VHM Limited

Goschen Mineral Sands and Rare Earths Project

Radiation Impact Assessment

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EXECUTIVE SUMMARY

Overview

This technical report is an attachment to VHM Limited's Goschen Rare Earth and Mineral Sands Project (the Project) Environment Effects Statement (EES). It has been used to inform the EES required for the Project.

Existing environment

The defined Study Area for the Project's Radiation Impact Assessment is predominantly cleared flat land, dissected by dirt roads (bordered by remnant vegetation verges), with scattered farming residences. The land is predominately used for mixed cropping purposes with occasional livestock grazing. Groundwater is not consumed or used for cultivation due to its high salinity. There are no bodies of surface water.

The Study Area's existing radiological environment has been assessed by monitoring which commenced in 2018 and is on-going. The radiological environment is consistent with general Australian and world radiological characteristics, though it should be noted that Rn-220 concentrations are higher than in areas where lower geological thorium concentrations are present. Additionally, groundwater radium levels are elevated.

Impact assessment findings

An iterative assessment was undertaken to evaluate potential radiological impacts associated with the Project, considering the existing environment within the Study Area and associated construction, operational and decommissioning activities.

The assessment found the following key impacts due to the Project:

- A conservative maximum dose to members of the public of 0.19 mSv/y. This is below the dose limit of 1 mSv/y.
- The radiological impact to flora and fauna, as assessed using the ERICA tool, is below the screening level of 10 µGy/h, with the maximum absorbed dose rate being 0.47 µGy/h for lichens and bryophytes.

- The radiological impact to grain crops is assessed to be minimal, as the modelled Project originated soil radionuclide increments are within the analysis error bands for existing soil radionuclide levels. For crop radionuclide activity concentrations, the calculated project increment is one to two orders of magnitude less than that calculated to currently be in the crops, based on the existing soil radionuclide activity concentrations.
- The radiological impact to groundwater is assessed to be low, due to the inert nature of the tailings, and also because the activity concentration of the tailings will be less than that of the activity concentration of the ore.
- The activity concentration of ore and tailings are less than 1 Bq/g. Some products with activity concentrations exceeding 1Bq/g will be stored at the processing facility, however, these products will be encapsulated, and impact to the environment is assessed to be not significant.

The assessment found the following key impacts due to the transportation of Project product materials:

- A conservative maximum dose to humans in the vicinity of the Ultima intermodal facility of 0.80 mSv/y, during Phase 1 of production, which is below the dose limit of 1 mSv/y. Once transport operations commence, monitoring will be conducted to verify the conservative nature of the assessment, and if necessary additional controls will be implemented. The dose reduces to a conservative maximum of 0.12 mSv/y for Phases 1a and 2.
- A conservative total dose to members-of-the public during the road or rail transportation of product material is 0.010 mSv/y.

Control measures

Potential radiological impacts due to the Project will be avoided, or minimised and managed to required standards through the recommended control measures which will be incorporated into the Radiation Management Plans. The recommended control measures are listed below.

Mechanical Controls, incorporated during mining and transportation of ore, will include:

- Dust minimisation and suppression systems.

Engineered Controls, incorporated during the design and construction of the Project, will include:

- tailing pipeline pumps fitted with *auto-stop* if a leak is detected,
- bunding for tanks,
- access and hose-down facilities for ease of clean up,
- drainage to sumps,

- extraction with baghouse system,
- contained storage of products,
- contained product packing,
- vehicle wash-down prior to exiting site, and
- restricted access to plant and product storage areas.

Administrative Controls will include:

- radiological contamination and clearance of equipment prior to leaving site,
- scheduled maintenance, and
- routine monitoring and reporting.

Mitigation measures

Potential radiological risks due to the Project will be avoided, or minimised and managed to required standards, through the Radiation Management Plans which will incorporate routine monitoring to identify any exceedances, and detail control measures which will be implemented to reduce impact.

QUALITY INFORMATION

Document Technical report N: Radiation Impact Assessment

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Prepared by Rose Secen-Hondros & Jim Hondros

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ABBREVIATIONS

Ac	actinium
ALARA	As Low As Reasonably Achievable with economic and social considerations
AMAD	Activity Median Activity Diameter
ARPANSA	Australian Radiation Protection and Nuclear Safeguards Agency
Bq	becquerel
DCCEEW	Department of Climate Change, Energy, the Environment and Water
EE Act	Environment Effects Act 1978
EES	Environment Effect Statement
EPBC	Environment Protection and Biodiversity Conservation
ERML	Environmental Radiation Monitoring Location
F_{eq}	equilibrium factor
ft	foot
g	gram
GL	giga litre
GPS	Global Positional System
Gy	gray
h	hour
HMC	heavy mineral concentrate
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
km	kilometre
L	litre
m	meter
M	mega
MREC	Mixed Rare Earth Carbonate
mSv/y	milli sievert/year
NHB	Non-Human Biota
OSL	Optically Stimulated Luminescence
Pb	lead
Po	polonium
ppm	parts per million
Ra	radium
REMC	Rare Earth Mineral Concentrate
REP	Radiation Environmental Plan
RMP	Radiation Management Plan
Rn	radon
Rn-220	radon-220
Rn-220DP	radon-220 decay product
Rn-222	radon-222
Rn-222DP	radon-222 decay product
ROM	run of min
RWMP	Radiation Waste Management Plan
Sv	sievert
Th_{nat}	Th-232 and it's decay products in secular equilibrium
U	uranium
U_{nat}	U-238 and its decay products in secular equilibrium
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
y	year

GLOSSARY

absorbed dose	The quantity of energy imparted by ionising radiation to unit mass of matter such as tissue.
activity	The rate of decay of radioactive material expressed as the number of atoms breaking down per second measured.
becquerel (Bq)	The unit of activity in System Internationale (SI), equivalent to one disintegration per second.
decay	The process of spontaneous transformation of a radionuclide. The decrease in the activity of a radioactive substance.
decay product	A nuclide or radionuclide produced by decay. It may be formed directly from a radionuclide or as a result of a series of successive decays through several radionuclides.
dose	A measure of the energy deposited by radiation in a target.
dose limit	The value of the effective dose or the equivalent dose to individuals in planned exposure situations that is not to be exceeded.
exposure pathway	A route by which a radionuclide or other toxic material can enter the body.
gray (Gy)	A measure of absorbed dose.
half-life	The time taken for the activity of a radionuclide to lose half its value by decay.
isotope	Nuclides having the same atomic number (number of protons) but different mass number (number of neutrons).
radioactive	Material that contains unstable atoms that give off radiation as they decay.
radionuclide	An unstable nuclide that emits ionising radiation.
radon	Both Rn-222 and Rn-220.
radon decay products	The short lived daughter isotopes of radon.
Rn-220	The radon isotope in the Th-232 decay chain
Rn-220DP	The decay products (daughter isotopes) of Rn-220, namely Po-216, Pb-212, Bi-212 and Tl-208
Rn-222	The radon isotope of the U-238 decay chain
Rn-222DP	The decay products (daughter isotopes) of Rn-222, namely Po-218, Pb-214, Bi-214 and Po-214
secular equilibrium	The condition that the activity (or activity concentration) of a radioactive decay product with a short half-life is equal to the activity (or activity concentration) of its much longer-lived parent radionuclide
sievert (Sv)	The SI unit of equivalent dose and effective dose.

1.0 INTRODUCTION

The aim of this report is to provide an assessment of the radiation related impacts to the public and to non-human biota for the VHM Goschen Project (the Project) in North-west Victoria.

This report consists of the following:

- An outline of the relevant radiological characteristics of the Project.
- A description of the assessment methods.
- Identification of the critical exposure groups.
- An assessment of the radiological impacts to the exposure groups.
- An assessment of the radiological impacts to a standard set of representative flora and fauna (referred to as non-human biota (NHB)).
- A description of the proposed management measures to ensure that radiation impacts are As Low As Reasonably Achievable (ALARA).

1.1 REQUIREMENT FOR AN EES

The Project was referred to the Minister for Planning to seek advice on the need for an EES under the Environment Effects Act 1978 (Vic) (EE Act).

On 10 October 2018, the Minister for Planning decided that an EES was required on the basis that the Project has the potential for a range of significant environmental effects.

On 19 December 2018 under delegated authority from the Minister for the Environment, the Department of the Environment and Energy (now referred to as the Department of Climate Change, Energy, the Environment and Water (DCCEEW)) made a decision that the Project is a controlled action under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act) and would require assessment and a decision about whether approval should be given under the EPBC Act. DCCEEW also confirmed the Victorian Government's advice that the Project will be assessed under a bilateral agreement under the EE Act.

The EES allows stakeholders to understand the likely environmental impacts of the Project and how they are proposed to be managed. The Minister's assessment of the EES will also inform statutory decisions that need to be made on the Project.

The EES was developed in consultation with the community and stakeholders.

2.0 PROJECT DESCRIPTION

2.1 PROJECT OVERVIEW

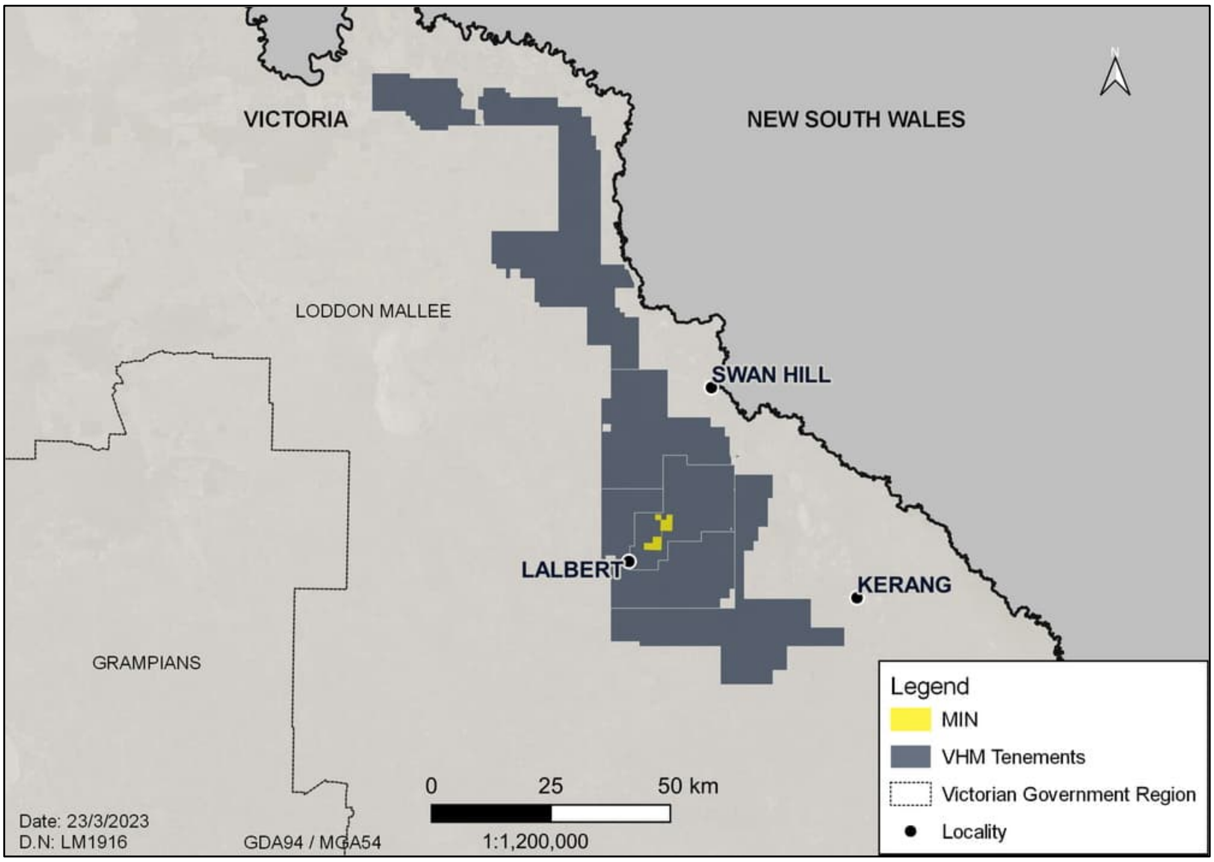
The Goschen Project is a rare earth and mineral sands mine and processing facility anticipated to operate for approximately 20 -25 years. VHM has been developing the Project in the context of a rapidly growing global demand for rare earths. One of the world's largest, highest grade zircon, rutile and rare earth mineral deposits is in the Loddon Mallee region of Victoria in Australia. VHM intends to establish the Project to mine these deposits, and process to produce and market a range of products to national and international consumers.

The mine footprint has been restricted to avoid direct intersection with groundwater and significant areas of remnant native vegetation. VHM will implement a staged development approach:

- Phase 1 will consist of a mining unit plant (MUP), wet concentrator plant (WCP) and rare earth mineral concentrate (REMC) flotation plant. The product suite for Phase 1 consists of a zircon/titania heavy mineral concentrate (HMC) and rare earth mineral concentrate (REMC).
- Phase 1a will commence approximately 18 months post-production and consist of a hydrometallurgical plant that will further refine the REMC. The product suite for Phase 1A consists of a zircon/titania heavy mineral concentrate (HMC) and mixed rare earth carbonate (MREC).
- Phase 2 will commence approximately 2 years post-production and consist of an additional mineral separation plant (MSP) and, subject to prevailing market circumstances at that time, hot acid leach (HAL) and chrome removal circuit, that will produce additional products such as premium zircon, HiTi rutile, Leucoxene, low chromium ilmenite and zircon concentrate.

The Goschen Project is located approximately 4 hours' drive (275 kilometres) northwest of Melbourne and 30 minutes (35 km) south of Swan Hill within Gannawarra Shire (Figure 1).

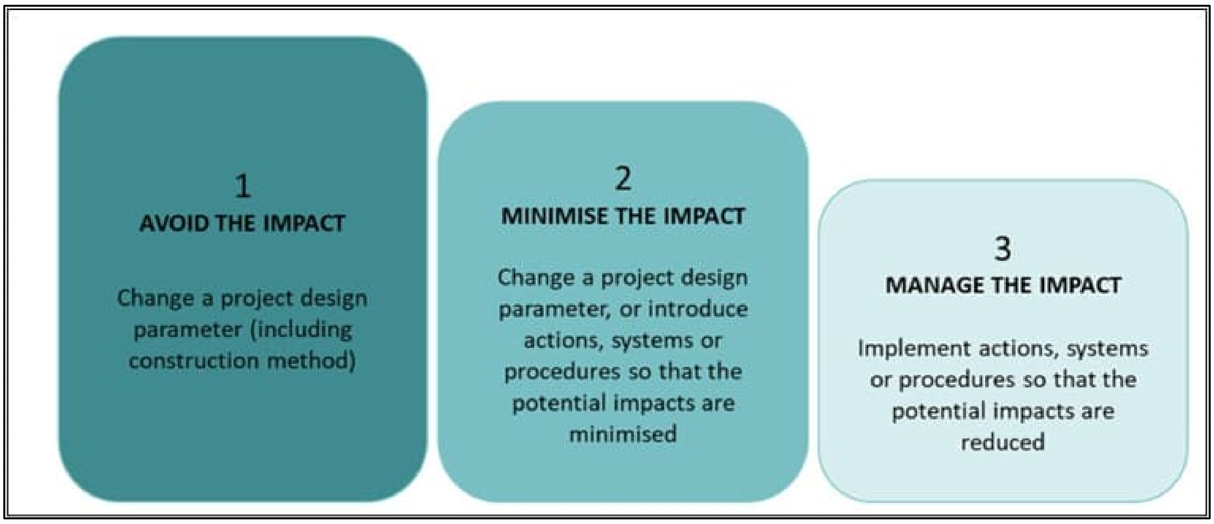
Figure 1: Goschen Project Location



2.2 PROJECT DEVELOPMENT

It is recognised that there are opportunities to avoid and minimise environmental impacts during the many stages of project development. During project inception and early design development stages of the project, decisions on the location of the project, its design and construction techniques have enabled impacts to be significantly avoided and minimised in accordance with the hierarchy presented in Figure 2.

Figure 2: Mitigation hierarchy



Avoidance and minimisation of social and environmental impacts is central to the project's decision making and as such, the project will continue to be refined in response to technical requirements and potential environmental and social impacts identified during the development phase.

This was considered in the preparation of a project description which is found at Chapter 4: Project description. A description of how avoidance of impact has informed the design in relation to potential radiological impacts can be found in Section 0.

After opportunities to avoid impact were incorporated into the project, minimisation and rehabilitation measures were developed. These are described in the construction and operation impact assessment sections that follow.

2.3 KEY PROJECT COMPONENTS

The Project site consists of a heavy mineral sand mining and processing operation that will produce several heavy mineral products and a range of critical rare earth minerals across two defined mining areas known as Area 1 and Area 3 (Figure 3 and Figure 4).

Figure 3: Project Area 1

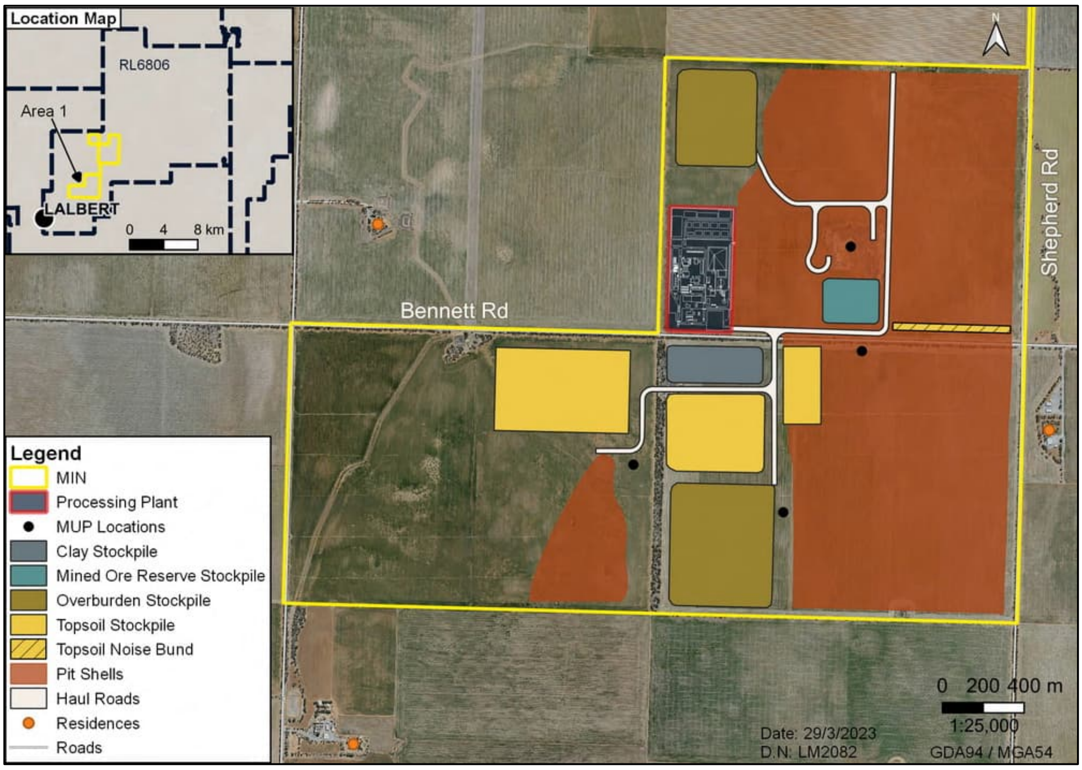
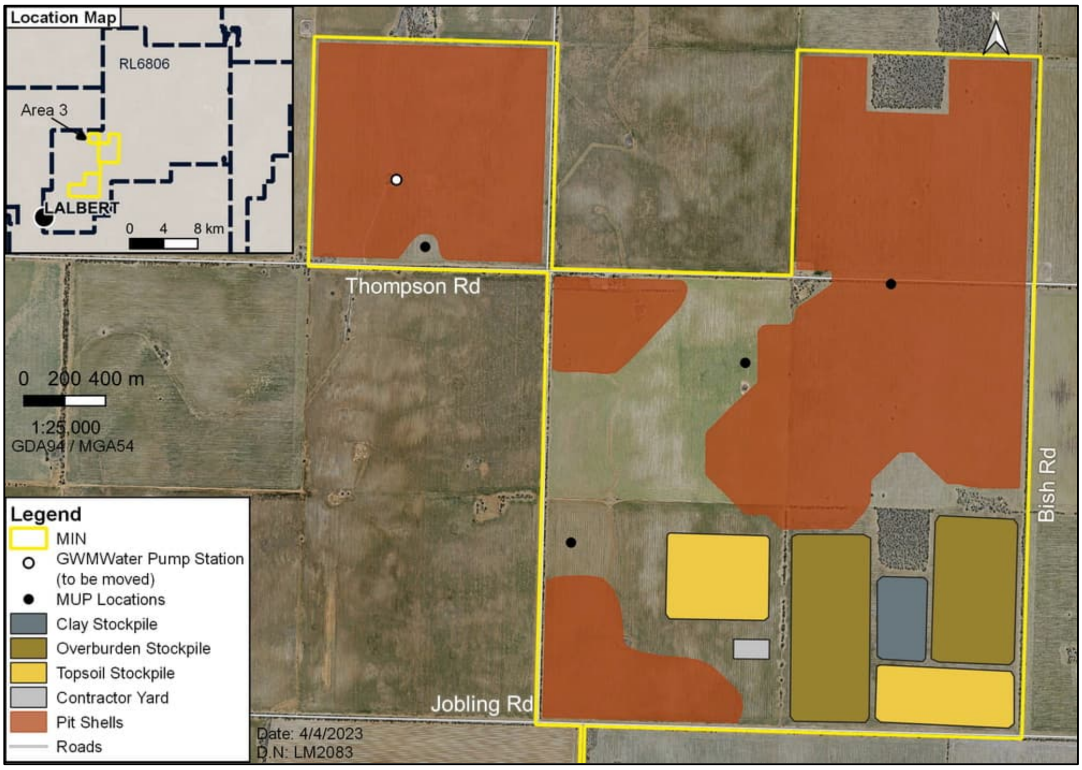


Figure 4: Project Area 3



The key components that make up the project are described below.

