1.0E-06
	inhalation DC [a] (Sv/Bq U-238 or Th-232 series)	2.5E-05	4.8E-05
	gamma radiation DC [b] (uSv/h per Bq/g U-238 or Th-232)	0.31	0.42

Estimated radiation doses (mSv/y):

	U-series	Th-series	Total	% contribution
gamma radiation (miners)	0.37	0.89	1.3	92%
ingestion	0.011	0.013	0.024	2%
inhalation	0.018	0.061	0.08	6%
	0.40	1.0	1.4	100%

a. Dose coefficients from Table 4.1.
b. From UNSCEAR (2000, Annex A) for radionuclides in the ground, and x2 for underground miners.

4.3 OUTLINE OF A RADIATION PROTECTION PROGRAM

The calculations provided in Section 4.2, although necessarily approximate, suggest the possibility of exceeding the Canadian NORM Guideline of 1 mSv/y for incidentally exposed workers (Health Canada 2000). This would result in the NORM classification of *Dose Management* and the possible need for a worker and workplace radiation program. The following outline of such a program is somewhat more detailed than strictly required by the NORM guidelines; however, the program outline below is consistent with good radiation protection practice, ALARA and corporate due diligence.

4.3.1 Elements of a Generic Radiation Protection Program

A radiation protection (RP) plan has several elements. While RP plans can be developed in various formats, they would typically include the following elements, among others:

- Clear statements of purpose and objectives of plan;
- Administration (clear definition of responsibilities and roles);
- Training;
- Monitoring;
    - Personal
    - Area (workplace)
    - contamination
- Dosimetry;
- Personal Protective equipment;
- Transportation Requirements;
- Radiation Emergency preparedness and other requirements.

The details of a RP plan will be developed in an iterative fashion as the project moves through different stages of development and licensing. The following preliminary generic comments are offered.

4.3.2 Purpose, Objectives and Scope of the Radiation Protection Plan

The <u>purpose</u> of the plan will be to provide guidance to workers and other personnel at the TLP sites to ensure that proper RP measures are in place and followed. These procedures will be documented in a detailed Radiation Protection Manual.

The <u>objective</u> of the plan is to carry out activities at the TLP sites in such a way as to minimize radiation exposure of workers to levels that are <u>a</u>s <u>l</u>ow <u>a</u>s <u>r</u>easonably <u>a</u>chievable (social and economic factors taken into account), referred to as ALARA. The ALARA program ensures the following:

- Management control over work practices;
- Personnel qualification and training;
- Control of occupational and public exposure to radiation;
- Planning for unusual situations.

The scope of the plan applies to all workers at site (miners, process plants, engineers, cooks etc) and to visitors.

4.3.2.1 Administration

The roles and responsibilities are to be determined; however, one approach may be to fold the radiation protection activities into the overall occupational health and safety program the TLP facilities and activities. Irrespective, there will need to be suitably trained personnel, a radiation control supervisor and radiation technicians for example, to administer and implement the RP program.

4.3.2.2 Training

All site personnel should be familiar with the radiation hazards that exist at the site and the various means of minimizing exposures through monitoring and radiation protection measures. Prior to commencing work on the site, all workers potentially exposed to workplace radiation would receive training on the hazards associated with exposure to radioactive materials. The training would be graduated and in keeping with the anticipated level of radiation hazard.

Training sessions may include the following and other topics:

1. Definition of Radiation and Radioactivity (including definition of and comparison to background radiation);
2. Radioactive materials which are on site (type and location);
3. Methods of Exposure to radiation and radioactivity;
4. Warning Symbols (How to recognize them, what do they mean);
5. Actions Expected in Case of Unexpected Radiation Release (e.g., potential emergency);
6. Method and person to contact regarding Radiation Safety issues, etc.

4.3.2.3 Personal Radiation Protection

Personal protective equipment (PPE) for radiation protection includes dust masks, respirators, gloves, safety boots, safety glasses with side shields, coveralls, etc.