Mining – Mining will take approximately 20 - 25 years at a rate of 5 M tonnes of ore per year and will occur only above groundwater (no dewatering) across approximately 1,479 hectares of farmland using conventional open cut mining methods of excavation, load, and haul.

Processing – Heavy mineral sands and rare earths minerals will be separated via an on-site WCP and MSP to generate a Rare Earth Mineral Concentrate (REMC) and various mineral sands products. Refining of the REMC on-site is limited to hydrometallurgical extraction to produce a mixed rare earth carbonate. Tailings from the various mineral processes will be homogenised and returned to the ore zone previously mined.

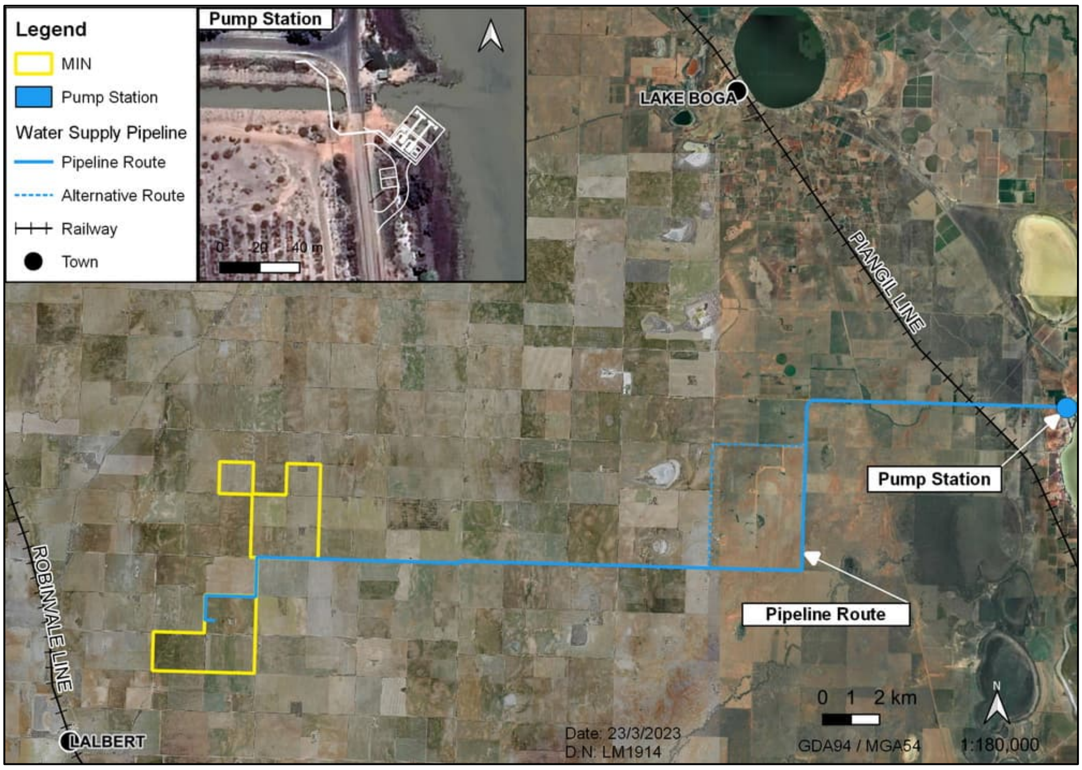
Rehabilitation – The mined areas will be progressively backfilled in a staged manner, with tailings dewatered in-pit to allow overburden and topsoil placement in a profile that reinstates the background soil structure. This will result in the ability for a return to the current agricultural land uses within 3 years.

Power – Electrical power needed for mining and processing will be produced on-site from dual fuel diesel/LNG fired power generators, with a gradual evolution over the life of mine to renewables, hydrogen and/or battery as technologies and commercial viability increase. Heat energy for the on-site gas fired appliances shall be provided from an extension of the distribution network from the main LNG storage and regasification system.

Transport – Final products shall be containerised in 20 ft sealed sea containers on site and exported via Melbourne Port using road and/or rail-based land logistics solutions. Ultima will provide intermodal rail solution, to reach the shipping export ports.

Water - Water will be required for construction earthworks, processing, dust suppression and rehabilitation. Up to 4.5 GL a year will be needed for the start-up of the Project. Water will be sourced from Goulburn Murray Water (GMW) from a new pumpstation at Kangaroo Lake via the open water market. A 38 km underground pipeline is proposed beneath existing local road easements as shown Figure 5 below. The section of the pipeline annotated as ‘alternative route’ shown in Figure 5 is not proposed to be constructed.

Figure 5: Proposed water supply pipeline route



3.0 SCOPING

3.1 EES EVALUATION OBJECTIVES AND SCOPING REQUIREMENTS

The May 2019 scoping requirements for the Goschen Mineral Sands and Rare Earths Project Environment Effects Statement ('scoping requirements') established by the Minister for Planning, set out the specific environmental matters the project must address in order to satisfy the Victorian assessment and approval requirements.

The scoping requirements include a set of evaluation objectives. These objectives identify the desired outcomes to be achieved in managing the potential impacts of constructing and operating the project in accordance with the *Ministerial guidelines for assessment of environmental effects* under the EE Act.

The following evaluation objective under Section 4.4 of the scoping requirements is relevant to the radiological assessment:

- To protect the health and wellbeing of residents and local communities, and minimise effects on air quality, noise and the social amenity of the area, having regard to relevant limits, targets or standards.

The key issues relevant to this assessment includes: the potential for risks to public health and safety and diminished social wellbeing at all stages of the project due to a range of factors including radiation. The aspects from the scoping requirements relevant to the evaluation objective are shown in Table 1 as well as the location where these items have been addressed in this report.

Table 1: Scoping requirements relevant to Radiation Impact

Aspect	Scoping requirement	Section addressed
Key issues	The potential for risks to public health and safety and diminished social wellbeing at all stages of the project due to radiation.	6.6.4 6.7.2 9.2 9.6
	Ore, product, overburden, tailings and mining by-products management, in the context of potential water quality impacts including those arising from the release of radionuclides.	6.6.5 9.5
	Comparison with the *nuclear action*s triggers of the EPBC Act. Note that this assessment considers only the radioactivity aspects of any EPBC Act assessment.	6.8 9.7
Existing environment	Characterise background radiation levels within the project site and the broader project area	6.3 7
	Identify sensitive receptors	6.2 6.6.2 6.7.1
	Describe the physical and chemical characteristics of overburden, ore, product, tailings and mining by-products to be removed during mine development and operations including specific aspects relevant to radiation	2.1 9.1
Likely effects	Assess likely radiation effects associated with the Project during operations, decommissioning and post-closure.	9.2 9.3 9.4 9.5 9.6
	Changes to groundwater and surface water quality at all project phases, including radionuclides.	9
Design and mitigation measures	Identify potential and proposed design responses and/or other mitigation measures in accordance with best management practice to avoid, reduce and/or manage any significant effects for sensitive receptors during the project construction, operation, rehabilitation, decommissioning and post-closure arising from adverse changes to the background radiation levels in the vicinity of the project (including the radionuclide content of vegetation, surface water and groundwater).	6.4 9.2.7 9.3.2 9.4.2 9.5.2 10
Approach to manage performance	Describe monitoring programs for potential effects on amenity, environmental quality, health and social wellbeing including a framework for identifying and responding to any emerging issue	10 Appendix D

4.0 EVALUATION FRAMEWORK

The assessment will consider legislation, policy, and standards relevant to Radiation Impact along with specific assessment criteria that have been derived for the purposes of the study.

4.1 LEGISLATION, POLICY, GUIDELINES AND STANDARDS

The legislation, policy, guidelines, and standards relevant to this Radiological Risk assessment are summarised in Table 2.

Table 2: Legislation, policy, guidelines, and standards relevant to the Radiological Risk assessment

Document title	Summary	Relevance to the project
International standards		
ICRP Publication 103, 2007 Recommendations of the ICRP [ICRP 2007-103]	The International Commission on Radiological protection (ICRP) is the internationally recognised authority on radiation protection and, based on scientific evidence, establishes the philosophical approach to radiation protection through a series of published recommendations. This document describes the System of Dose Limitation, which includes: • justification of a practice that results in radiation exposure, • optimisation of the delivered doses and controls to reduce dose (also known as the ALARA principle) • prescribed limits on dose.	The ICRP system of dose limitation is the recognised philosophical approach to radiation protection around the world. The system is used as the basis of IAEA standards and for National and State regulation of radiation. Reference to, and consideration of, the ICRP system is necessary to establish that the approach to radiation protection is at an International Standard. The dose limits have been adopted in regulations for Australia. The limit considers exposure from all exposure pathways, above natural background levels, and is: • 1mSv/y for members of the public who may be impacted by an activity
ICRP Publication 91, 2003 A framework for assessing the impact of ionising radiation on non-human species [ICRP 2003-91]	This document established that radiological impacts to environmental systems should be considered. This is a change from the previous ICRP position where the protection of people was assumed to automatically protect the environment.	The radiological impacts to the environment and non-human species are required to be considered for an activity. This has been adopted into National Standards in Australia.
ICRP Publication 137, 2017 Occupational Intakes of Radionuclides: Part 3. [ICRP 2017-137]	This document provides comprehensive tables of dose coefficients for naturally occurring radionuclides for both inhalation and ingestion pathways.	The dose coefficients are recognised in Australia by ARPANSA and are used in worker and public dose assessment.

Document title	Summary	Relevance to the project
IAEA Safety Standards Series GSR Part 3, 2014 Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [IAEA 2014]	The International Atomic Energy Agency (IAEA) is a body of the United Nations that provides International Standards and Guidance on radiation protection. IAEA documents are based on and are consistent with the philosophy developed by the ICRP. The IAEA produces a number of *Requirements* documents which are mandatory for member states of the IAEA. *Guidance* documents also provide international consensus on the standards for radiation protection. The IAEA GSR Part 3 document generally forms the basis for regulation in member states.	Confirms that National and State regulation is based on International consensus. Establishes the basic requirements for radiation protection in Australia.
IAEA Technical Reports Series # 472, 2010 Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments [IAEA 2010]	This document collates the results of international studies which have determined concentration ratios for the transfer of radionuclides into plants and animals. Though generally not regionally specific, the values can be used in a screening manner to identify if additional area specific work is necessary.	The TRS 472 concentration ratios are used to assess the potential ingestion doses from emissions from the project that impact the food chain.
Commonwealth government		
Environment Protection and Biodiversity Conservation Act (EPBC Act) 1999 [Au Govt 1999] and regulations made under the Act Environment Protection and Biodiversity Conservation Regulations (EPBC Act) 2000 [Au Govt 2000]	The nuclear action trigger for the EPBC Act refers to the radioactivity concentrations of materials. The nuclear action triggers are: • Ore, waste, or tailings with radioactivity that exceeds the prescribed concentrations. • Construction and operation of a facility for the disposal of material classified as radioactive waste. • Establishing, significantly modifying, decommissioning, or rehabilitating a facility where radioactive materials at or above a specified activity level are, were, or are proposed to be used or stored.	The activity concentration of mined materials and tailings do not exceed the threshold radioactivity concentrations for nuclear actions. Some of the products that the project will produce and hold for transport on site, are expected to be above the radioactivity threshold.

Document title	Summary	Relevance to the project
Australian Radiation Protection and Nuclear Safety Act (ARPANS Act) 1998 [Au Govt 1998] and regulations made under the Act Australian Radiation Protection and Nuclear Safety Regulations (ARPANS Regulations) 2018 [Au Govt 2018]	This Act aims to protect the people and the environment from the harmful effects of radiation, thorough the establishment of APRANSA and councils. The regulations provide details and definitions.	The regulations are referred to by the EPBC Regulations. The also include dose limits and references to Australian Standards and Codes.
Australian Standards		
ARPANSA 2005 Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (The Mining Code) [ARPANSA 2005]	The Australian Radiation Protection and Nuclear Safeguards Agency (ARPANSA) is the national authority on radiation protection and develops and endorses national standards and codes of practice. Whilst ARPANSA is only the regulatory authority for Commonwealth entities, its publications are adopted in State Regulations. The Mining Code outlines the expectations for radiation protection in mining and processing of radioactive ores.	The Mining Code provides guidance material for the assessment of doses. It also provides guidance for an operational Radiation Management Plan RMP.
ARPANSA 2010 Environmental Protection: Development of an Australian approach for assessing effects of ionising radiation on non-human species. Technical Report Series No. 154 [ARPANSA 2010]	In this document, ARPANSA published the results of their review into the international approach to assessment of radiological impacts to non-human biota, following on from the ICRP requirement to conduct such assessments. ARPANSA determined that the ERICA assessment method, and software tool, provided a suitable mechanism for assessment of impacts.	The ERICA assessment methodology has been used to assess the radiological impacts of the project.
ARPANSA 2015 Guide for Radiation Protection of the Environment (2015), Radiation Protection Series G-1 [ARPANSA 2015]	This document provides guidance on the methods to assess the radiological impacts to the non-human species based on recognised international methods and systems.	Establishes guidance on the use of environmental reference levels or generally applied screening levels (measured in Gy/h) for non-human biota. The minimum screening level from this document (10 µGy/h) is used in the assessment. It is noted that the screening level is not classified as a limit. It is a level, above which, a more detailed assessment is required.
ARPANSA 2019 Radiation Doses from the Average Australian Diet, Technical Report 181 [ARPANSA 2019]	This technical report document, provides useful guidance and reference material for the assessment of ingestion dose.	The diet used in TR181 has been used in the assessment of ingestion dose for the project.

Document title	Summary	Relevance to the project
ARPANSA 2019b Code of Practice for the Security of Radioactive Sources (2019) [ARPANSA 2019b]	This Code categorises radioactive sources and refers to security requirements for categories which are considered to pose a radiological security risk.	Provides the activity values and requirements for the Project's radioactive sources.
ARPANSA 2019c Code of Practice for the Safe Transport of Radioactive Material RPS C-2 [ARPANSA 2019c]	This Code provide the requirements for the transport of radioactive material in Australia.	Provides transport requirements including packaging, and labelling to ensure control of materials during transport, to ensure safety of emergency services, members of public and the environment.
ARPANSA Code for Radiation Protection in Planned Exposure Situations (2020) ARPANSA 2020	This ARPANSA Code aligns Australian requirements with the Planned Exposure requirements outlined in the International Basic Safety Standards - General Safety Requirements, IAEA Safety Standards Series GSR Part 3 [IAEA 2014].	The specific requirements of the Code are generally adopted in operational and radiation related management plans.
ARPANSA Updates Radiation Dose Conversion Factors 4 July 2022 [ARPANSA 2022]	ARPANSA recently published new guidance on dose factors for radon and thoron and their decay products on their website.	Guidance is used in assessing potential radiological impacts of the Project.
Victorian government		
Radiation Act 2005 [Vic Govt 2005]	Provides the legal basis for the management and control of radiation in Victoria, which is based on national standards and the ICRP system of dose limitation. The Act also provides a description of the optimisation requirements.	The Act is applicable to the project. Reference to definition of "optimisation" is used in the assessment.
Radiation Regulation 2017 [Vic Govt 2017]	Establishes the requirements for licenced facilities for radioactive materials based on prescribed levels of both the activity concentration and activity amount. Establishes the requirements for a management licence and use licences. Identifies the transport requirements for radioactive materials.	Some of the process streams and products from the project exceed the prescribed levels and a management licence is required. It is noted that the mined material and waste materials are not classified as radioactive materials. Establishes the dose limits for workers and the public. Note that the Regulations specifically refer to the Code for the Safe Transport of Radioactive Material (2014), which has been superseded by the 2019 version of the Code (referred to above).

4.2 ASSESSMENT CRITERIA

The assessment criteria relevant to this Radiation Impact Assessment are outlined in this section.

The assessment criteria for radiation impacts link back, through legislation, to the recommendations of the ICRP which are:

- A requirement to ensure that public doses do not exceed the dose limit.
- A requirement to ensure that any doses are As Low As Reasonably Achievable (ALARA).

The *dose limit* refers to the combined dose from all exposure pathways ,which are:

- gamma irradiation,
- inhalation of radionuclides in dust,
- ingestion of radionuclides, and
- inhalation of the decay products of radon.

The dose limit for members of the public is 1 mSv/y.

The criteria for ALARA are described in the Victorian Radiation Protection Act [Vic Govt. 2005] which notes that the magnitude of exposures, and number of people exposed, and the likelihood of exposure, should be kept *as low as reasonably achievable, taking into account economic, social and environmental factors*.

Assessment of whether ALARA has been achieved can be subjective, however, it is generally accepted that ALARA is demonstrated when unnecessary exposures have been minimised, and when the predicted and then measured doses, are well below the statutory dose limits. In practice, this may translate to compliance with a dose constraint. To this end the Project has established a dose constraint for the public of 0.3 mSv/y, and this dose constraint will be included in the Radiation Management Plans.

For impacts to non-human biota, the approach is to adopt the guidance provided in ARPANSA 2015 which notes that, a screening level of 10 µGy/h is a level above which more detailed assessments are required.

5.0 CONSULTATION AND ENGAGEMENT

Development of the project and preparation of the EES have been informed by consultation with stakeholders. Table 3 lists stakeholder feedback on the potential for radiological impacts and how this feedback has been considered in this impact assessment.

Table 3: Stakeholder engagement undertaken for Radiation Impact Assessment

Stakeholder feedback	Consideration in Project design or impact assessment
Department of Health – Victoria Health Protection Branch o Baseline Monitoring Requirements o Impact Assessment Requirements	o Comprehensive baseline monitoring program o Understanding of radionuclide deportment in process and activity concentrations
TRG Meeting (3/8/2022)	o Dose assessment o Dust monitoring and dust AMAD
Community Consultation Meetings (Kerang, Lalbert & Swan Hill (September 2022)	o Dose assessment o Soil radiological increment due to Project generated dusts

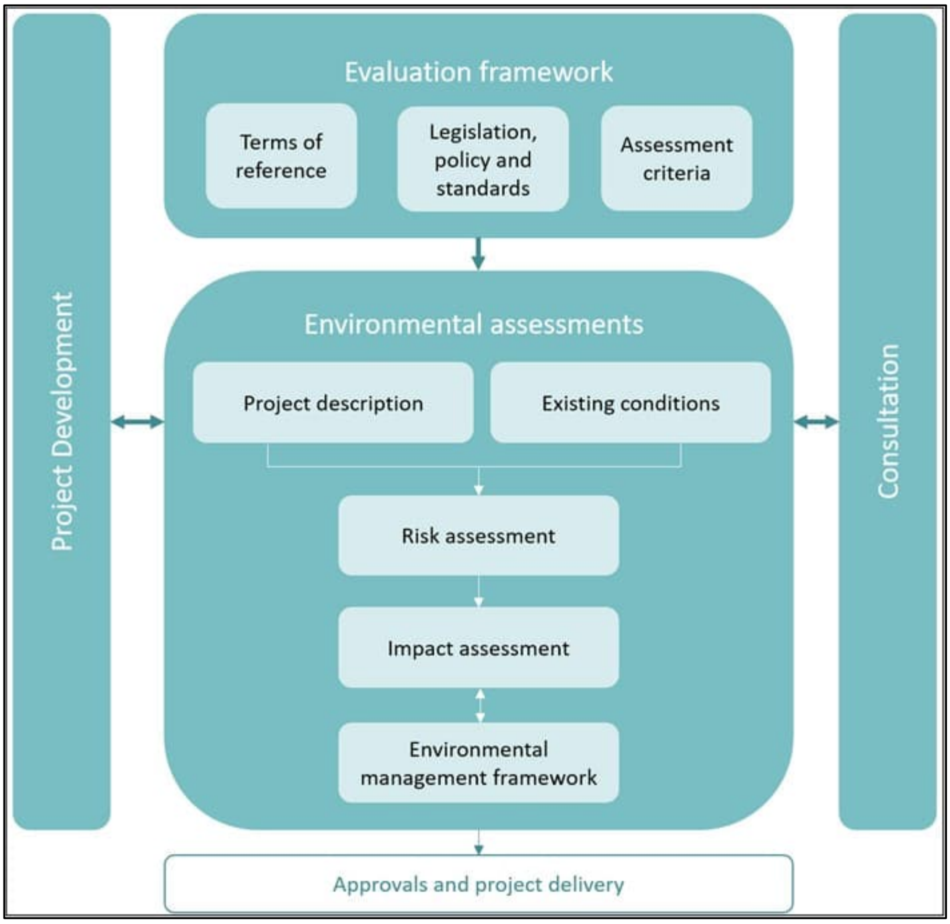
6.0 METHODOLOGY

6.1 OVERVIEW OF METHOD

This section describes the method that was used to assess the potential radiological impacts of the project. Figure 6 shows an overview of the assessment method. A risk-based approach was applied to prioritise the key issues for assessment and inform measures to avoid, minimise and offset potential effects.

The approach used in the assessment has been guided by the evaluation framework that applies to the project comprising the regulatory framework (that is, applicable legislation and policy) as well as the scoping requirements set by the Victorian Minister for Planning.

Figure 6: Overview of assessment framework



The environmental assessments were undertaken according to the following steps:

- Establishment of a study area and characterisation of existing environment.
- Review of the project description, comprising the key project components (including locations and form), proposed construction and operation activities (in the context of existing environment) and decommissioning activities to determine the location, type, timing, intensity, duration and spatial distribution of potential project interactions with sensitive receptors.
- An initial risk based analysis to evaluate the potential effects of proposed project activities and their likelihood of occurring (considering initial mitigation measures) to determine the relative importance of environmental impacts associated with the project and therefore prioritise issues for attention in the subsequent assessment of impacts. Initial mitigation measures would include measures that are common industry practice or required to meet legislation.
- An assessment of impacts that examines the severity, extent, and duration of the potential impacts and considers the sensitivity and significance of the affected receptors.
- Evaluation of predicted outcomes against benchmarks and criteria such as those described in applicable legislation, policy and standards.
- Evaluation of the potential for cumulative impacts (where relevant) caused by impacts of the project in combination with impacts of other existing and proposed projects that may have an overall significant impact on the same environmental asset.
- Identification of additional mitigation measures where necessary to address potentially significant environmental impacts.
- Evaluation and reporting of the residual environmental impacts including magnitude, duration and extent, taking into account the proposed mitigation measures and their likely effectiveness.

Based on the findings of the environmental assessments, an Environmental Management Framework (EMF) has been prepared to monitor and control environmental performance during project implementation. The EMF has specified the committed control measures to avoid, minimise and manage impacts, proposed contingency measures and offset commitments, and describe the roles and responsibilities for implementation throughout project construction, operation and decommissioning.

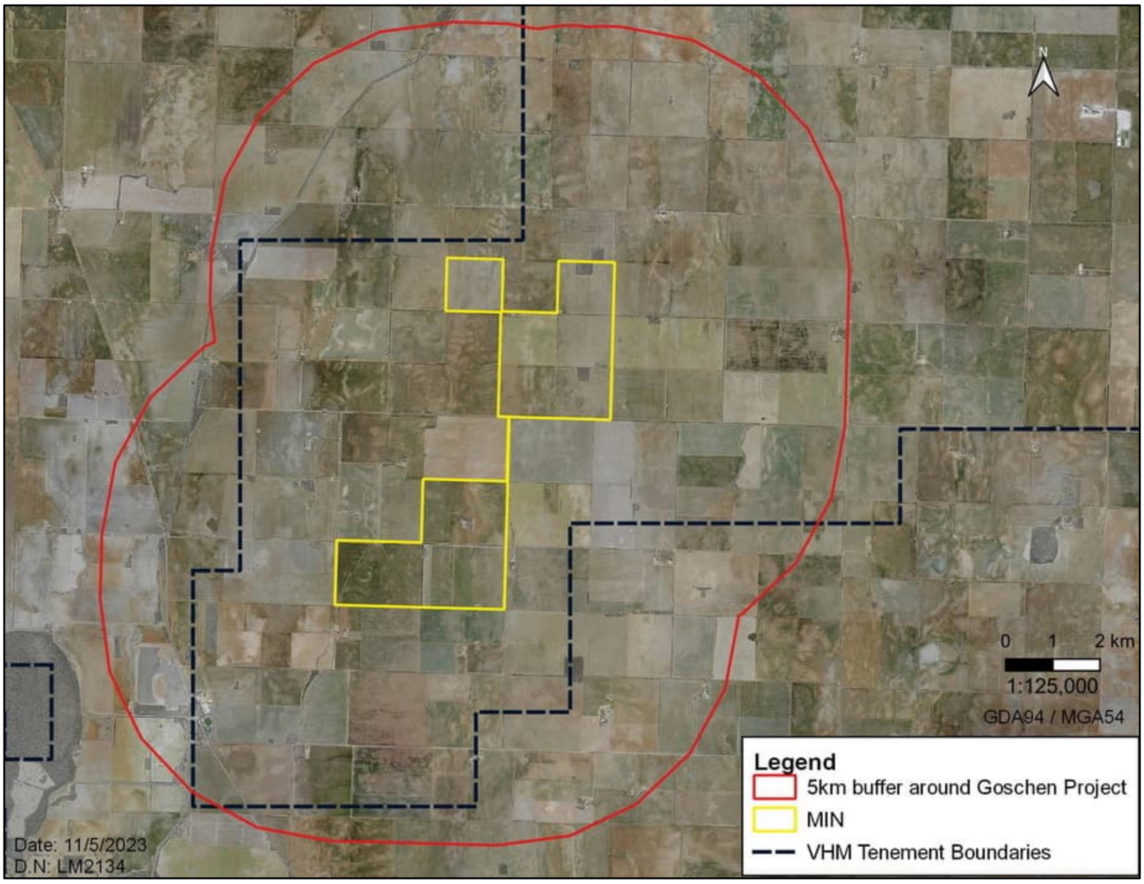
The specific methods adopted during the key steps are described in the sections below.

6.2 STUDY AREA

6.2.1 PROJECT STUDY AREA

To quantify the existing radiological environment at the Project and nearby receptors, the Radiation Impact Assessment Project Study Area (Study Area) was defined as, the area within a 5 km zone around the Project. The Study Area is shown in Figure 7.

Figure 7: Study Area



The Project's radiological emissions will be airborne. The SLR Air Quality Assessment [SLR 2022] Appendix G modelling has identified that deposition and dispersion processes result in, negligible Project generated radiological increments, beyond the Study Area.

6.2.2 Transport Study Area

All product from the Project will be packed on site in sealed shipping containers, and will be transported via road and rail. The Transport Study Area (TSA) includes:

- the 46 km road route from the Project to the Ultima intermodal facility (as shown in Figure 8),
- the storage facility at Ultima (as shown in Figure 9),
- the potential rail and road transport routes from Ultima to the Port of Melbourne (shown in Figure 10), and
- the port facilities.

Figure 8: Road transport route from Project to Ultima intermodal facility

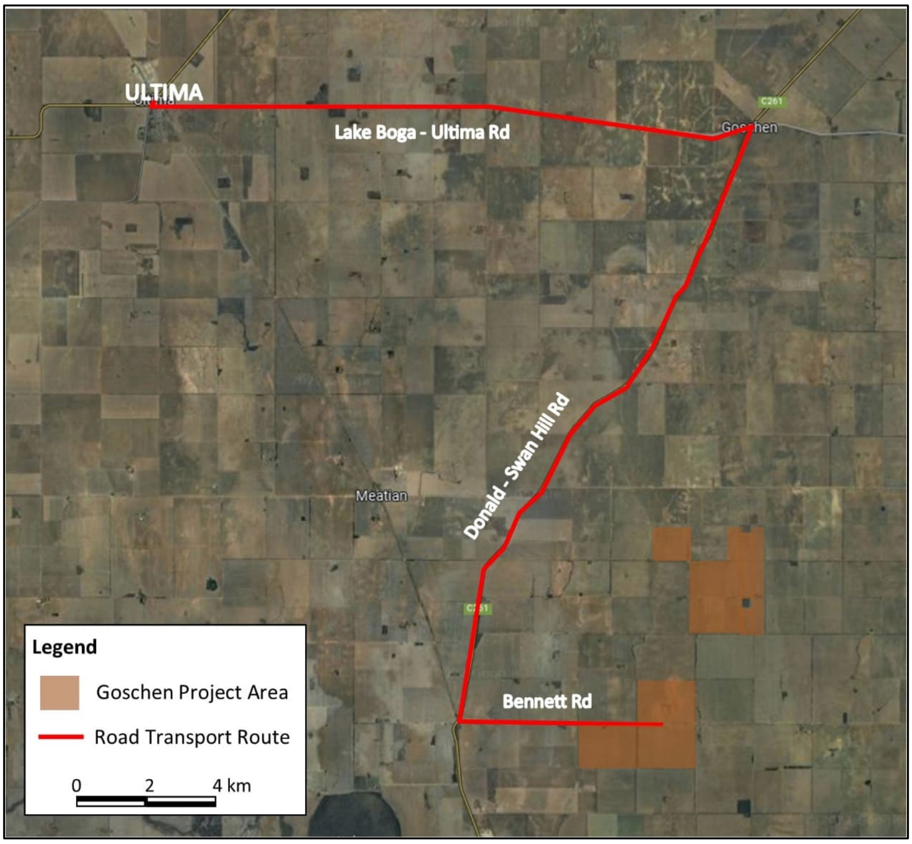
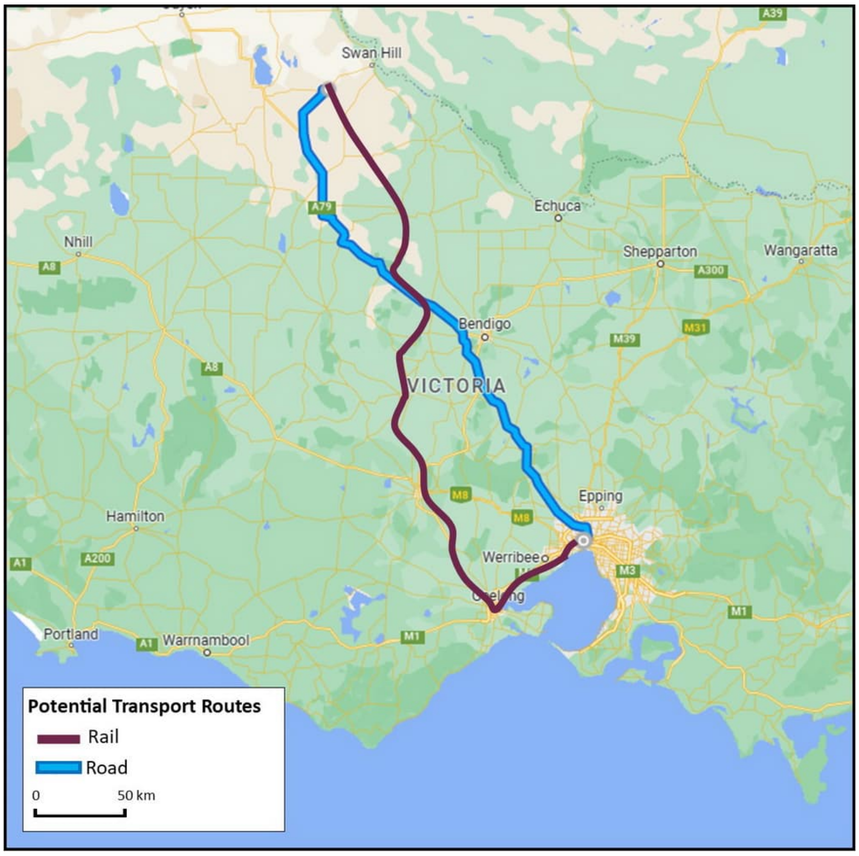


Figure 9: Ultima intermodal facility

Figure 10: Potential rail and road transport routes from Ultima to Port of Melbourne



6.3 EXISTING ENVIRONMENT

6.3.1 PROJECT AREA

A comprehensive study was undertaken to understand the existing radiological environment of the Study Area and to inform the environmental impact assessment for the Project. This study incorporated:

- Fieldwork to collect data on:
  - instantaneous gamma dose rates,
  - quarterly average gamma dose rates,
  - quarterly average isotopic radon (Rn-222 and Rn-220) concentrations,
  - hourly radon concentrations,
  - isotopic radon, and radon decay product concentrations (for a defined period),
  - quarterly passive dust deposition rates,
  - annual radionuclide activity concentrations of deposited dust,
  - surface soil radionuclide activity concentrations, and
  - radionuclide concentrations in ground water.
- Modelling to estimate crop radionuclide concentrations.

6.3.2 TRANSPORT ROUTE

Prior to the commencement of road transportation of Project product material, a gamma survey will be undertaken at 1 km intervals along the 46 km road transport route to Ultima. This will be undertaken once all road upgrades have been completed.

Baseline monitoring to quantify the background radiation levels (gamma and radon) will commence at the Ultima Intermodal facility in 2023, and a detailed gamma survey of the site will occur prior to the commencement of interim product storage.

Prior to the commencement of transportation of product from Ultima to the Port of Melbourne a gamma survey along the transport route will be undertaken to meet statutory requirements.

6.4 AVOIDANCE AND MINIMISATION

Radiological impacts to the environment occur when radionuclides enter the environment. The major pathways for radionuclides to enter the environment are via:

- release into the atmosphere,
- spillages, and
- migration into groundwater systems.

6.4.1 PROJECT

Design controls are the most effective means for controlling any releases to the environment, and the design features for the Project will include:

- Restricted access to the Project, to prevent intentional or inadvertent removal of contamination from the Project area.
- Dust suppression at the source of emissions, and minimisation through capture mechanisms (such as dust extraction) or covers.
- Contained material transfers and storage of products.
- Concrete bunding of tanks to capture spillages and provision of equipment to enable ease of clean up.
- Pressure detection systems on pipelines to identify failures and stop pumps.
- Wash-down facilities for vehicles and equipment exiting site, to minimise any spread of contamination off site.
- Final rehabilitation of all Project areas to radiation levels that are consistent with pre-Project levels.

In addition to design controls, administrative controls, such as management systems and work instructions will be used to ensure that emissions are controlled during operations, and will include:

- Detailed procedures for the clean-up of spills.
- Incident reporting and investigation procedures to minimise recurrences.
- Monitoring and reporting on the performance of design controls.

The management systems will be detailed in the Project's Radiation Management Plan, Radiation Environmental Plan and Radioactive Waste Management Plan.

6.4.2 TRANSPORT

Product material be packaged, as per transport regulations [Vic Govt. 2017], either directly into lined shipping containers, or into bulk-bags/drums which will then be loaded into containers. The shipping containers will be sealed prior to leaving the Project. This double encapsulation minimizes the likelihood of material being released into the environment.

VHM will ensure that its Transportation Contractor has administrative controls, such as management systems and work instructions, which ensure that transport radiation regulations and emergency procedures are met. This will include:

- Detailed procedures for the clean-up of spills.
- Incident reporting and investigation procedures to minimise recurrences.

The management systems will be detailed in the Transportation Contractors Facilities and Transport Management Plans.

6.5 RISK ASSESSMENT

A risk assessment of project activities was performed to prioritise the focus of the impact assessments and development of mitigation measures. The risk pathways link project activities (causes) to their potential effects on the environmental assets, values or uses that are considered in more detail in the impact assessment. Risks were assessed for the construction, operation and decommissioning phases of the Project.

The likelihood and consequence ratings determined during the risk assessment process and the adopted mitigation measures are presented in Appendix A. The risk assessment has been undertaken in line with the Preparation of Work Plans and Work Plan Variations Guideline for Mining Projects December 2020 (version 1.3).

6.6 PROJECT IMPACT ASSESSMENT

A change to baseline conditions (or the no-Project case) caused by Project activities in any of the project phases (construction, operation or decommissioning) may give rise to impacts.

The impact assessment involved identifying the severity, extent and duration of any impacts, positive or negative, that the Project may have on the existing environment.

The significance of the impacts has been assessed in accordance with the evaluation framework, based on applicable legislation, policy and standards and the evaluation objectives and environmental significance guidelines arising from the government terms of reference established to guide the assessments.

This study has assessed the radiological impacts of construction, operation and decommissioning of the Project, to the public and to the environment.

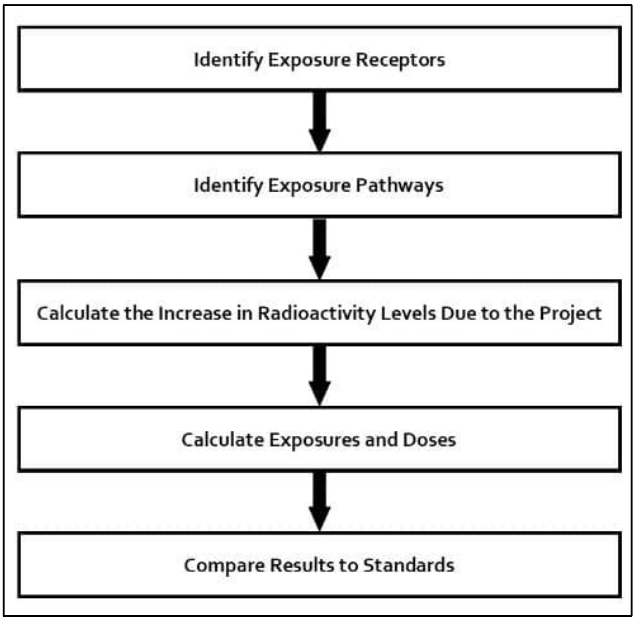
6.6.1 OVERVIEW OF THE IMPACT ASSESSMENT METHODOLOGY

The Radiation Impact Assessment aims to quantify the impacts of Project originated radiation. For people, the radiological impact is determined as a potential radiation *dose*. For non-human biota, an *absorbed dose rate* is calculated, and this provides a measure of the relative radiological risk. In both cases, the incremental impacts, above natural background radiation levels, are determined and assessed and compared to relevant standards and limits.

Potential doses to the public are calculated for critical groups of people at locations of interest (receptors). Whilst it is usual to use the same locations to quantify the impacts to people and to non-human biota, any location can be selected. For this assessment the same locations were used for both human and non-human biota.

The assessment methods are based on internationally recognised standards [IAEA 2014, ICRP 2006-101, ARPANSA 2011] and a simplified assessment framework is shown in Figure 11.

Figure 11: Assessment Framework



6.6.2 Impact Assessment Receptors

The Radiation Impact Assessment has been conducted for residences in the vicinity of the Project, which are identified as Receptors 1 – 17, and are shown in Figure 12. The distance of the receptors from Area 1 and Area 3 of the Project are listed in Table 4. Several other sensitive receptors (Receptors 18 – 24) are located in the vicinity of the Project, but generally further away than Receptors 1-17, and as such the radiological impacts will be less than those at the assessed receptors.