Personnel protection is achieved through training, awareness and assignment of protective clothing or equipment. Workers and visitors to the TLP should be made aware of the radiation hazards that might potentially exist in the areas they work. Actual requirements for an RP program (not all workplaces would exhibit radiation hazards) would be based on measurements in the various workplaces of the operating facilities.

4.3.2.4 Monitoring

Personal Monitoring

Workers who work in areas with potentially elevated gamma radiation levels should be provided with a thermoluminescent dosimeter (TLD) or equivalent monitoring device while in these areas. TLDs measure and record the effective and shallow doses of radiation received by the workers. Dependent on the evaluation of the radiation control supervisor, badges may be issued selectively to workers considered as "representative" of a class of workers.

It is anticipated that TLDs provided by the National Dosimetry Services (NDS) branch of Health Canada will be used, although alternative sources are available. Subject to a detailed evaluation of likely workplace radiation levels, given the anticipated levels of gamma radiation, TLDs would be issued on a quarterly basis.

At this time, personal monitoring for radioactive dust and radon is not anticipated.

The needs and requirements for personal monitoring should be reviewed on a regular basis and adjusted as needed.

Area Monitoring

Area monitoring should include regular gamma radiation surveys using hand-held meters. As indicated elsewhere, surface contamination surveys will be performed on a regular basis.

In addition, periodic surveys of radon and decay products in work areas should be performed.

Finally, radioactivity in airborne dust should be periodically measured at selected workplaces underground and in the process areas.

Contamination Monitoring

Contamination monitoring using meters and swipes could be conducted on a regular basis to ensure that inadvertent spread of contamination from process areas to “clean” areas such as lunch rooms and offices is identified and cleaned up quickly. This might be more relevant in workplaces where radioactivity is concentrated in waste or other materials by processes at the hyrometallurigcal plant.

4.3.2.5 Dosimetry

The radiation safety program should establish administrative levels of dose, procedures to calculate dose and associated record keeping.

Doses should be estimated from the results of individual monitoring and area monitoring combined with task-time analyses.

As previously indicated, external radiation is considered the most likely radiological hazard at the proposed TLP at this time.

4.3.2.6 Emergency preparedness

Despite careful attention to policies and procedures, accidents can still occur; therefore, those involved with radioactive materials must be familiar with the emergency procedures to be followed in the event of an accident involving a radioactive nuclear substance, during transport for example.

Spill response procedures should be developed to support emergency response in the event of a spill.

5.0 SUMMARY AND DISCUSSION

The proposed Thor Lake Project (TLP) is intended to recover and process rare earth elements (REE) from Avalon's Nechalacho REE deposit located in the Northwest Territories. The project facilities will be at two site locations: the Nechalacho Mine and Flotation Plant located on Avalon's Thor Lake Property, and the Hydrometallurgical Plant located at the brownfield site of the former Pine Point Mine near Hay River, NWT.

In addition to the rare earth metals and a number of other metals such as niobium, zirconium, tantalum, the Thor Lake ore also contains naturally occurring radioactive material (NORM). The NORM consists of naturally occurring uranium and thorium and associated radioactive decay products. The uranium and thorium concentrations in the Thor Lake ore are on average approximately 24 ppm and 130 ppm, respectively, or above typical background levels of about 1 to 10 ppm in rocks and soils. The presence of NORM in rare earth deposits is not unusual as NORM occurs in other rare earth deposits and in many resource industries around the world. However, the presence of NORM in the Thor Lake ore suggests the need to address potential radiological exposures to workers arising from the mining and processing of the ores.

This report considered the nominal levels of uranium and thorium in the ore, as well as recognizing the variability in these levels, the possibility that levels of radioactivity are enhanced at certain steps in the process. By means of illustrative calculations, the report provided an evaluation of the possible types and levels of radiation exposure to workers and outlined suggestions for components of a modest radiological protection program that could be implemented.