Figure 12: Project Receptors

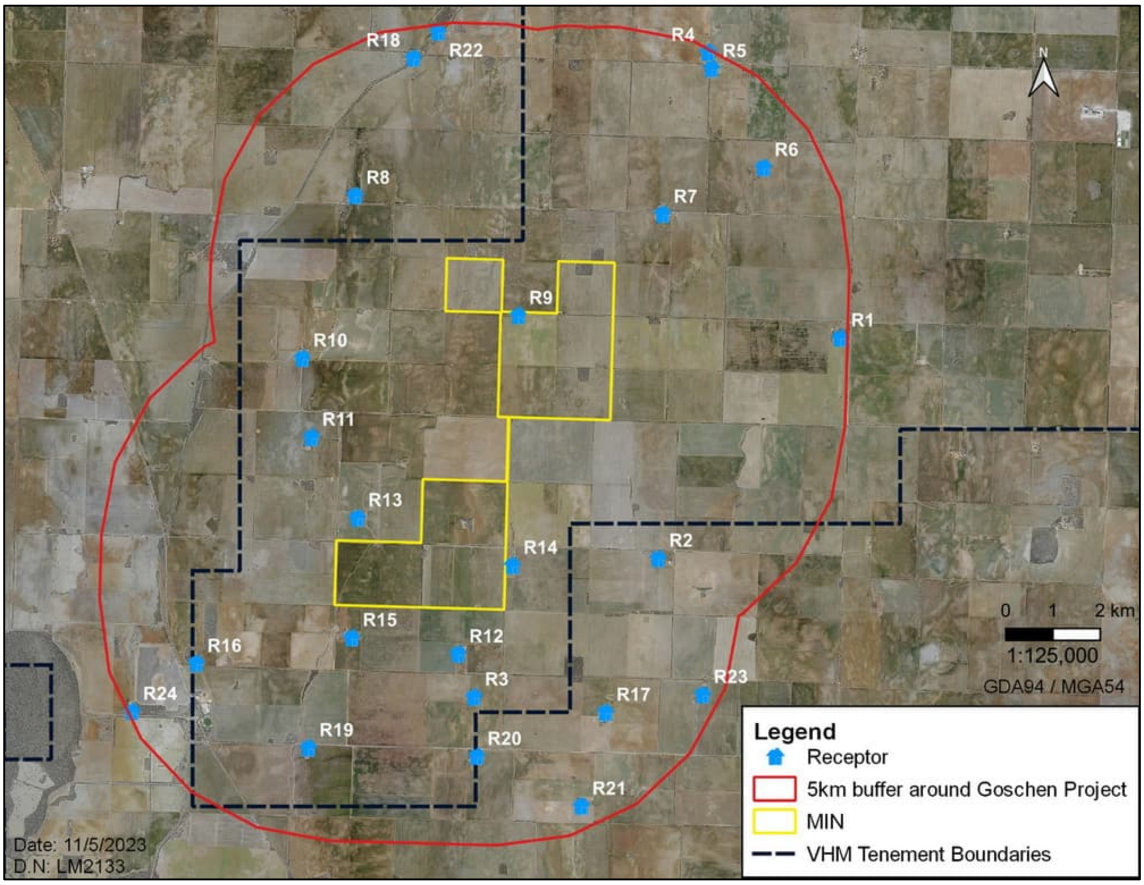


Table 4: Distance of Receptors from Area 1 and Area 3 Boundaries

Receptor ID	Distance from Project Area Boundary (km)	
	Area 1	Area 3
R1	7.7	4.9
R2	3.2	3.2
R3	2	6
R4	10.1	5
R5	9.8	4
R6	8.6	4
R7	6.6	1.6
R8	6.3	2.3
R9	3.6	0.1
R10	3.7	3
R11	2.6	4
R12	1	5.1
R13	0.6	3.7
R14	0.2	3.2
R15	1	5.7
R16	4.2	8.3
R17	3.1	6.3

6.6.3 PROJECT RADIOLOGICAL INCREMENTS

The Radiation Impact Assessment uses the outputs of Air Quality Modelling, which was performed by SLR [SLR 2022], to assess the impact of the Project. Modelling was performed for the following parameters:

- Annual average Project generated Rn-222 and Rn-220 in air concentrations,
- Annual average Project generated total suspended particulates (TSP) (dust) in air concentrations, and
- Annual average Project generated dust deposition rates,

and for the following operational scenarios and times which were selected based on air quality modelling which identified that they represent periods of maximum emissions from the Project:

- Area 1 Year 1 Quarter 1,
- Area 1 Year 6 Quarter 2,
- Area 3 Year 11 Quarter 3, and
- Area 3 Year 15 Quarter 2.

The modelled outputs are included in Appendix B.

6.6.4 HUMAN RADIATION EXPOSURE PATHWAYS AND ASSESSMENT METHODOLOGY

An *exposure pathway* describes the mechanism by which a person may be exposed to radiation. The dose assessment methodology for each exposure pathway varies but is always based on an incremental change in the radiological environment due to the Project. The dose assessment methodology for the human exposure pathways is detailed in Table 5, with the calculation parameters listed in Appendix C.

Table 5: Exposure Pathways and Assessment

Exposure Pathway	Assessment Methodology
Irradiation by gamma radiation	o Calculate project originated incremental gamma radiation levels at receptor. o Determine exposure hours. o Multiple levels by hours to calculate dose.
Inhalation of radionuclides in dust	o Calculate project originated incremental dust-in-air concentrations at receptor. o Convert to incremental radionuclide concentrations. o Determine exposure hours. o Multiply radionuclide concentrations by exposure hours and breathing rate to calculate exposure. o Convert exposure to dose using the dose coefficients.
Ingestion of radionuclides in foods	o Calculate project originated incremental radionuclide in media concentrations at receptor. o Calculate flora and fauna radionuclide uptakes using the concentration ratios. o Determine consumption rates. o Calculate the intake of radionuclides. o Convert uptake to dose using recognised dose coefficients.
Inhalation of radon decay products (also known as RnDP)	o Calculate project originated incremental radon concentrations at receptor. o Convert to incremental radon concentrations to decay product concentrations. o Determine exposure hours. o Multiply decay product concentrations by exposure hours and breathing rate to calculate exposure. o Convert exposure to dose using the dose coefficients.

The assessment method for each exposure pathway results in a *dose* which is a measure of the relative radiological impact for that exposure pathway. The impacts from each exposure pathway are summed to give a total dose which is compared against dose limits and constraints.

6.6.5 Non-Human Biota Radiation Exposure Pathways and Assessment Methodology

The method for assessing the radiological impact of the Project on non-human biota uses the change in soil radionuclide concentrations over time, due to the deposition of dusts emitted by the Project. The changes in soil radionuclide concentrations are then used as the basis of a Radiological Risk Assessment, which is undertaken using a software program called the ERICA Tool. ARPANSA [ARPANSA, 2010] has recognised the ERICA Tool as an accepted non-human biota assessment methodology. The ERICA Tool provides a three tiered assessment where the level of assessment is commensurate with the actual risk.

The ERICA Tool, uses changes in media radionuclide concentrations, and concentration ratios, to provide a dose rate for a list of reference species. The dose rates are then compared to *screening levels,* which are the level below which no effects would be observed on a species. The reference species are; amphibian, annelid, arthropod (detritivorous), bird, flying insects, grasses and herbs, lichen and bryophytes, mammal (large), mammal (small-burrowing), mollusc (gastropod), reptile, shrub and tree.

6.7 Transport Impact Assessment

This study also has assessed the radiological impacts to the public and to the environment, due to any change in existing radiation levels, resulting from the transportation of Project product materials.

The introduction of Section 6.6, and subsection 6.6.1 are applicable to the Transport Impact Assessment.

6.7.1 Impact Assessment Receptors

The Radiation Impact Assessment for transportation has been conducted for the residences and non-transportation workplaces closest to the Ultima Intermodal Facility, which are identified as receptors TR1 (residence), TR2 (silos at railway siding), and TR3 (residence), and are shown in Figure 13. The transport impact assessment also considers, as receptors, residences adjacent to transport routes, vehicles stopped at rail crossings and beside road freight trucks, and vehicles following road freight trucks from Ultima to Port. The distance of the receptors from the Ultima Intermodal boundary and transportation vehicle are listed in Table 6.

Figure 13: Receptors in the vicinity of Ultima Intermodal

Table 6: Distance of Receptors from Area 1 and Area 3 Boundaries

Receptor	Distance from (m)		
	Ultima Intermodal boundary	Rail	Road
TR1	280		
TR2	30		
TR3	200		
Residence adjacent to transport route		20	20
Vehicle stopped at railway crossing		5	
Vehicle following road freight truck to port			20
Vehicle parked alongside road freight			5

6.7.2 HUMAN RADIATION EXPOSURE PATHWAYS AND ASSESSMENT METHODOLOGY

As the material is encapsulated during transportation, the only applicable exposure pathway is irradiation by gamma radiation. The dose assessment methodology for gamma radiation is detailed in Table 5, with the calculation parameters listed in Appendix C.

6.7.3 Non-Human Biota Radiation Exposure Pathways and Assessment Methodology

Except in the case of an incident which resulted damage to containers and release of material to the environment, there are no radiation exposure pathways applicable to non-human biota for the encapsulated transportation of Project product material.

6.8 Assessment of potential impacts on matters of national security and environmental significance

6.8.1 Code for Security of radioactive sources

Sealed radioactive sources, such as density gauges, may require additional security arrangements depending on the c*ategory* for the Project. The *category* is determined based on the activities and radioisotopes of all sources at the Project, using the methodology in ARPANSA 2019b.

6.8.2 EPBC Act

The radiological nature of the Project requires assessment under the Environmental Protection and Biodiversity Conservation (EPBC) Act [Au Govt 1999].

The relevant sections of the EPBC Act related to radioactivity are listed below:

- Section 528 of the EPBC Act provides definitions for the terms *nuclear action* and *nuclear installation* which refers to the meaning provided in section 22(1) of the EPBC Act.
  In 22(1) of the Act, amongst other items, a *nuclear action* is defined as:

  > *"(e) establishing or significantly modifying a large-scale disposal facility for radioactive waste;"*
  >
  > *"(g) any other action prescribed by the regulations".*

- The EPBC Regulations in Division 2.1 provide further detail on the definition of a *nuclear action*, in particular in relation to subclause (g) of clause 22(1) of the Act. Specifically, Clause 2.01 of the Regulations states that a *nuclear action* includes;

  > *"establishing, significantly modifying, decommissioning or rehabilitating a facility where radioactive materials at or above the activity level mentioned in regulation 2.02 are, were, or are proposed to be used or stored.*"

- In clause 2.02 of the EPBC Regulations, a detailed definition of the *activity level* is provided, which is linked to the ARPANS Regulations. The *activity level* is a combination of the mass of the material, and the radionuclide activity concentrations of the material.
- Clause 2.03 refers to a *Nuclear Action* also including a large scale disposal facility as a facility used for the disposal of radioactive materials above the *activity level.* This would include a tailings facility or waste facility where the volume of material is sufficient, and the radionuclide activity concentration exceeds the *activity level*.

Section 9.6 presents the data required to assess against the Act in a consolidated manner.

6.9 LIMITATIONS, UNCERTAINTIES AND ASSUMPTIONS

The following limitations, uncertainties and assumptions apply to this assessment:

- Assumptions for calculations are detailed in Appendix C.
- Radionuclide concentration of process streams and material are based upon metallurgical testwork to date, and testwork is still being finalised.

6.10 LINKAGES TO OTHER TECHNICAL REPORTS

This report has interdependencies with the SLR Air Quality report, in relation to the assessment of impacts associated with the Project's dust and radon emissions . The Air Quality specialists undertaking this assessment worked collaboratively with the authors to quantify these potential impacts.

7.0 EXISTING ENVIRONMENT

Radiation naturally exists at varying levels everywhere within the environment. For example, uranium is a naturally occurring heavy metal and is widespread in the Earth's crust, with an average concentration of about three parts per million (ppm). Since, radionuclides naturally occur in materials, it is usual to only define a material as *radioactive* when the concentration of a radionuclide in the material exceeds a certain level.

Radiological aspects need to be considered in resource development for projects where the material to be mined and processed contains elevated concentrations of the naturally occurring radioactive elements of uranium and thorium.

As previously noted, quantification of the existing environment for the transportation of product material component of the Project Impact Assessment will commence in 2023 and be completed prior to the commencement of the movement of product material.

7.1 DESCRIPTION OF STUDY AREA

The defined Study Area for the radiological risk assessment is predominantly cleared flat land dissected by dirt roads (bordered by remnant vegetation verges), with scattered farming residences (receptors). The land is predominately used for mixed cropping purposes (canola, chickpea, lentil, wheat, barley, oat and vetch) with occasional livestock (sheep) grazing. Groundwater is not consumed or used for cultivation due to its high salinity. There are no surface water bodies in the Study Area.

7.2 RADIOLOGICAL MONITORING

Quantification of the existing radiological environment commenced in April 2018 with a gamma survey. In February 2019 a continuous routine monitoring program commenced with the establishment of five Environmental Radiation Monitoring Locations (ERMLs) within the defined Study Area. Monitoring during 2020 was largely interrupted due to Covid related travel restrictions, but recommenced in full in 2021, and is on-going. The monitoring years completed to date are:

- Year 1 16/2/2019 to 12/3/2020, and
- Year 2 27/2/2021 to 6/6/2022.

The location of the ERMLs in relation to the Project and Receptors is shown in Figure 14, with GPS coordinates listed in Table 7. Table 8 list the routine ERML monitoring along with additional non-routine radiological monitoring and sampling that has occurred. To enhance understanding of the existing radiological environment, VHM will expand its ERML network.

Figure 14: Location of ERMLs and Receptors with Study Area

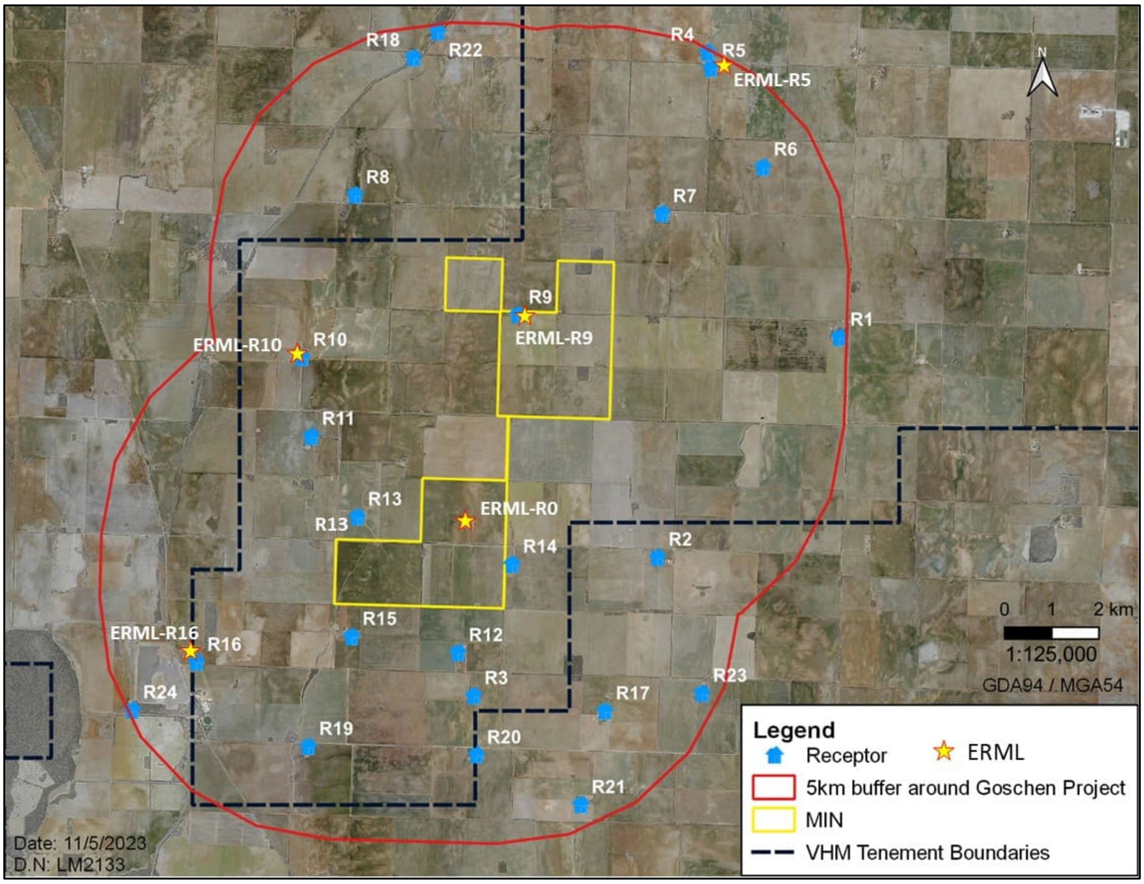


Table 7: Location of ERMLs

Site Name	GPS Co-ordinates	
	Latitude	Longitude
ERML-RO	-35.633894	143.438296
ERML-R9	-35.597392	143.450018
ERML-R10	-35.602396	143.397139
ERML-R16	-35.660471	143.375166
ERML-R5	-35.544358	143.494115

Table 8: Details of Radiological Baseline Monitoring in the Study Area

Type of Monitoring	Location	Monitoring Period/Type	Monitoring Equipment / Method
Gamma dose-rate	Project Area	Immediate Spot	Hand-held gamma meter
	ERMLs	Immediate Spot	
	ERMLs	Quarterly Passive	inLight Environmental OSL dosimeter
Radionuclides in dust (which naturally deposits from the air)	ERMLs	Quarterly Passive	Collection of dust passively depositing from the atmosphere. Mass reported quarterly. Annual site composite analysed.
Rn-222 and Rn-220 concentrations	ERMLs	Quarterly Passive	RadTrak2® Rn-222 and Rn-220 pair
Rn-222 and Rn-220 concentrations	ERML-R9	Six days Continuous	Durridge RAD7
Radon concentration	ERML-R9	Hourly Continuous	RadonEye
Rn-222DP and Rn-220DP concentrations	ERML-R9	Six days Continuous	WLM30
Radionuclides in Soil	ERMLs	Immediate Spot	Collection of soils samples and analysis
Radionuclides in Groundwater	Monitoring wells	Immediate Spot	Collection of well waters and analysis

Passive radon and gamma detectors are provided and analysed by Landauer, Australia. All radionuclide analysis has been undertaken by SGS, Notting Hill, Melbourne.

7.2.1 Gamma Dose Rate

Background gamma radiation dose rates vary as they depend primarily on the natural levels of radionuclides in soil. A portion of the background gamma dose rate also comes from cosmic radiation. The results of gamma monitoring at the ERMLs are shown in Table 9.

Table 9: Baseline Gamma Dose Rates at ERMLs

Site ID	Gamma Dose Rate (µSv/h)								
	Passive Detector Average								Spot Feb-19
	16/2 - 31/5/19	31/5 - 2/9/19	2/9 - 28/11/19	28/11/19 - 12/3/20	12/3/20 - 27/2/21	27/2- 5/12/21	5/12/21- 28/2/22	28/2 – 6/6/22	
ERML-RO	< 0.01	0.03	0.03	0.05	0.02	< 0.01	<0.01	0.09	0.10
ERML-R9	< 0.01	0.04	0.05	0.05	0.01	< 0.01	<0.01	0.09	0.10
ERML-R10	< 0.01	0.02	0.04	0.05	<0.01	< 0.01	<0.01	0.07	0.10
ERML-R16	0.02	0.04	0.06	0.06	0.02	< 0.01	<0.01	0.09	0.12
ERML-R5	0.01	0.03	0.05	0.04	0.01	< 0.01	<0.01	0.08	0.10

In April 2018 the Project area was surveyed. Survey locations are shown in Figure 15 with the distribution of baseline gamma dose rates shown in Figure 16.

Figure 15: Baseline Gamma Survey Locations

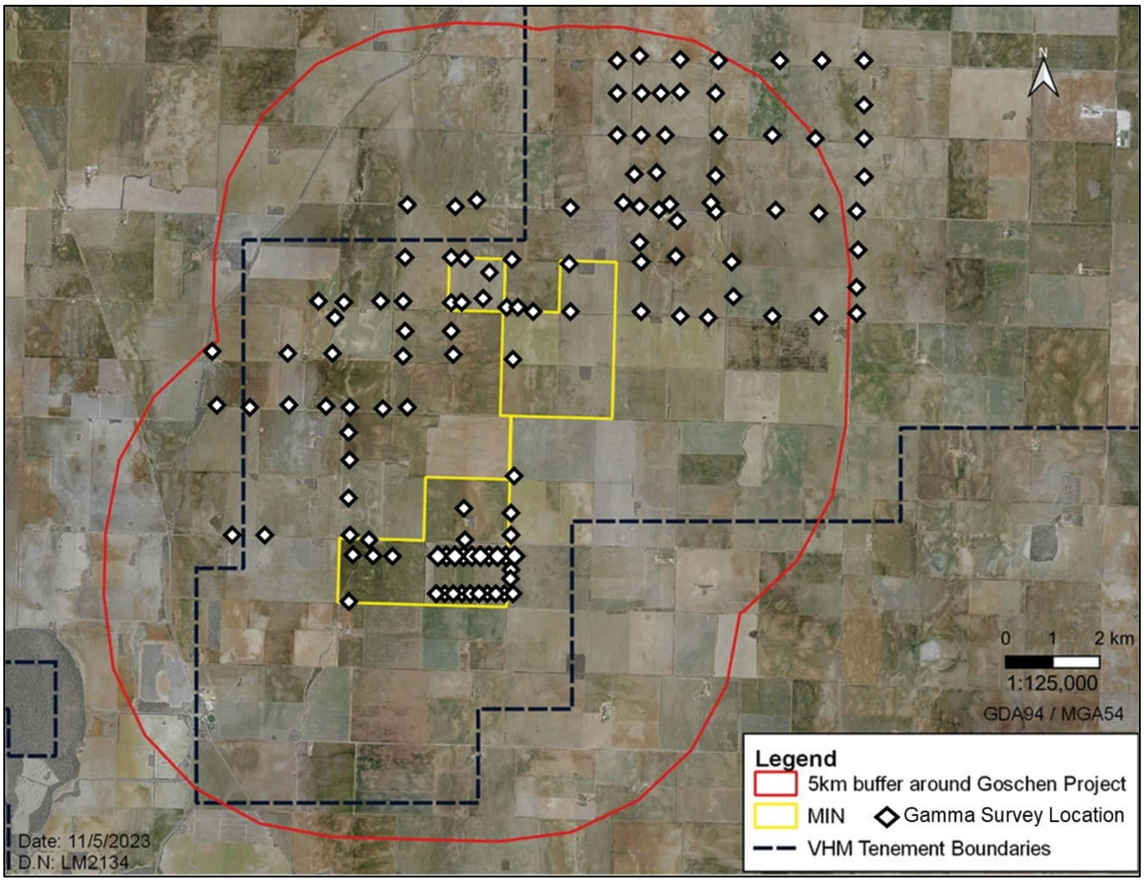
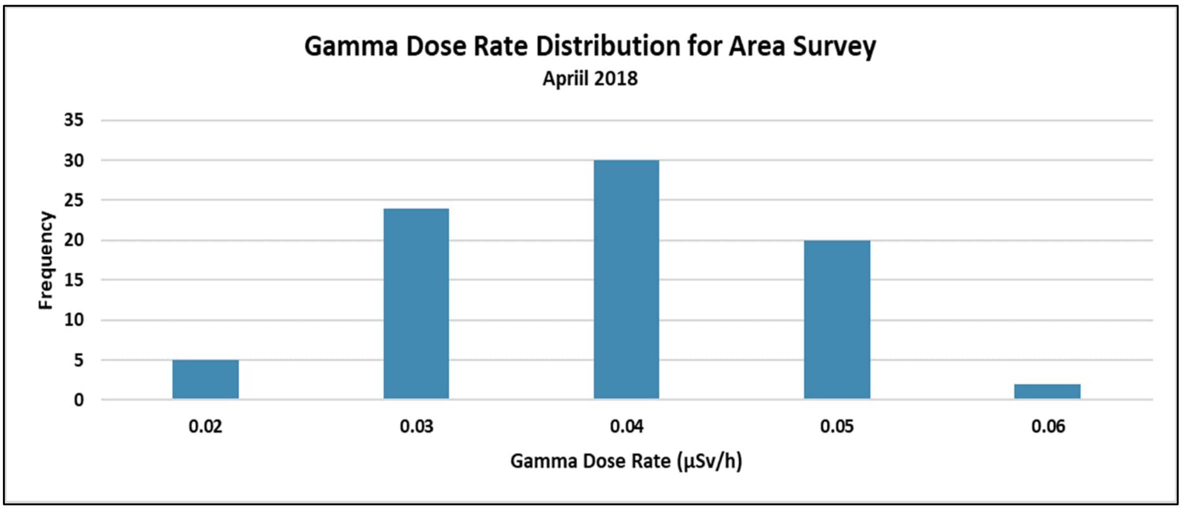


Figure 16: Baseline Gamma Dose Rate Distribution



The gamma dose rates for other areas in Australia are presented in Table 10.

Table 10: Gamma Dose Rates across Australia

Location	Gamma Dose Rates (µSv/h)	Reference
Central South Australia	0.1	BHP Billiton 2009
Australian Average	0.07	Inferred from ARPANSA 2005
Typical for Australia	0.02 – 0.1	Mudd 2002
Honeymoon Uranium Mine, SA	0.1	Kvasnicka 1998
Western Plains Zoo Area, NSW	0.2 – 0.4	Hewson 2002
Macquarie River Bank, NSW	0.2 – 0.4	Hewson 2002
REX Hillside Project, SA	0.11 – 0.16	Trevlyn Radiation & Environment 2013
Centipede Deposit, WA – Sand dune	0.10	TORO 2010
Centipede Deposit, WA – over deposit	0.07 – 0.86 (av 0.17)	
Melville Island, NT – undisturbed areas	0.06 (av)	Matilda Minerals 2005

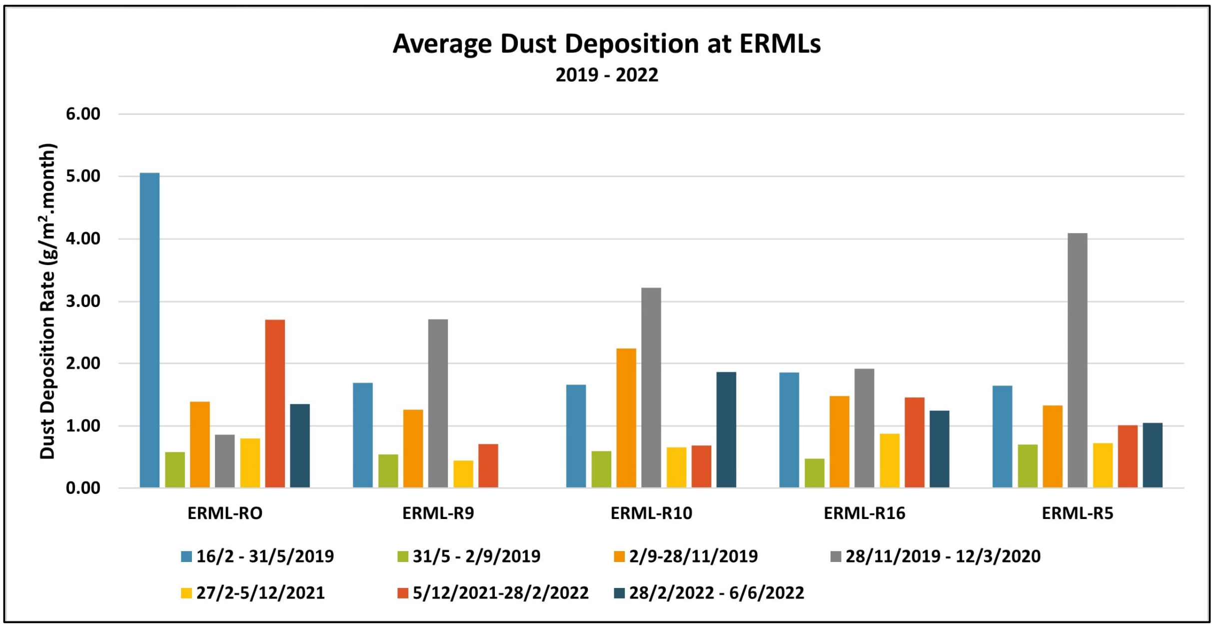
The gamma dose rates in the Study Area are similar to the gamma dose rates in other areas of Australia.

7.2.2 Radionuclides in Dust

Soils and materials, which contain naturally occurring radioactive materials, can become airborne and generate dusts. Airborne dusts may move significant distances, before they deposit back out of the air. This deposition may result in changes in the radiological environment. Dust generation and deposition rates vary, based on climatic conditions and mechanical activities. By collecting and analysing deposited dust samples, the dust deposition rate, concentration of radionuclides in airborne dusts and radionuclide deposition rates can be determined.

The average baseline dust deposition rates at the ERMLs are shown in Figure 17.

Figure 17: Average Baseline Dust Deposition Rates at ERMLs



The activity concentrations of radionuclides in dust and the radionuclide deposition rates, are shown in Figure 18 and in Figure 19. The Year 1 samples were not analysed for Po-210, as the Covid related analysis delay meant that Po-210 would likely have reached equilibrium with Pb-210.

Figure 18: Baseline Activity Concentrations of Radionuclides in Dust

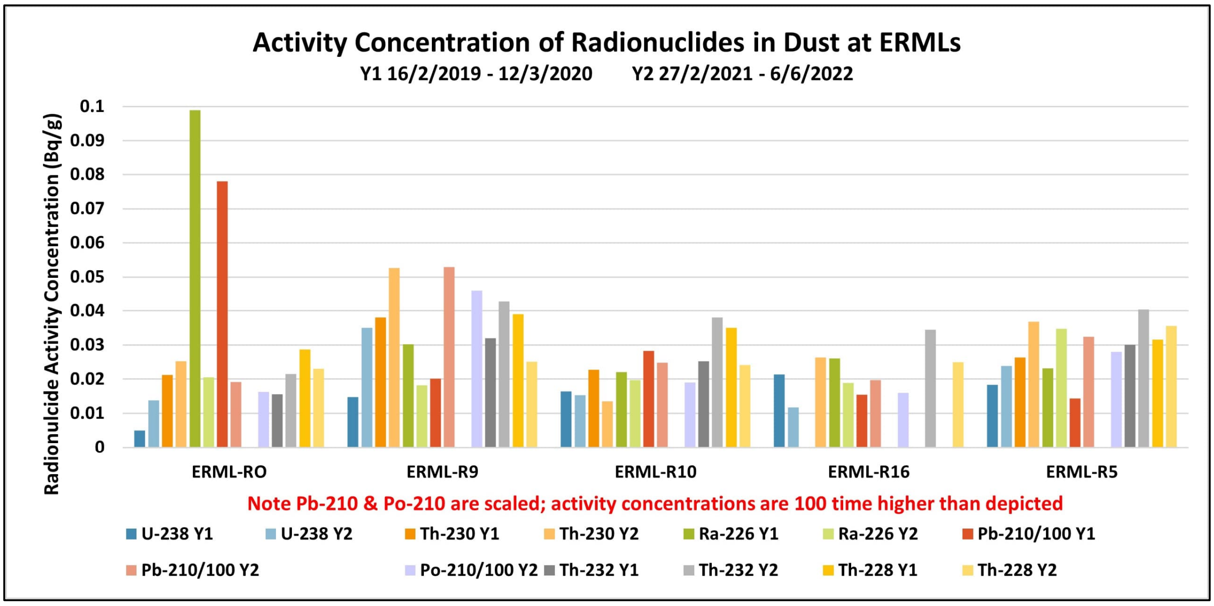
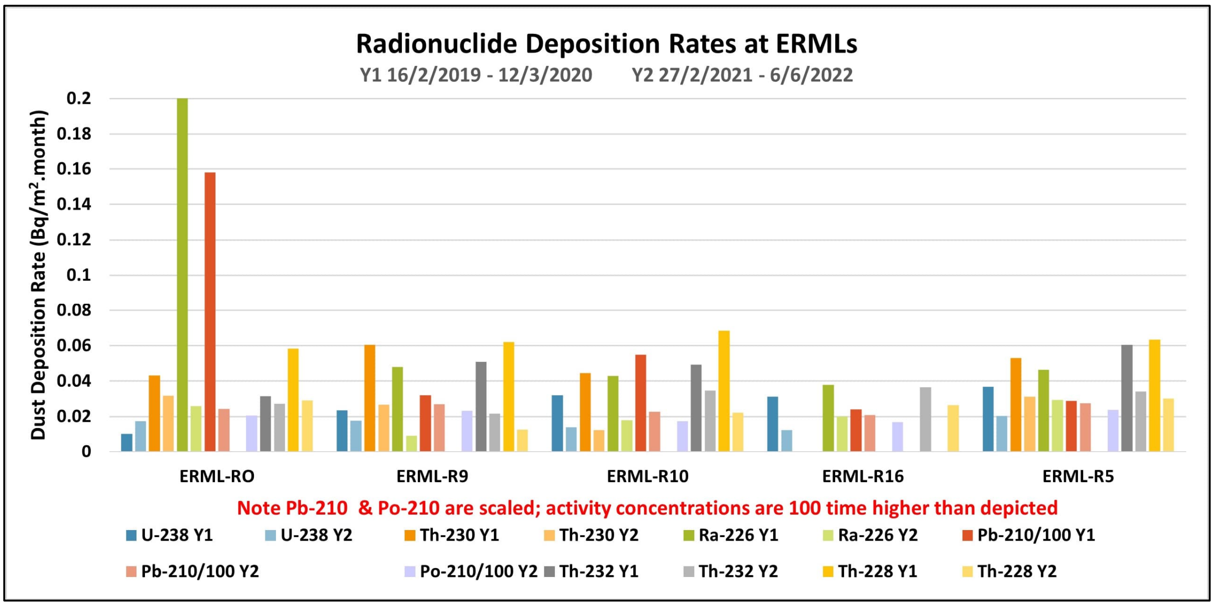


Figure 19: Baseline Radionuclide Deposition Rate



There is a lack of published data on passive dust radionuclide deposition rates and thus it is difficult to contextualise data, except for Pb-210, as detailed in Table 11.

Table 11: Global Pb-210 deposition rates

Location	Pb-210 Deposition (Bq/m^2.month)	Reference
Darwin, Australia	7.92	Bonnyman 1972
Townsville, Australia	3.16	Bonnyman 1972
French Guiana	13.6	Melieres 2003
Netherlands	4.66 – 6.83	Beks 1988
Germany	15.0	Rosner 1988 & Winkler 2000
Texas, USA	10.8 – 14.1	Baskaran 1995
Connecticut, USA	16.8	Turekian 1983
Bermuda	9.58	Turekain 1983

The baseline Pb-210 deposition rates, as measured in the Study Area, with a range of 2.1 – 15.8 Bq/m^2.month and median of 2.7 Bq/m^2.month, are comparable to global Pb-210 deposition rates.

7.2.3 RADON

Radon (Rn) is a naturally occurring inert radioactive gas produced by the radioactive decay of radium (Ra), an element found naturally in soil and rocks. Atmospheric radon concentrations constantly vary based on the emanation rate and the movement from the emanation source, which is affected by climatic variations (temperature, humidity, rain, wind and soil moisture content).

The two isotopes of radon that are passively measured at each ERML are;

- Rn-222 which is the decay product isotope from the U-238 decay chain, and
- Rn-220 which is the decay product isotope from the Th-232 decay chain.

The measured average baseline Rn-222 and Rn-220 concentrations are shown in Figure 20 and Figure 21.

Figure 20: Average Baseline Rn-222 Concentrations

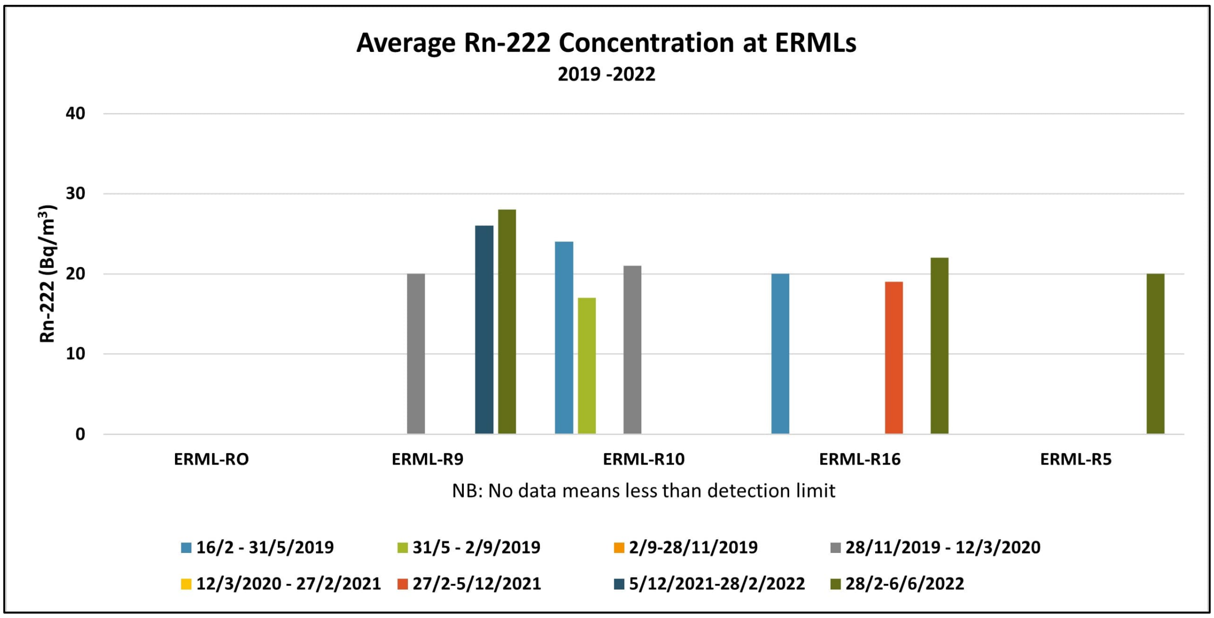
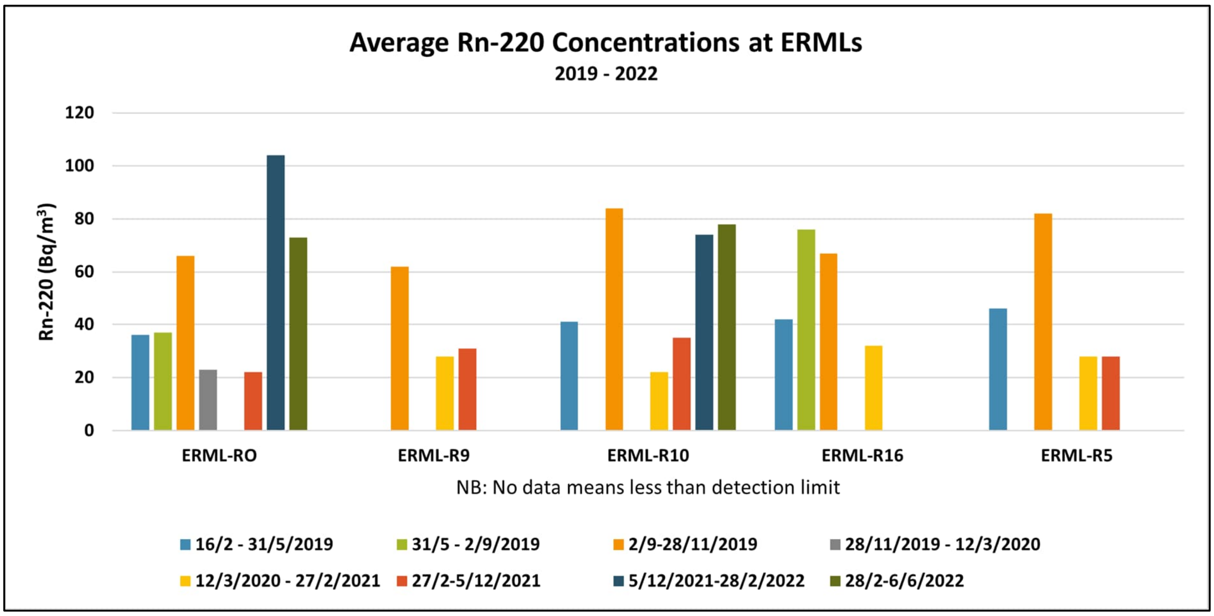


Figure 21: Average Baseline Rn-220 Concentrations



Hourly baseline radon concentrations were measured at ERML-R9. Figure 22 and Figure 23 shown the diurnal and monthly/seasonal variation in radon concentrations.