Potential radiological exposures of workers at the proposed TLP would arise from external gamma radiation and also through inhalation and ingestion of NORM in the workplace. Based on the information currently available, the largest source of worker exposure at the proposed TLP is anticipated to be external gamma radiation, which was estimated to account for approximately 90% of the dose under the assumptions used in the dose calculations. For the currently understood levels of uranium and thorium in the ore, potential exposures to radon and its decay products are anticipated to be controlled through conventional mine ventilation practices (as for example required for diesel equipment) and good industrial hygiene. Nonetheless, the radiation dose to some workers when exposed to average ore grades was estimated to be above 1 mSv per year, the dose limit for incidentally exposed workers recommended in the Canadian NORM Guidelines. The dose limit for incidentally exposed workers is the same as that of general members of the public. Should such exposures occur, a radiation protection program (RPP) would be indicated.

The general features of a potential radiation protection program for the proposed Thor Lake Project were outlined in previous sections of this report. In general terms, this would include an ALARA program to ensure that doses to workers are as low as reasonably achievable, monitoring, training and the development of emergency preparedness programs (spill response plan for example) amongst other elements.

Given the quite modest levels of NORM in the TLP and the implementation of a radiation protection program consistent with these levels, no undue radiological concerns were identified.

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APPENDIX A

OVERVIEW OF RADIOLOGICAL ISSUES AT OTHER NORM FACILITIES

APPENDIX A: OVERVIEW OF RADIOLOGICAL ISSUES AT OTHER NORM FACILITIES

A.1 INTRODUCTION

Naturally Occurring Radioactive Materials (NORM) is present in resource-based industries throughout the world. These include for example the oil and gas industry, phosphate fertilizer facilities, aluminum wastes, gold and silver mining, niobium and zirconium recovery operations, and titanium production wastes, to name a few, as well as rare earth facilities. Thus, the potential radiological issues at the Thor Lake Project (TLP) are not unique and the experience from other NORM projects benefits the TLP. This chapter briefly provides some background on the radiological issues noted at some rare earth and heavy mineral facilities from the context of occupational exposures.

A.2 EXPOSURES AND DOSES

At any sites with radioactive materials, occupational exposures can occur through inhalation, ingestion, and through external irradiation to gamma radiation. The inhalation of radon and thoron gas and their progenies (decay products) can also cause internal exposure to the workers (see for example UNSCEAR 2008(Annex E), U.S. NCRP 1993, IAEA 2006). These exposure pathways come into play when workers are mining and handling ores containing NORM.

The IAEA report on minerals and raw materials provides a convenient review of potential exposure pathways associated with the mining and processing of NORM materials. Amongst other suggestions, this report proposes a graded approach to radiation protection whereby *"the nature and extent of such measures will be commensurate with the type of practice and the levels of exposure, but will generally entail the establishment of some form of radiation protection programme with suitable provisions for monitoring and dose assessment at a more detailed level than in the initial assessment referred* " (ibid p10) This is actually the path proposed in the current report. As indicated by the IAEA, The main types of exposure arising from work with NORM are:

- external exposure to gamma radiation;
- internal exposure to inhaled dust; and
- inhalation of radon (decay products).

The IAEA also suggests that, while specific radiological measures in the workplace (for example, engineering controls through dust suppression and ventilation, shielding of external gamma radiation and control of airborne dust) may be necessary, anticipated engineering or administrative controls that will already be in place through OHS for conventional contaminants, (diesel exhaust for example) may already address potential radiological protection issues. Hence, control for radiation protection will build on existing engineering and administrative systems and practices.

A.3 EXAMPLES OF RADIATION DOSES IN THE MINERAL INDUSTRY

The section discusses the radiation doses measured at various mineral/rare earth mining and processing facilities in different parts of the world.

A mineral sand processing plant in Australia that uses wet and dry separating techniques in Australia reported an average effective dose of 7 mSv/y, most of which was due to internal exposures. Workers in the dry separation plants are designated as radiation workers since they receive a dose greater than 5 mSv/y (UNSCEAR 2000).