Figure 22: Hourly Baseline Radon Concentrations

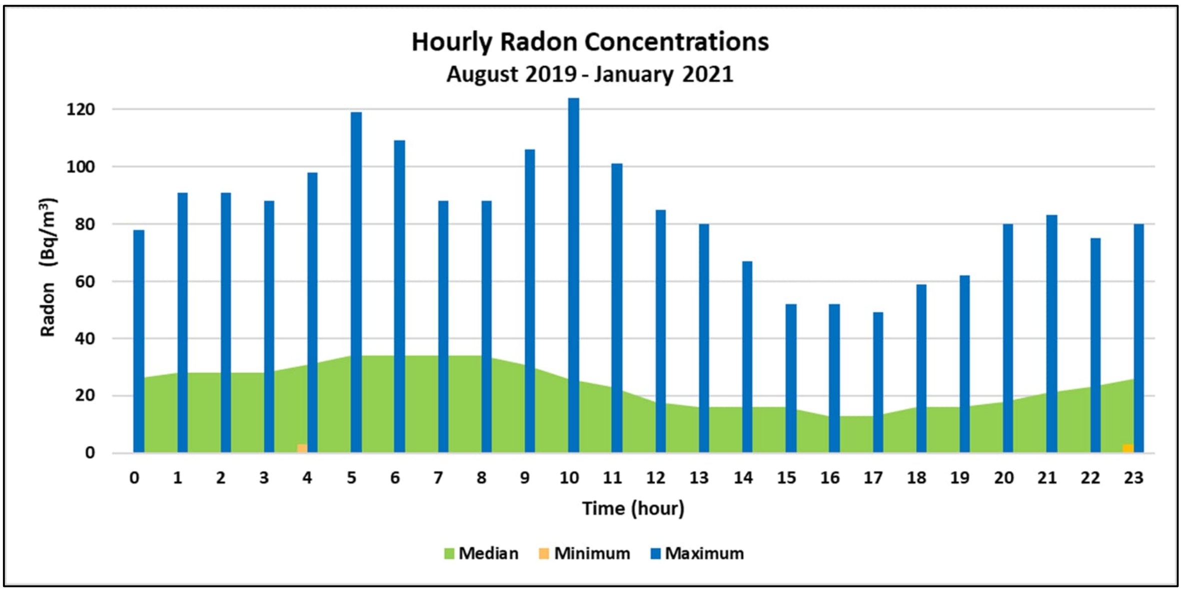
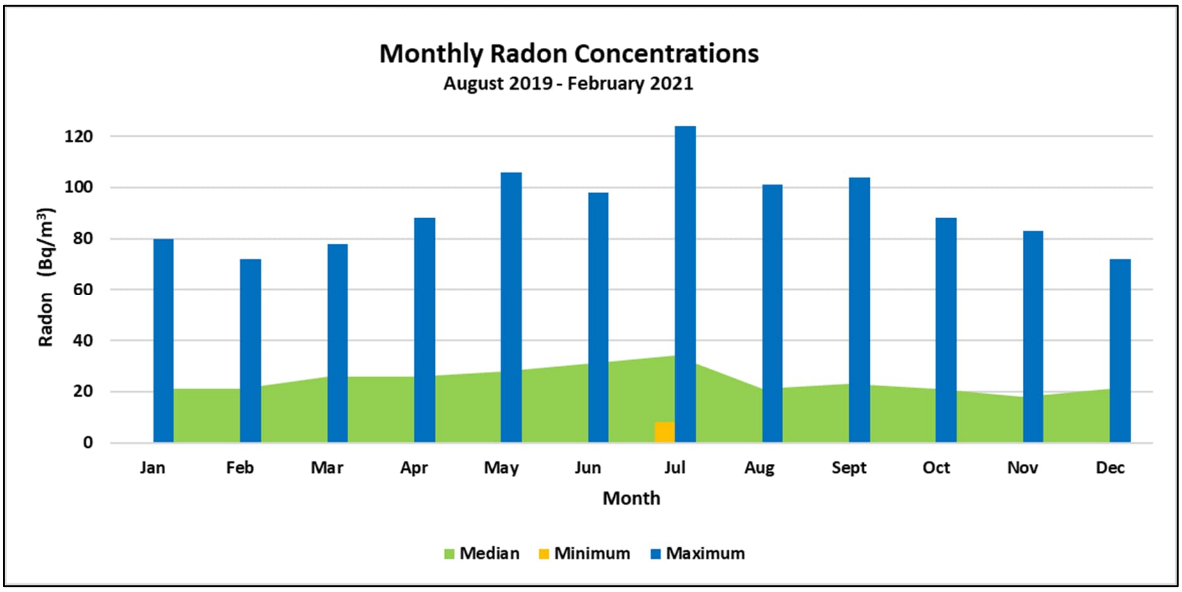


Figure 23: Monthly Baseline Radon Concentrations



Australian and world Rn-222 and Rn-220 levels are presented in Table 12. Note that there is little published data on outdoor Rn-220 levels.

Table 12: Australian and World Rn-222 and Rn-220 Concentrations

Location	Rn-222 (Bq/m^3)	Rn-220 (Bq/m^3)	*Reference*
World	1 -100 average 10	average 10	UNSCEAR 2000
Arafura Nolan's Project mine foot-print	44	470	Arafura 2016
Arafura Nolan's Project mine foot-print	29	120	
Honeymoon	28		Honeymoon 2006
Olympic Dam	20		BHP Billiton 2009
REX Hillside Project, SA	8 - 35		Trevlyn 2013
Centipede Project Area, WA	13 - 66		TORO 2010
Wiluna Uranium Project Area & communities, WA	9 - 142		TORO 2010

Rn-222 concentrations in the Study Area (maximum of 28 Bq/m^3) are consistent with naturally occurring Australian Rn-222 concentrations.

7.2.4 Radon Decay Products

When radon decays, it produces a series of short-lived progeny isotopes. These progeny isotopes, collectively known as *decay products,* are highly radioactive due to their short half-lives. The decay products of Rn-222 are Rn-222DP, and of Rn-220 are Rn-220DP.

Critical to dose calculation is the equilibrium factor (F_{eq} - where $_{eq}$ is substituted with Rn-222 or Rn-220) for each radon isotope. Whilst there are default equilibrium factors, it is preferable to determine site specific equilibrium factors as the factor can vary significantly. Equilibrium factors are determine by the simultaneous measure of;

- Rn-222 and Rn-222DP, and
- Rn-220 and Rn-220DP.

Simultaneous monitoring was undertaken at the Project in September 2019 and the results are shown in Figure 24 and in Figure 25. The calculated equilibrium factors along with other equilibrium factors are listed in Table 13.

Figure 24: Simultaneous Rn-222 and Rn-222DP Concentrations

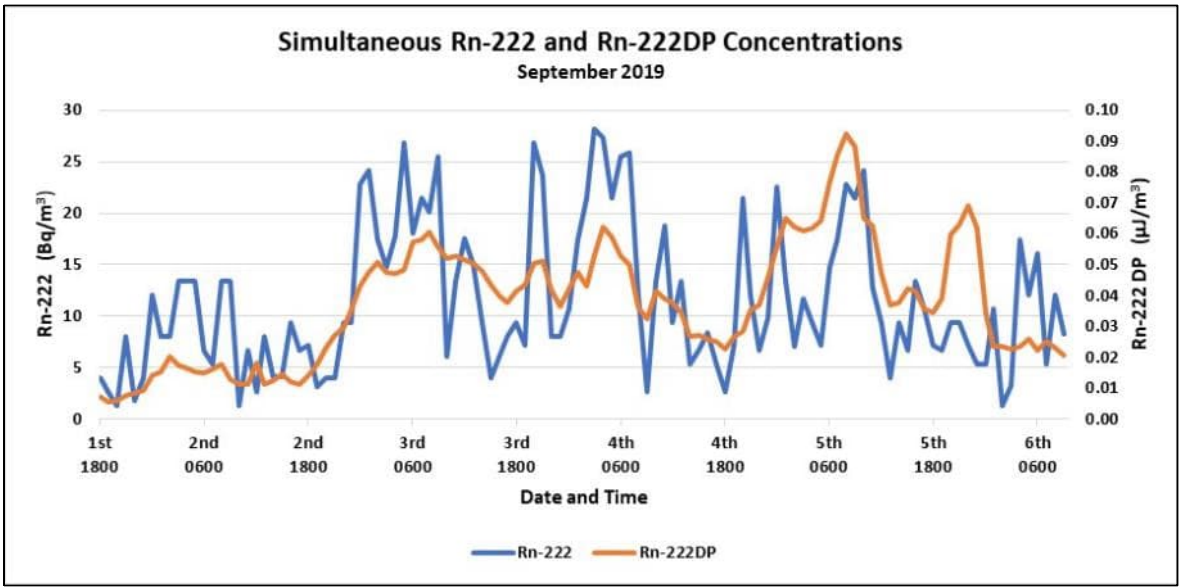


Figure 25: Simultaneous Rn-220 and Rn-220DP Concentrations

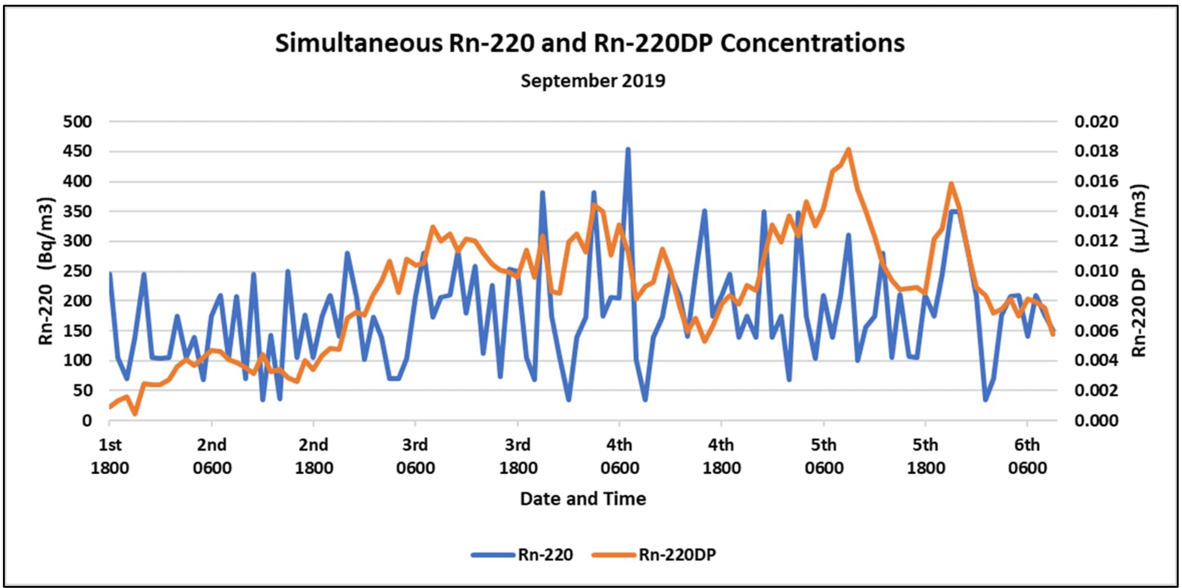


Table 13: Radon Equilibrium Factors (outdoor except where specified)

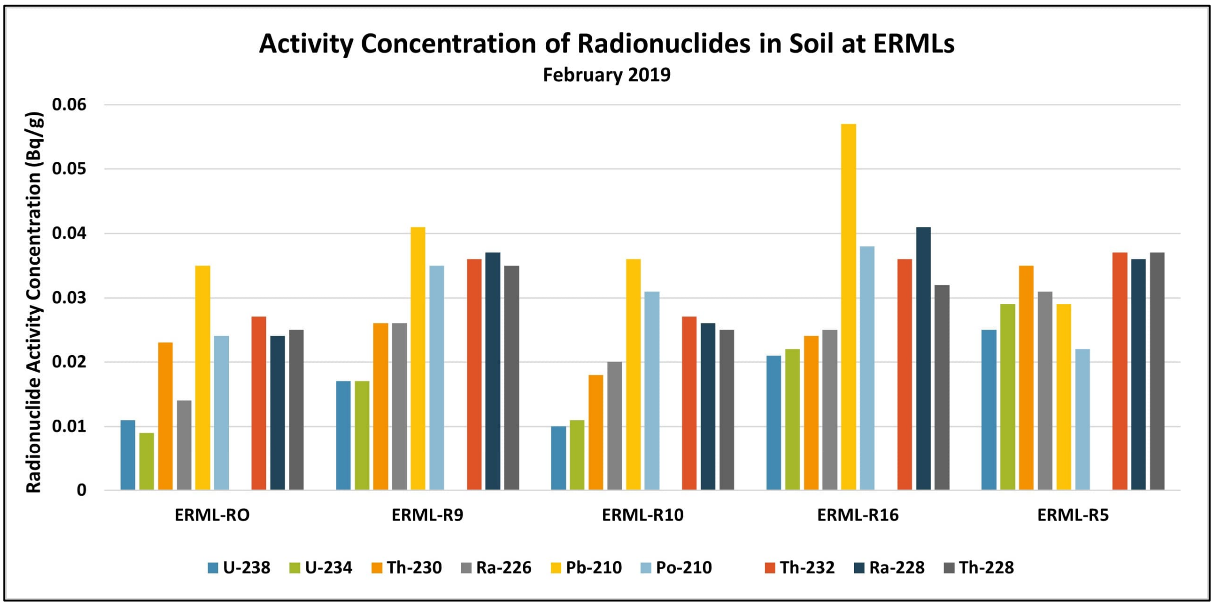
Source		Equilibrium Factor	
		F_{Rn-222}	F_{Rn-220}
Project	Range	0.170 - 3.15	0.0004 - 0.0046
	Median	0.577	0.0006
UNSCEAR 2016 and 2008		0.6	0.02 (indoor)
Harley et al 2010			0.004
Arafura - Nolans Bore 2016			0.001 – 0.004
Hosoda 2017			0.0080 – 0.0700
DMIRS 2021	Outdoors	0.2	0.004
	Indoors	0.4	0.04

The Project F_{Rn-222} is consistent with the UNSCEAR F_{Rn-222}. The Project F_{Rn-220}, whilst significantly lower than the UNSCEAR F_{Rn-220} (for indoors), is consistent with the outdoor measurements determined at Nolan's Bore, Australia. In ARPANSA RPS 9.1 (part 4.2.3) F_{Rn-220} of 1 is assumed, although it is noted that the equilibrium factor is likely to be variable and different from 1, and ARPANSA 2022 notes that in the absence of site-specific factors, and equilibrium factor of 0.01 can be used. The West Australia Department of Mines (DMIRS) provides a F_{Rn-220} of 0.004 where site specific F_{Rn-220} have not been determined.

7.2.5 RADIONUCLIDES IN SOIL

Soils contain naturally occurring radionuclides, which are present due to a combination of locational geology, land-use practices (past and present), climatic events and dust deposition. Surface soil samples were collected at each of the ERMLs and the measured baseline activity concentrations are shown in Figure 26.

Figure 26: Baseline Soil Radionuclide Activity Concentrations



Australian and world soil radionuclide concentrations are presented in Table 14.

Table 14: Radionuclide Concentrations in Soil

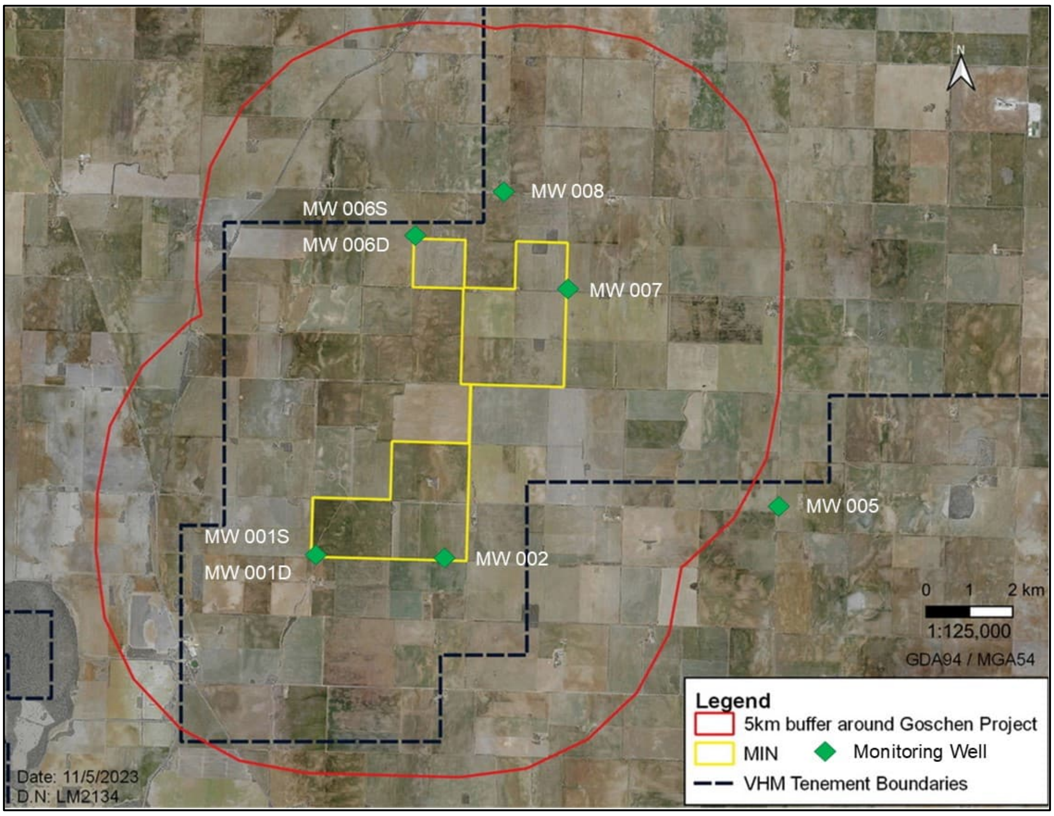
Location	Radionuclide Concentration (Bq/g)				Reference
	U-238	Ra-226	Pb-210	Th-232	
World	0.016 – 0.11 median 0.035	0.017 -0.060 median 0.035		0.011 – 0.064 median 0.030	UNSCEAR 2000
Lake Way & Centipede regions, WA		0.027 – 0.40 median 0.062			TORO 2010
REX Hillside Project, SA	0.006 – 0.010	0.008 – 0.03	0.035 - 0.278		Trevlyn Radiation & Environment 2013

Baseline soil radionuclide concentrations in the Study Area are consistent with worldwide soil radionuclide concentrations.

7.2.6 RADIONUCLIDES IN GROUNDWATER

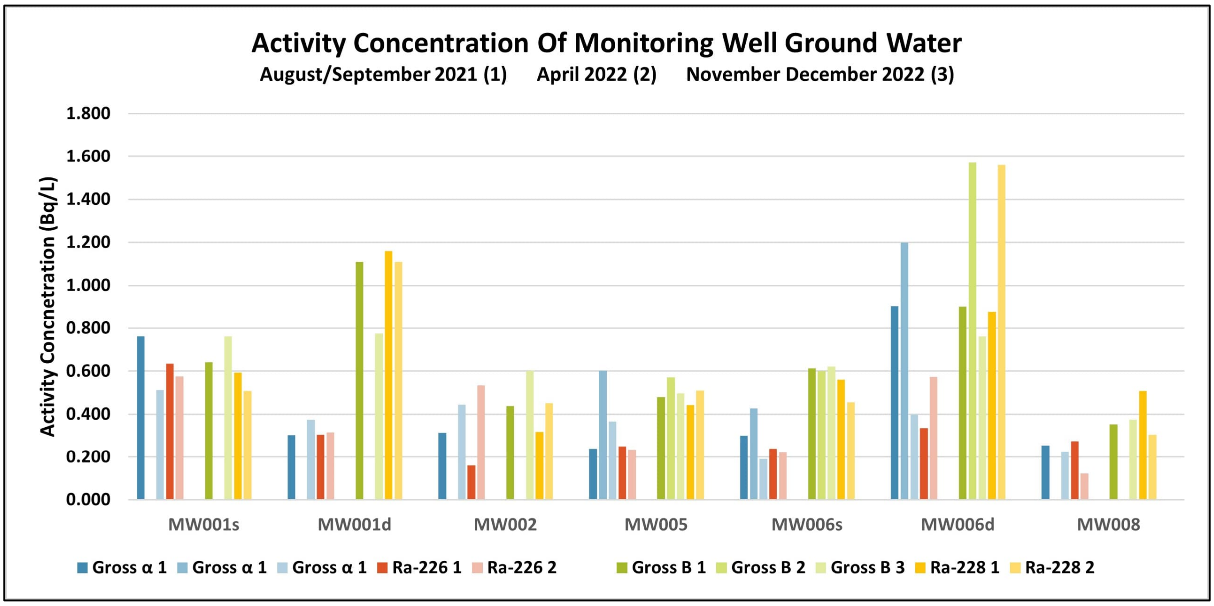
Groundwater contains naturally occurring radionuclides, which are present due to a combination of locational geology, hydrogeology and land-use practices (past and present). Groundwater samples were collected from the monitoring wells located within the Project area, as shown in Figure 27 in August/September 2021, April 2022 and November/December 2022.