From 1986-1995, the mean annual effective dose in mineral processing industries in Western Australia have decreased from 25 mSv/y to 6 mSv/y. The majority of the decline occurred in internal doses while external doses remained relatively constant in the range of 1-2 mSv/y. From 1983 to 1988, the average annual effective does to 376 workers was 20 mSv/y. Of these workers, 50% received a dose above 15 mSv/y, and 90% of the dose was due internal exposure (UNSCEAR 2000).

A paper in the IAEA NORM V proceeding discusses the presence of NORM in the extraction and processing of rare earths in India (Pillai in IAEA 2008). According to this article the range of average annual dose is 1.5 to 9 mSv for mineral and rare earth plants in India and the composition of monazite in India was found to be 0.35% U_3O_8 and 8.0% ThO_2, much higher than the uranium and thorium values in the TLP ore.

In Australia, a study regarding radiation and dust hazards was performed by Johnston (1991) on a mineral sand processing plant containing monazite with 3.4% thorium and 0.16% uranium. The plant and its environments were surveyed using a radiation meter in order to determine the external gamma radiation. The average measured dose was 400 nSv/h. This would deliver an annual dose equivalent of 1 ± 0.5 mSv/y. The gross airborne alpha activity caused by the exposure to ore dust would give a whole body dose of 7 mSv. Radon gas levels measured ranged from 30 Bq/m^3 to 220 Bq/m^3 which were smaller than the derived air concentration limit of 1500 Bq/m^3. The author calculated the average annual dose from radon to be 1.7 mSv by assuming an average concentration of radon gas to be 100 Bq/m^3 and the equilibrium factor to be 0.5. This low level of radon gas was associated with high levels of ventilation caused by numerous large open windows. Although thoron levels were not measured, the author states that the high ventilation rates would also reduce the thoron progeny concentration to significantly lower levels than the radon progeny. The article highlights how radioactive dust is the greatest source of potential radiation exposure in this mineral sand processing plant.

Haridasan et al. (2008) studied a rare earth compounds production facility that uses caustic digestion of the mineral followed by selective acid extraction to separate the rare earth fraction. The monazite processed contained 9% ThO_2 and 0.35% U_3O_8. The external gamma radiation dose was estimated to be 0.7 mSv/y and the inhalation dose was calculated to be 1.22 mSv/y resulting in a total dose of 1.92 mSv/y.

A study in China on thorium lung burdens in rare earth and iron mine miners was conducted in 2005. The study compared high dust exposed and low dust exposed miners. The dust produced in the mines contained 10% silica and 0.04% thorium by weight, comparable to the approximate 0.02% thorium in Thor Lake ore. The thorium lung burden estimates for the high dust exposed miners was almost 3 times larger than the lung burden estimates for the low dust exposed miners. It was found that 18.75% of the high dust exposed group had a case of pneumoconiosis compared to only 1% in the low dust exposed group. There was also significant severe breathlessness observed in the high dust exposed group compared to the low dust exposed group. It was suggested that the observed health effects were mainly caused by the SiO_2 component of the dust rather than the thorium component due to the low concentration of thorium (Chen et al, 2005).

A study by Terry and Hewson (1995) measured thorium lung burdens in dry separation plant workers in the mineral sands industry in Western Australia. It was calculated that these workers received an average annual committed effective dose of 8 mSv. Two and eight workers were found to have a dose (averaged over their working period) of over 50 mSv/y and 20 mSv/y, respectively. The eight workers have been employed at the plant for over 6 years and most of their exposure occurred in the earlier years of their employment when there was a lack of proper dust control measures.

Radon and Thoron dose

Annual radon and thoron lung dose were measured and calculated in a rare earth pilot processing plant in Bangkok, Thailand. The lung doses calculated were up to 0.7 mSv/y due to radon and up to 2.4 mSv/y due to thoron (for 2000 hours per year) (UNSCEAR 2008).

Appendix G.2

Preliminary Results of Radiological Pathways Assessment Memorandum.