Figure 27: Location of Groundwater Monitoring Wells



The baseline activity concentrations of the groundwater samples are shown in Figure 28. Both U and Th were below detection limits of 0.01 mg/L which equates to 0.1 Bq/L U-238 and 0.041 Bq/L Th-232. Pb-210 was detected in only one sample with an activity concentration of 0.15 Bq/L.

Figure 28: Baseline Groundwater Activity Concentration 2021 and 2022



Australian drinking water guidelines and groundwater radionuclide concentrations are presented in Table 15.

Table 15: Australian Drinking Water Guidelines and Groundwater Radionuclide Concentrations

Data type and Reference	Activity concentration (Bq/L)		Radionuclide concentration (Bq/L)				Metal (mg/L)
	Gross alpha	Gross Beta minus K-40	U-238	Ra-226	Pb-210	Ra-228	U
Australian Drinking Water Guideline values [Au Govt 2011]	0.5	0.5					0.0175
Australian Groundwater Samples [ARPANSA, 2008 TRS 148]	0.02 - 1	0.02 - 0.9	<0.01 - 0.12	<0.01 - 0.77	<0.01 - 0.06	<0.01 - 0.68	
Daylesford Hepburn Spring Region, Victoria [Cooper et al 1981]				0.1 - 0.9		0.08 - 1.03	

The groundwater in the Study Area is radiologically elevated. The gross alpha and gross beta activity concentrations exceed Australian Drinking Water guidelines, and isotopic radium concentration are elevated. The groundwater is also highly saline, and consequently is not used for human consumption, stock watering or irrigation.

7.3 RADIOLOGICAL MODELLING

7.3.1 RADIONUCLIDE CONTENT OF CROPS

Radionuclides are taken up from soils by plants. The amount of a radionuclide that is taken up is quantified by applying the *concentration ratio* which is the ratio between the concentration of a radionuclide in the soil and the concentration of the radionuclide in the particular species (as has been determined by studies [IAEA 2010]). The concentration ratio is generally constant for the type of species and, has been used for the ingestion dose calculations in Section 9.2.3.

Using the Study Area soil samples radionuclide activity concentrations, as reported in Figure 26, it is possible to calculate the grain crop radionuclide activity concentrations, and these are listed in Table 16. These Crop activity concentrations do not consider the application of fertilisers (some of which contain uranium).

Table 16: Calculated Grain Radionuclide Activity Concentrations

ERML	Calculated Grain Crop Activity Concentration (Bq/kg)								
	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Ra-228	Th-228
ERML-RO	0.059	0.049	0.012	0.067	0.108	0.003	0.015	0.116	0.012
ERML-R9	0.089	0.091	0.014	0.128	0.126	0.004	0.019	0.178	0.019
ERML-R10	0.054	0.060	0.010	0.098	0.111	0.004	0.015	0.126	0.014
ERML-R16	0.109	0.119	0.013	0.122	0.782	0.005	0.020	0.198	0.017
ERML-R5	0.134	0.152	0.019	0.151	0.088	0.003	0.020	0.174	0.020

8.0 RISK ASSESSMENT

The radiological risk assessment presented in this section focusses on events or situations where changes to predicted impacts may occur. In the field of radiation protection, there are nuances in the terminology used for discussing exposure to radiation:

- A *Radiological Impact* is an exposure scenario (known/predicted/modelled) that is going to occur. *Controls* are implemented to minimise the effect.
- A *Radiological Risk* is when there is only a probability an exposure scenario might occur. Mitigation measures are implemented to reduce the likelihood, and consequences should the scenario occur.

The identified risks and associated residual risk ratings are listed in Table 17. The likelihood and consequence ratings determined during the risk assessment process and the mitigation measures to be achieved are presented in Appendix A.

Table 17 Radiological Risks

Risk ID	Potential threat and effects on the environment	Residual risk rating
Construction		
##R01	Mineralization exposed during mining pre-strip and site preparation activities leading to exposure of people and the environment	Low
Operation		
##R02	Airborne emissions of dust and radon, above modelled levels, resulting in radiological exposure to people and the environment.	Low
##R03	Public radiation exposure greater than predicted due to errors in modelling methods.	Low
##R04	Radioactively contaminated equipment and materials leaving the site.	Low
##R05	Process and material spills resulting in release of material into the environment.	Low
##R06	Failure of process material or tailings pipelines resulting in release of slurries into the environment.	Low
##R07	Increased dust emissions from dust control equipment leading to elevated emissions from the project and higher than predicted impacts.	Low
##R08	Seepage/run-off from stockpile and processing areas leading to radiological impacts on the environment	Low
##R09	Extreme rainfall event leading to potentially contaminated water leaving site	Low
##R10	Bushfire destroying processing plant	Medium

Risk ID	Potential threat and effects on the environment	Residual risk rating
Decommissioning and Closure		
##R11	Radioactively contaminated equipment and materials leaving the site.	Low
##R12	Release of radioactive materials from closed out operation	Low
##R13	Higher than predicted post-closure public doses.	Low
Transportation		
##R14	Incident during transport resulting in release of radioactive material to soil	Medium
##R15	Incident during transport resulting in release of radioactive material to air and waterway	Low

9.0 CONSTRUCTION, OPERATION AND DECOMMISSIONING IMPACT ASSESSMENT

This section discusses the potential radiological impacts of the Project as a result of the combined construction, operation and decommissioning activities. Also discussed are the associated control measures that aim to reduce impacts to as low a level as possible. Control measures referred in this section are summarised in Section 10.0.

The potential radiological impacts are based on the outputs of the air quality modelling, and conservatively use cumulative dust deposition for the life of the Project. Therefore, this assessment represents a worst case situation.

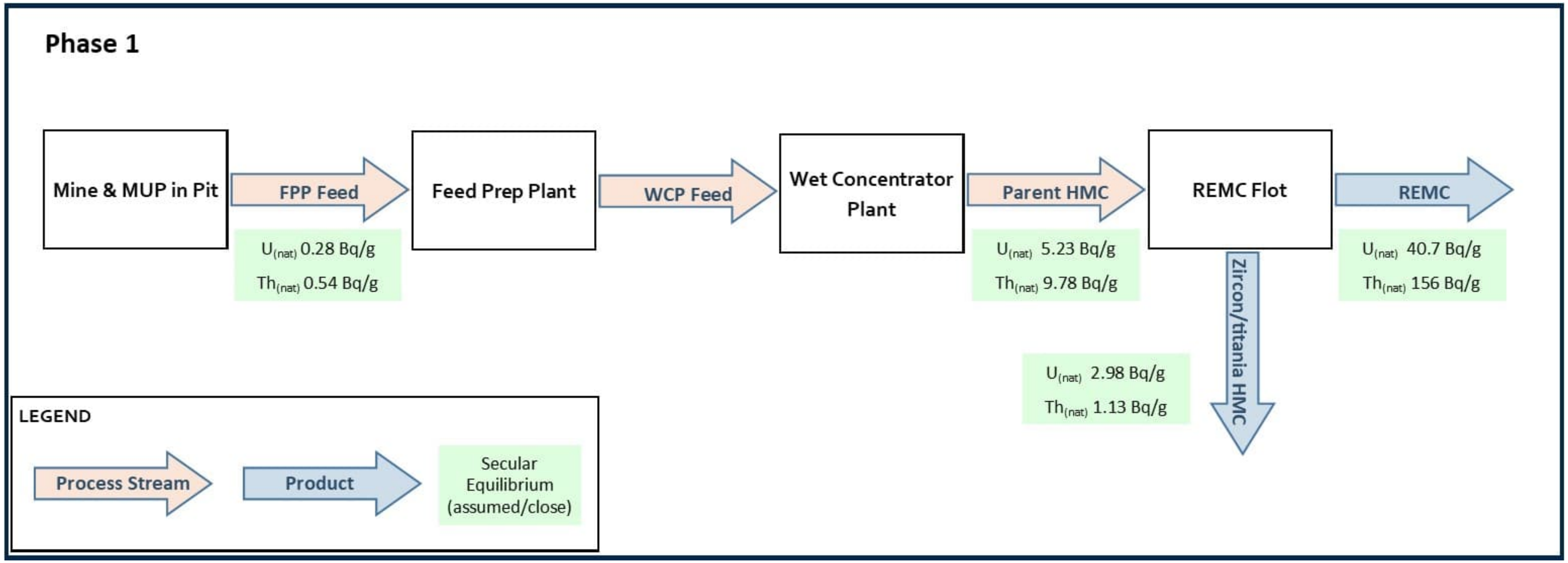
As previously noted calculation parameters and assumptions are detailed in Appendix C.

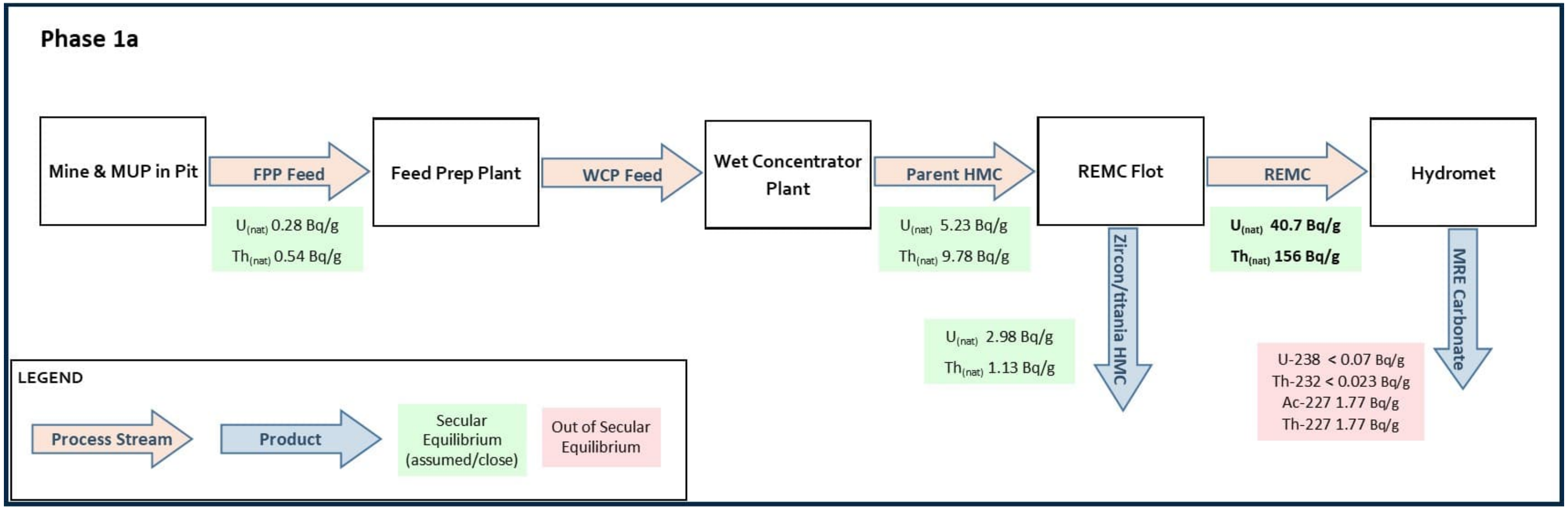
9.1 RADIOLOGICAL OVERVIEW OF PROCESS AND PRODUCTS

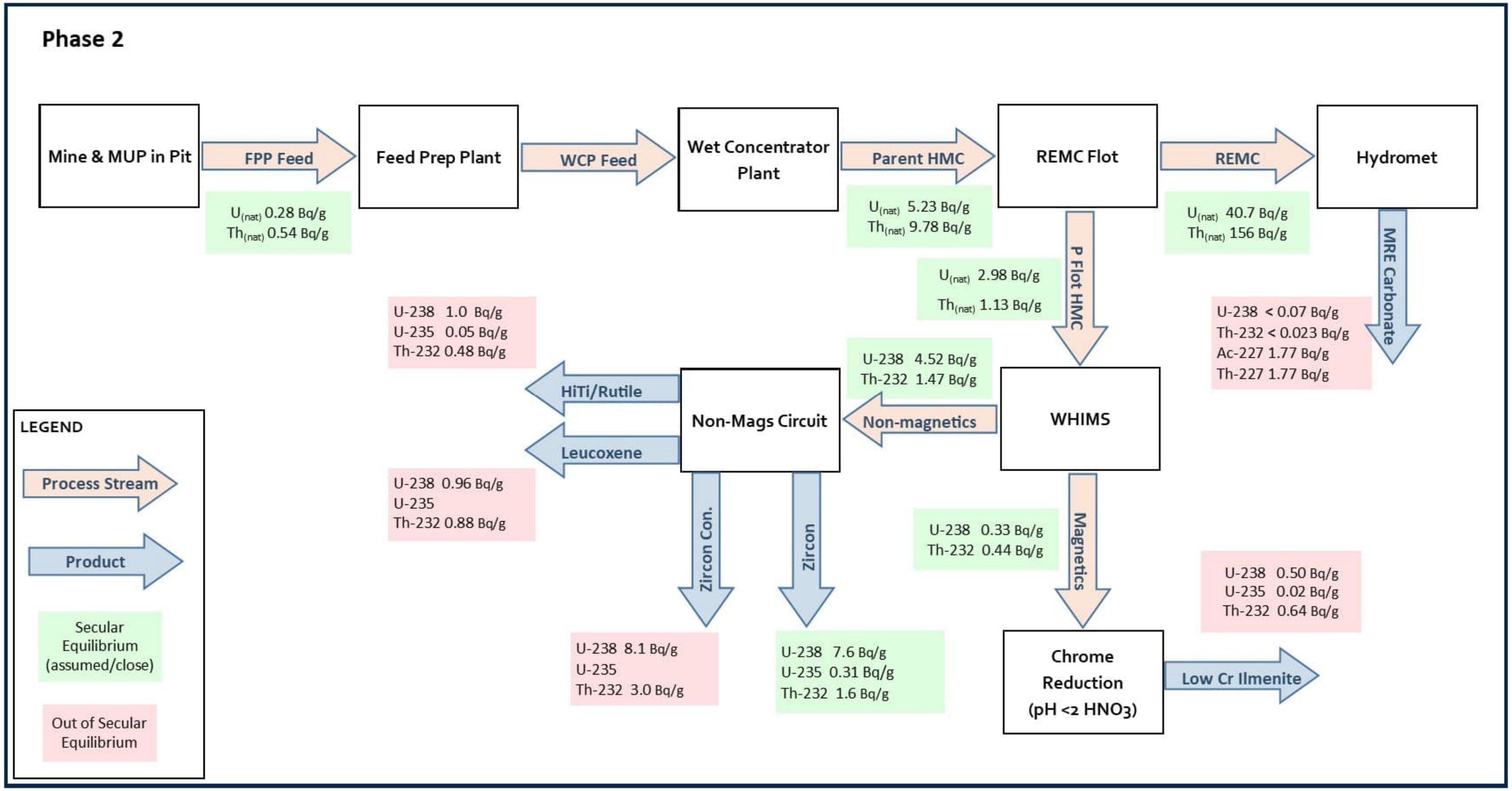
The basis for the Radiation Impact Assessment requires an understanding of radiological properties of the ore, process streams and products. The information provides the basis for quantifying the potential radiological emissions from the project which when combined with the air quality modelling, provides radiological concentrations at the receptors.

The Phases 1, 1a and 2 process streams and products and their radiological content are show in Figure 29.

Figure 29: Flowcharts of Process Streams and Products




Phase 1a
Mine & MUP in Pit
FPP Feed
Feed Prep Plant
WCP Feed
Wet Concentrator Plant
Parent HMC
REMC Flot
REMC
Hydromet
U(nat) 0.28 Bq/g
Th(nat) 0.54 Bq/g
U(nat) 5.23 Bq/g
Th(nat) 9.78 Bq/g
Zircon/titania HMC
U(nat) 40.7 Bq/g
Th(nat) 156 Bq/g
MRE Carbonate
U(nat) 2.98 Bq/g
Th(nat) 1.13 Bq/g
U-238 < 0.07 Bq/g
Th-232 < 0.023 Bq/g
Ac-227 1.77 Bq/g
Th-227 1.77 Bq/g
LEGEND
Process Stream
Product
Secular Equilibrium (assumed/close)
Out of Secular Equilibrium


Phase 2
Mine & MUP in Pit
FPP Feed
U(nat) 0.28 Bq/g
Th(nat) 0.54 Bq/g
Feed Prep Plant
WCP Feed
Wet Concentrator Plant
Parent HMC
U(nat) 5.23 Bq/g
Th(nat) 9.78 Bq/g
REMC Flot
REMC
U(nat) 40.7 Bq/g
Th(nat) 156 Bq/g
Hydromet
MRE Carbonate
U-238 < 0.07 Bq/g
Th-232 < 0.023 Bq/g
Ac-227 1.77 Bq/g
Th-227 1.77 Bq/g
P Flot HMC
U(nat) 2.98 Bq/g
Th(nat) 1.13 Bq/g
WHIMS
Non-magnetics
U-238 4.52 Bq/g
Th-232 1.47 Bq/g
Non-Mags Circuit
HiTi/Rutile
U-238 1.0 Bq/g
U-235 0.05 Bq/g
Th-232 0.48 Bq/g
Leucoxene
U-238 0.96 Bq/g
U-235
Th-232 0.88 Bq/g
Zircon Con.
U-238 8.1 Bq/g
U-235
Th-232 3.0 Bq/g
Zircon
U-238 7.6 Bq/g
U-235 0.31 Bq/g
Th-232 1.6 Bq/g
Magnetics
U-238 0.33 Bq/g
Th-232 0.44 Bq/g
Chrome Reduction (pH <2 HNO3)
Low Cr Ilmenite
U-238 0.50 Bq/g
U-235 0.02 Bq/g
Th-232 0.64 Bq/g
LEGEND
Process Stream
Product
Secular Equilibrium (assumed/close)
Out of Secular Equilibrium

The radiological properties of the average run-of-mine (ROM) feed for Area 1 and Area 3 of the Project are listed in Table 18.

Table 18: Radiological Properties of ROM Feed

Material	Material Equilibrium Status	Concentration (ppm)		Activity Concentration (Bq/g)	
		U	Th	$U_{(natural)}$	$Th_{(natural)}$
Area 1	In secular equilibrium	23	132	0.28	0.54
Area 3		17	85	0.21	0.35

9.2 RADIOLOGICAL IMPACTS TO THE PUBLIC AT PROJECT RECEPTORS

The radiological impacts to the public are assessed by calculating the potential total effective dose from all the exposure pathways. The calculated dose is then compared to the accepted dose limit of 1 mSv/y.

The Radiation Impact Assessment has been conducted in accordance with the methods in Section 6.0 of this report.

9.2.1 DOSE FROM IRRADIATION BY GAMMA RADIATION

The highest gamma dose rates will occur closest to the Project boundary as gamma levels decrease with distance. Gamma doses were calculated for Receptors 14 and 9, the closest receptors to Areas 1 and 3, and are listed in Table 19.

Table 19: Dose from Gamma Irradiation

Receptor	Material	Gamma Dose Rate (mSv/y)
9	1Mt stockpile Area 3 ore	0.021
14	1 Mt stockpile Area 1 ore and 300 t stockpile of REMC	0.034

The conservative gamma dose rate of 0.034 mSv/y will be used for the total annual dose calculations at all receptors.

Conservative Assumptions:

- Material stockpiles are on the Project boundary.
- There is continuous exposure (all year) at receptor with no shielding from gamma radiation source.

9.2.2 DOSE FROM THE INHALATION OF DUST CONTAINING RADIONUCLIDES

Doses due the inhalation of Project originated dust were calculated for the highest modelled dust scenarios for mining in Area 1 and in Area 3, which are listed in Table 20.