SENES Consultants Limited

MEMORANDUM

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Introduction and Objective

SENES Consultants Limited (SENES) has been contracted by Avalon Rare Metals Incorporated (Avalon) to conduct a Radioactivity Pathways Assessment of the Thor Lake Project, a proposed rare earth mineral mine and processing facility on Great Slave Lake, Northwest Territories. The Thor Lake Project has three main components located at two sites: the Nechalacho Mine and Flotation Plant (within the East Arm of Great Slave Lake), and the Hydrometallurgical Plant (southern shore of Great Slave Lake). The screening level pathways assessment examined the potential exposure of human and ecological receptors to radiological contamination from the Thor Lake Project. This memorandum presents an overview of the methodology used to conduct the pathways assessment, valued ecosystem components (VECs) and receptors, constituents of potential concern (COPC), as well as preliminary findings of the assessment.

A radiological exposure pathways assessment was conducted to evaluate contaminant sources, assesses the environmental fate of released radioactive species, and estimate doses to members of the working public, people who hunt, fish or live in the surrounding area, and to non-human biota (aquatic and terrestrial receptors) present in the area.. Utilizing findings of baseline studies of environmental media and receptors (Stantec 2010), test-run laboratory results of mine wastes (SGS 2010); mathematical modelling of air dispersion (RWDI 2011) and water dispersion (EBA 2011), the potential risks to both the human and ecological populations were assessed.

The assessment exclusively examined pathways of radiological exposure to ecological and human receptors, and did not assess other potential contaminants to receptors (e.g. metals, organic compounds). The assessment of potential radiation exposures to workers is provided under separate cover (SENES 2011).

Assessment Methodology

For the current work program, the environmental modelling and pathways analysis were performed at a screening level and, as such, simplifying assumptions were made. Environmental modelling estimated the steady-state (long-term) concentrations of the COPC in the environmental media of interest. Pathways modelling combines the receptor characteristics (i.e., ingestion rate, body weight, time at site, etc.) with the estimated environmental media concentrations of COPC to estimate exposure of each receptor. For this screening level assessment, a spreadsheet pathways model was used. This spreadsheet model was built on the INTAKE pathways model, which calculates exposures and doses to ecological and human receptors. The INTAKE model has been applied to several uranium mining projects in northern Saskatchewan to simulate radiological and non-radiological constituent fate and transport in the environment and the subsequent evaluation of exposures to ecological species and humans. The dose estimates are then compared to appropriate limits in the risk assessment to identify any areas of concern.

The focus of this assessment is to evaluate radiation exposure pathways to members of the public and biota living in and around the project area. Two receptors were selected to represent the members of the public, member of the local First Nations that may obtain some country food in the area; and, members of the working public (e.g. camp cook, office worker). The Nechalacho Mine and Flotation Plant site was evaluated separately from the Hydrometallurgical Plant Site, as the two areas are distant from each other with differing infrastructure, processes, and land use which results in unique pathways for the two sites.

The pathways assessment methodology utilized the following procedures to assess the exposure and risk attributable to the Thor Lake Project:

A. *Identification and Characterization of VECs and Receptors*: Principal components of the ecosystem were selected on a site-specific basis, with receptors selected to best represent the ecosystem and identify potential impacts.

B. *Identification and Characterization of COPC*: Radiological COPC were identified for the Thor Lake Project. The parameters necessary to model the fate and transport of the selected COPC (e.g. transfer factors) were collected for use in the assessment.

C. *Pathways Assessment*: The potential exposure pathways of the COPC to each of the selected receptors was identified for the two sites of the Thor Lake Project.

D. *Risk Characterization*: INTAKE spreadsheets were utilized to quantify the exposure and dose to receptors from all pathways. Radioactivity doses were compared to benchmarks set to be protective of the receptors, to identify potential radioactivity hazards to receptors.

Valued Ecosystem Components (VEC) and Receptors

Valued Ecosystem Components (VECs) in the existing environment are environmental attributes or components identified as having a "legal, scientific, cultural, economic or aesthetic value". From each VEC, a suitable receptor was selected for use in the pathways assessment. Using the VEC selection criteria, the findings of the Baseline Wildlife Studies (EBA 2010), wildlife species with special conservation status (under Canada's Species at Risk Act (SARA) or by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC)), and species known to have particular importance (as a food source or of cultural significance) to local First Nations communities, receptors were selected for inclusion in the assessment.

Exposure of ecological receptors to radioactivity was considered in both the aquatic and terrestrial environment. Receptors in the aquatic environment were selected to include consideration of external radiation from water and sediment as well as radiation exposure through water consumption, and through the consumption of fish, benthic invertebrates and aquatic vegetation. Terrestrial receptors were chosen in consideration of radiation through direct sources (e.g. gamma radiation), intake of water, and consumption of food sources. Ecological receptor characteristics were assumed to represent a reasonable maximum exposure scenario, in that cautious assumptions were made regarding the receptor's behaviour and home range.

The ecological receptors that have been selected for inclusion in the pathways assessment include the following:

- Aquatic biota (including aquatic plants, benthic invertebrates, predatory and forage fish, etc.)
- Waterfowl (mallard, merganser, and scaup);
- Predatory birds (Peregrine falcon);
- Small mammals (hare);
- Predatory large mammals (wolf and black bear); and,
- Non-predatory large mammals (barren-ground caribou and moose).

The human receptors selected for the evaluation are a working member of the public (e.g. site cook or security guard) and First Nations members who hunt in the area.

Constituents of Potential Concern (COPC)

The average uranium concentration in Thor Lake ore (about 24 ppm) is higher than typical background rock and soil levels (which would typically be less than 10 ppm except in areas of mineralization) but is far below those of even very low grade uranium deposits (e.g. 1000 ppm). Average thorium levels in the Nechalacho deposit are higher at about 130 ppm (SENES 2011). Site-specific COPC were identified for the Thor Lake Project. Radionuclides of potential concern include the thorium series radionuclides (including thorium-232, radium-228 and thorium-228) and the uranium series (including uranium-238, thorium-230, radium-226, lead-210 and polonium-210). These radionuclides will normally be in secular equilibrium (i.e., each radionuclide will be present at the same activity, Bq/g, as the parent U-238 for the uranium -238 decay chain, and as the parent Th-232, for the thorium-232 decay chain. This allows for radioactivity to be calculated from the mass concentrations of U and Th, where radioisotope concentrations are unavailable.

Baseline and incremental radionuclide concentrations were determined from available baseline studies (Stantec 2010), mine material assessments (SGS 2010), air quality modelling (RWDI 2011), and water modelling (EBA 2011).

Exposure Pathways

A conceptual site model was developed for the Nechalacho Mine and Flotation Plant site, identifying potential pathways of exposure. This site consists of an underground mine, diesel generator, flotation plant, tailings management facility, and docking area. COPC may be introduced to the water and sediment through the use of the Thor Lake water system as a Tailings Management Area (TMA). Ore extraction, transfer, and processing may introduce radiological COPC to the air as suspended particulate, which may be respired by receptors, or fall as dust to enter the soil profiles and be taken up by vegetation. Radioactivity pathways to human and ecological receptors were determined using conservative assumptions and are provided in Table 1. Source terms included in the Nechalacho Mine and Flotation Plant models include:

- Air emissions of radon;
- Total of dust emitted from mining, milling, and site operations (RWDI 2011) which was used to estimate the radionuclides associated with dust; and
- Radionuclide concentrations in Thor Lake, modelled from inputs to the upstream tailings management area (EBA 2011).

Table 1 Nechalacho Mine and Flotation Plant Exposure Pathways

Receptor*	EXPOSURE PATHWAYS					
	Intake of Water	**Intake of Terrestrial Vegetation**	**Inhalation of Dust+**	**Radon**	**Consumption of Aquatic Biota**	**Consumption of Game (waterfowl, hare, caribou)**
Camp Cook**	Y[A]	N	Y[B]	Y[B]	N	N
First Nations***	Y[A]	Y[B]	Y[B]	Y[B]	Y[A]	Y
Aquatic Biota	Y[A]	N	N	N	Y[A]	N
Waterfowl	Y[A]	N	Y[B]	N	Y[A]	N
Predatory Birds	Y[A]	N	Y[B]	N	Y[A]	Y
Non-Predatory Terrestrial Birds	Y[A]	Y[B]	Y[B]	N	N	N
Small Mammals	Y[A]	Y[B]	Y[B]	N	N	N
Large Predators	Y[A]	N	Y[B]	N	Y[B]	Y
Non-Pred. Large Animals	Y[A]	Y[B]	Y[B]	N	Y[B]	N

* Conservative assumptions made for all receptors. Receptors placed in the location of maximum possible exposure (Nechalacho Mine and Camp Area).
N=No Exposure
Y=Exposure possible, quantified in assessment
**=Workers are not permitted to hunt or consume local biota while on site
***=Members of First Nations groups are not expected to occupy the main mine area, but are assessed at this location as a conservative assumption
+=Dust was conservatively assessed assuming 100% ore when in fact both ore and waste rock are associated with mining.
A=Thor Lake
B=Nechalacho Mine/Camp Area

Owing to the absence of radiological source data for the downstream environments, First Nations groups were conservatively modeled to obtain food and water from the Thor Lake Project area proper. Adult and toddler age groups were assessed, using studies of traditional land use and food consumption to determine exposure scenarios.

At the Hydrometallurgical Plant Site, there were no pathways identified that could lead to a significant incremental increase in radioactivity exposure for receptors. Ore is to be containerized while mobilizing to and from site, and hydrometallurgical processing is within an enclosed facility. Results of air quality modelling at the site indicated there is no significant increase to suspended particulate or dustfall due to the Hydrometallurgical Plant, with no subsequent loadings of particulate (or radioactive particulate) to the air, soil, or vegetation. The tailings slurry is to be discharged to the L-37 pit (former pit within the brownfield site), and excess water to the N-42 pit. The pits are isolated from the surface hydrological regime and tailings water will discharge to the groundwater system, requiring decades within the groundwater flow regime before discharge to Great Slave Lake. The residence time, dilution factors, and processes of natural attenuation in flow through porous media, eliminate the groundwater pathway as a source of radiological concern. There are consequently no pathways of incremental radioactivity due to the Hydrometallurgical Plant Site, and the plant was removed from the assessment.

Dose Characterization Summary

The water quality modelling (EBA 2011) showed that the impact of radionuclides in the tailings is expected to be low; additional calculations showed that potential radon concentrations due to mine emissions were very low. Dose Coefficients (DCs) were used to estimate the doses to human receptors as a result of ingestion and inhalation exposure. The incremental doses were then compared to the dose constraint of 0.3 millisieverts per year (300 µSv/y) recommended by Health Canada in the Canadian NORM Guidelines (Health Canada 2000). Doses below this level are considered as “unrestricted” and no further action is needed to control doses or materials. Since the appropriate comparison benchmark is incremental, the estimated doses exclude background. The estimated doses to both the site worker and a member of the First Nations were well below the dose constraint.

The results of the pathways assessment showed that the dose to aquatic biota were below the accepted benchmark dose. A range of values of relative biological effectiveness (RBE) for alpha radiation were used in the assessment to account for the uncertainty associated with the choice of RBE. The results showed that no adverse effects on aquatic biota are expected from the release of low levels of radionuclides to the water.

Similar to the approach adopted for aquatic biota, a range of RBE and dose benchmarks were used in the assessment of terrestrial biota. The results showed that no adverse effects on terrestrial biota are expected from the release of low levels of radionuclides to the air and water.

Considering the conservative nature of the calculations, it is unlikely that there would be any environmental impacts resulting from exposure to radioactivity from the Thor Lake site.

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