Table 20. Dose from the Inhalation of Dust containing Radionuclides

Receptor	Inhalation Dose (mSv/y)	
	Area 1 ore	Area 3 ore
R1	7.15E-05	1.15E-04
R2	2.62E-04	1.62E-04
R3	4.73E-04	8.09E-05
R4	5.24E-05	8.76E-05
R5	5.34E-05	9.43E-05
R6	6.14E-05	1.21E-04
R7	9.06E-05	2.83E-04
R8	9.27E-05	8.76E-05
R9	2.22E-04	9.43E-04
R10	1.71E-04	7.41E-05
R11	2.92E-04	7.41E-05
R12	9.77E-04	9.43E-05
R13	8.26E-04	1.01E-04
R14	3.42E-03	2.09E-04
R15	5.94E-04	6.74E-05
R16	1.21E-04	3.44E-05
R17	1.81E-04	6.74E-05

The highest of the doses for each receptor will be used in the total dose calculations.

Conservative Assumptions:

- All project generated dust is ore, with an AMAD of 1 µm.
- The maximum dust generating scenarios are modelled.
- All year is spent outside at the receptor.

9.2.3 Dose from Ingestion of Food

The assessment assumed a standard Australian diet [ARPANSA 2019] and that half of the ingested food, excluding milk and fish which are not considered, is grown at the Receptor, where Project dust has deposited and has been taken up into plants and animals. The calculations are based on the soil radionuclide increment at the conclusion of the Project (after 20 years of dust deposition). Ingestion doses are calculated for four age groups due to differences in dietary intake and in dose coefficients. The ingestion does are listed in Table 21.

Table 21: Doses from Ingestion of Food

Receptor	Food Ingestion Dose (mSv/y)			
	1 Y	5 Y	10 - 15 Y	Adult
R1	0.0017	0.0021	0.0041	0.0007
R2	0.0034	0.0041	0.0082	0.0015
R3	0.0042	0.0051	0.0101	0.0018
R4	0.0014	0.0016	0.0032	0.0006
R5	0.0014	0.0017	0.0034	0.0006
R6	0.0018	0.0022	0.0043	0.0008
R7	0.0049	0.0059	0.0117	0.0022
R8	0.0013	0.0016	0.0031	0.0006
R9	0.0098	0.0118	0.0234	0.0043
R10	0.0014	0.0017	0.0034	0.0006
R11	0.0021	0.0025	0.005	0.0009
R12	0.0078	0.0095	0.019	0.0034
R13	0.0053	0.0064	0.0128	0.0023
R14	0.032	0.0388	0.0774	0.0139
R15	0.0033	0.0041	0.0081	0.0015
R16	0.0008	0.0009	0.0019	0.0003
R17	0.0019	0.0023	0.0046	0.0008

Conservative Assumptions:

- All project generated dust is ore.
- The maximum dust generating scenarios modelled.
- The calculation is for 20 years of dust deposition – 7 years of Area 1 ore and 13 years of Area 3 ore.
- 50% of all food consumed (milk and fish not considered) is grown at the receptor.

9.2.4 DOSE FROM INGESTION OF TANK WATER

The primary source of water at receptors is tank water which collected from roofing at the receptors during rainfall events . The doses due to the ingestion of tank have been conservatively calculated and are listed in Table 22.

Table 22: Doses from Ingestion of Tank Water

Receptor	Tank Water Ingestion Dose (mSv/y)			
	1 Y	5 Y	10 - 15 Y	Adult
R1	0.0005	0.0006	0.001	0.0003
R2	0.0014	0.0016	0.0027	0.0007
R3	0.0026	0.003	0.0051	0.0013
R4	0.0004	0.0005	0.0008	0.0002
R5	0.0005	0.0005	0.0009	0.0002
R6	0.0006	0.0007	0.0012	0.0003
R7	0.0019	0.0022	0.0035	0.0009
R8	0.0004	0.0004	0.0007	0.0002
R9	0.0037	0.0043	0.007	0.0018
R10	0.0007	0.0008	0.0013	0.0003
R11	0.0011	0.0013	0.0022	0.0006
R12	0.0054	0.0062	0.0104	0.0026
R13	0.0034	0.004	0.0066	0.0017
R14	0.023	0.0264	0.0443	0.0112
R15	0.0021	0.0024	0.0041	0.001
R16	0.0004	0.0005	0.0008	0.0002
R17	0.0010	0.0012	0.0019	0.0005

Conservative Assumptions:

- All project generated dust is ore.
- The maximum dust generating scenarios modelled.
- All water consumed is tank water.
- The maximum dose, of either Area 1 or Area 3 ore, has been used.
- There is fifty percent dissolution of all radionuclides in dust.

9.2.5 DOSE FROM THE INHALATION OF RADON DECAY PRODUCTS

The dose due to the inhalation of the decay products of Rn-222 and Rn-220 were calculated for Area 1 and Area 3 ores and are listed in Table 23.

Table 23: Dose for the Inhalation of Radon Decay Products

Receptor	Area 1 ore		Area 3 ore	
	Rn-222DP Dose (mSv/y)	Rn-220DP Dose mSv/y)	Rn-222DP Dose (mSv/y)	Rn-220DP Dose (mSv/y)
R1	0.0003	1.02E-12	0.0005	3.42E-09
R2	0.0009	7.39E-07	0.0007	5.28E-07
R3	0.0013	3.06E-05	0.0004	1.06E-10
R4	0.0002	5.91E-16	0.0005	2.57E-09
R5	0.0002	1.38E-15	0.0006	4.37E-08
R6	0.0003	4.94E-14	0.0007	5.47E-08
R7	0.0004	2.14E-11	0.0017	1.24E-04
R8	0.0004	4.91E-11	0.0006	5.41E-06
R9	0.0012	3.06E-07	0.0081	0.04131
R10	0.0007	1.28E-07	0.0005	7.44E-07
R11	0.0009	4.24E-06	0.0005	4.01E-08
R12	0.0023	0.0009	0.0005	1.78E-09
R13	0.0020	0.0025	0.0005	9.38E-08
R14	0.0067	0.0259	0.0008	6.33E-07
R15	0.0014	0.0006	0.0003	2.24E-10
R16	0.0004	2.07E-08	0.0002	8.58E-14
R17	0.0007	7.00E-07	0.0004	4.37E-11

The highest Rn-222DP and Rn-220DP doses for each receptor will be used in the total dose calculations.

Conservative Assumptions:

- All Rn-222 and Rn-220 contained and generated in the materials is released to the atmosphere during the mining processing of materials.
- All year is spent outside at receptor.

9.2.6 TOTAL ESTIMATED DOSE

9.2.6.1 CONSERVATIVE

The summary of Radiological Impact to humans at each receptor has been calculated for all exposure pathways. The conservative annual total dose for each age group at all receptors is listed in Table 24.

Table 24: Conservative Annual Total Dose at Receptors

Receptor	Conservative Project Impact Radiological Dose (mSv/y)			
	1 Y	5 Y	10 - 15 Y	Adult
R1	0.037	0.037	0.040	0.036
R2	0.040	0.041	0.046	0.037
R3	0.043	0.044	0.051	0.039
R4	0.036	0.037	0.039	0.035
R5	0.037	0.037	0.039	0.035
R6	0.037	0.038	0.040	0.036
R7	0.043	0.044	0.051	0.039
R8	0.036	0.037	0.038	0.035
R9	0.098	0.100	0.115	0.090
R10	0.037	0.037	0.040	0.036
R11	0.038	0.039	0.042	0.037
R12	0.051	0.054	0.068	0.044
R13	0.048	0.050	0.059	0.043
R14	0.125	0.135	0.192	0.095
R15	0.042	0.043	0.049	0.039
R16	0.036	0.036	0.037	0.035
R17	0.038	0.038	0.041	0.036

The conservative estimates of total doses to humans at the Receptors, due to the Project, are low with a range of 0.035 – 0.192 mSv/y and a median of 0.039 mSv/y, and well below the recognised public dose limit of 1 mSv/y.

9.2.6.2 REALISTIC

A number of the factors for parameters used in the dose calculations in Sections 9.2.1 to 9.2.5 have been identified as being overly conservative. These have been listed in Table 25, with the more *realistic* factors included.

Table 25: Conservatism and realism for dose calculations

Dose Component	Parameter	Conservative %	*Realistic* (less conservative) %
Gamma	Time outside at receptor	100	40
Inhalation	Quantity of ore in dust	100	30
Ingestion	Quantity of ore in dust	100	30
	Receptor grown food in total diet (milk and fish excluded)	50	10
Ingestion Tank water	Quantity of ore in dust	100	30
	Dissolution of all radionuclides contained in dust	50	10
Radon Decay Products	$F_{Rn\text{-}220} = 0.004$	0.004	0.0006 (measured median)

Dose calculations undertaken with the *realistic* factors provide total estimated doses to humans at the Receptors, due to the Project, with a range of 0.035 – 0.086 mSv/y and a median of 0.035 mSv/y, and well below the recognised public dose limit of 1 mSv/y.

9.2.7 Controls

The conservative dose assessment indicates that radiological impacts will be low, which is partly due to the low levels of radioactivity in the mined material.

The ICRP [ICRP 2007-103] and the IAEA [IAEA 2014] comment that *controls are to be commensurate with the magnitude of the impact*. Consequently, additional controls for the purposes of radiation protection are unnecessary.

The standard dust controls that all mining and processing operations generally employ, will act to control both emissions and potential radiological impacts.

The Radiation Management Plans will ensure continuance of radiological environmental monitoring, the results of which will enable assessment of impact. If the measured impact is above specified action levels, mitigation measures will be implemented, as identified in the risk assessment.

9.2.8 Residual Impacts

It is expected that the actual doses to humans at Receptors will be lower than the conservative assessments that have been undertaken.

9.3 Radiological Impacts to Flora and Fauna

9.3.1 ERICA Tool Assessment

The radiological impact to flora and fauna due to the Project was assessed based on the soil radionuclide increment at the conclusion of the project (after 20 years of dust deposition) which was greatest at Receptor 14. The ERICA Tool Tier 2 assessment level was conducted for Receptor 14 and the output of the assessment are listed in Table 26.

Table 26: Outputs of ERICA Tool Tier 2 Assessment for Flora and Fauna

Reference Species	Dose Rate (µGy/h)
Amphibian	5.23 E-2
Annelid	6.57 E-2
Arthropod – detritivorous	7.34E-2
Bird	1.10E-2
Flying insects	1.72E-2
Grasses & Herbs	1.23E-1
Lichen & Bryophytes	4.66E-1
Mammal – large	2.46E-2
Mammal – small-burrowing	2.76E-2
Mollusc – gastropod	1.60E-2
Reptile	5.25E-2
Shrub	1.34E-1
Tree	9.03E-3

The screening level (absorbed dose rate above which additional assessment is required, due to possible impact to species) for additional or more detailed assessment is 10µGy/h [ARPANSA 2015]. The assessed potential impact to all reference species is very low.

For comparison purposes, the estimated additional gamma dose to flora and fauna from project dust emissions depositing in the environment, based on the full Project life, is on average one- tenth of the natural gamma radiation background levels, and well within the natural environmental radiological variation.

Potential radiological impacts to flora and fauna in the Study Area due to the Project are assessed a being very low.

9.3.2 Controls

The assessment of potential radiological impact to flora and fauna indicate that no additional controls are justified due to the very low potential impacts. The standard dust controls that all mining and processing operations generally employ, would act to further reduce potential impacts.

The Radiation Management Plans will ensure continuation of dust deposition monitoring and sample analysis, the results of which will enable flora and fauna impact assessment. If the measured impact is above specified action levels, mitigation measures would be implemented, as identified in the risk assessment.

9.3.3 Residual Impacts

Radiological impacts to flora and fauna from the operations are expected to be very low.

9.4 Radiological Impacts to Crops

The modelling applied in Section 7.3.1 can be applied to determine the Project's impact on crops.

9.4.1 Variation in Soil Concentrations

Soil samples from the Study Area have been sampled and analysed, with the results reported in Figure 26, and detailed in Table 27. The conservative calculated maximum change in soil radionuclide activity concentration at the end of the Project life, is also included in Table 27, as head of chain, with decay products in secular equilibrium.

Table 27: Measured Soil Radionuclide Activity Concentrations and Project Soil Increment

ERML	Soil Radionuclide Activity Concentration – 2019 samples (Bq/kg)								
	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Ra-228	Th-228
ERML-RO	11.2±2.5	9.2±2.3	22.7±5.1	13.9±1.6	35.4±6.1	23.7±3.6	27.0±5.5	24.0±3.0	22.2±5.3
ERML-R9	16.8±3.1	17.1±3.1	25.8±5.1	26.4±2.8	41.2±7.4	35.1±4.6	35.5±5.9	36.8±3.4	34.5±5.9
ERML-R10	10.2±2.5	11.4±2.6	18.3±4.3	20.1±2.2	36.4±7.7	31.3±4.4	27.4±5.2	26.0±3.4	24.9±5
ERML-R16	20.5±3.7	22.4±3.9	24.3±4.5	25.2±2.3	56.5±8.3	37.8±5.1	36.2±5.6	40.9±4.0	31.6±5.2
ERML-R5	25.2±4.3	28.7±4.6	34.8±6.1	31.2±3.1	28.8±6.1	21.5±3.8	36.6±6.1	35.9±4.1	37.1±6.2
Project Soil Increment	0.968						1.82		

The modelled radiological changes in soil concentrations are an order of magnitude less than current measure concentrations and are less than the analytical error bands. As such measurement of project increment is likely to be undetectable.

The calculated grain crop radionuclide activity concentrations, based on the current measured soil data in Table 27, are listed in Table 28, along with the project increment.

Table 28: Calculated Grain Radionuclide Activity Concentrations

ERML	Calculated Grain Crop Activity Concentration (Bq/kg)								
	U-238	U-234	Th-230	Ra-226	Pb-210	Po-210	Th-232	Ra-228	Th-228
ERML-RO	0.059	0.049	0.012	0.067	0.108	0.003	0.015	0.116	0.012
ERML-R9	0.089	0.091	0.014	0.128	0.126	0.004	0.019	0.178	0.019
ERML-R10	0.054	0.060	0.010	0.098	0.111	0.004	0.015	0.126	0.014
ERML-R16	0.109	0.119	0.013	0.122	0.782	0.005	0.020	0.198	0.017
ERML-R5	0.134	0.152	0.019	0.151	0.088	0.003	0.020	0.174	0.020
Project Increment	0.007	0.007	0.001	0.007	0.004	0.000	0.001	0.012	0.001

The increase in grain radionuclide activity concentration due to twenty years of Project dust deposition is minimal.

9.4.2 Controls

Based on the assessed impacts, there are no additional controls necessary for the radiological purposes. The major pathway for radionuclides into the environment, from the Project, is by dust emission, and standard operational dust controls will be used to control emissions. Routine environmental monitoring would identify areas for improvement.

9.4.3 Residual Impacts

Potential radiological impacts to crops are expected to be negligible.

9.5 Radiological Impacts to Groundwater

9.5.1 Impact

The groundwater in the Study Area is below the zone to be mined. The groundwater has no current use due to high salinity levels. Baseline monitoring (Section 7.2.6) has identified that the Study Area has elevated radionuclide concentrations in groundwater compared to other regions in Australia.

The mining, processing and subsequent placement of tailings is unlikely to have an impact on groundwater from a radiological perspective. This is due to the low solubility of the radionuclides. Additionally, the tailings will be returned to what was the ore zone, and the activity concentration of Phase 1a and Phase2 tails (0.68Bq/g) is less than that of the ore (0.72 Bq/g), and Phase 1 tails will be lower due to radionuclides in product. It is therefore unlikely that any radiological change in groundwater will occur.

9.5.2 Controls

The general controls for seepage of radionuclides from the Project to groundwater include:

- Dewatering of tailings during placement to minimise standing water and removal of the pathways for seepage.
- Bunding in the processing plant area to contain spillages.
- Ongoing groundwater monitoring and radiological analysis to identify any potential changes.

The Radiation Environmental Plan will ensure continuance of groundwater monitoring, the results of which will enable assessment of impact. If the measured impact is above specified action levels, mitigation measures will be implemented, as identified in the risk assessment.

9.5.3 Residual Impacts

Potential radiological impacts to groundwater from the operations are expected to be minor.

9.6 RADIOLOGICAL IMPACTS TO THE PUBLIC AT TRANSPORT RECEPTORS

The radiological impacts to the public are assessed by calculating the potential effective dose from gamma exposure, as the other exposure pathways are negated due to the product being encapsulated in shipping containers. The calculated dose is then compared to the accepted dose limit of 1 mSv/y.

The highest gamma dose rates will occur during Phase 1 of the Project, when REMC is being transported, and the Radiation Impact Assessment has been conducted in accordance with the method in Section 6.0 of this report.

The impact assessment is based on the storage and transportation tonnages detailed in Table 29. It is planned for two trains per week to transport product from Ultima to the Port, however contingency has also been made for an extreme event which may impact rail transport, in which case up to ten days production may be stored at Ultima. Shipping containers may also be transported by road. At this time the frequency of shipping from the Port of Melbourne is unknown, and consequently the amount of material to be stored at the Port is unknown.

Table 29: Approximate storage and transportation tonnages

Phase	Product material	Approximate storage and transportation tonnages				
		Ultima normal	Ultima extreme event which delays transportation	Weekly transportation	Per Train	Per trucked shipping container
1	REMC	105	300	210	105	25
	Zircon Titania HMC	1,969	5,625	3,938	1,969	25
1a	MREC	105	300	210	105	25
	Zircon Titania HMC	1,969	5,625	3,938	1,969	25
2	MREC	105	300	210	105	25
	Low Chrome Ilmenite	534	1,525	1,068	534	25
	HiTI/Rutile	175	500	350	175	25
	Leucoxene	35	100	70	35	25
	Zircon	534	1,525	1,068	534	25
	Zircon concentrate	105	300	210	105	25

9.6.1 Gamma Doses during interim storage at Ultima Intermodal Facility to Receptors

The highest gamma doses will be received at receptors closest to the storage facility boundary, as gamma levels decrease with distance. Gamma doses were calculated for each receptor with the conservative assumption that all containers are placed on the boundary closest to that specific receptor. The dose assessment also considered both normal transportation storage, and normal storage with one annual extreme event, and product materials from Phase 1, Phase 1a and Phase 2. The gamma doses are listed in Table 30.

Table 30: Dose from Gamma Irradiation at Ultima

Product Material	Storage duration	Gamma Dose Rate (mSv/y)		
		TR1	TR2	TR3
Phase 1	Normal	0.01	0.80	0.11
	Normal with 1 extreme event	0.08	0.80	0.20
Phase 1a	Normal	<0.001	0.02	0.09
	Normal with 1 extreme event	0.002	0.02	0.09
Phase 2	Normal	0.001	0.12	0.003
	Normal with 1 extreme event	0.001	0..12	0.01

Conservative Assumptions:

- All containers are at storage facility boundary.
- There is no shielding from gamma radiation source.
- There is continuous exposure (all year) at receptors TR1 and TR3.

9.6.2 Gamma Doses during road and Rail transportation of material

The four exposure scenarios that have been modelled for the transportation of Phase 1 product are:

- A person in a vehicle stopped at a railway crossing as train whilst a train carrying product passes.
- A residence adjacent to a transport route which is used for product movement.
- A person in a vehicle that follows a truck, carrying product, for the entire transport route from Ultima to the Port of Melbourne.
- A person in a vehicle that is parked alongside a truck, carrying product material, for 30 minutes.

All scenarios were modelled based on two trains per week carry product, and the same quantity of product being transported by road. The gamma doses are listed in Table 31.

Table 31: Dose from Gamma Irradiation during transportation of Phase 1 material

Modelled Scenario	Frequency	Gamma Dose Rate (mSv/y)
Vehicle parked at a train crossing	1 crossing event	2.3×10^{-4}
Residence adjacent to transport route.	2 trains/week equivalent road transportation	0.006
Vehicle following truck from Ultima to Port of Melbourne	1 following event	0.023
Vehicle parked beside truck for 30 minutes	1 adjacent parking event	0.010

Conservative Assumptions:

- Train is travelling at 10 km/h
- There is no shielding from source of gamma radiation.
- Transportation of Phase 1 product material, which has the highest radionuclide concentration than Phase 1a and Phase 2 materials.

9.6.3 CONTROLS

The assessment of potential radiological exposure, due to the interim storage at the Ultima intermodal facility, indicates that doses whilst lower than the member of public limit and conservatively calculated, do require quantification at the commencement of use of the facility. Due to the shielding afforded by containerisation and the density of the material, gamma doses are expected to be considerably lower. This will be confirmed by a detailed gamma survey of the site during the first occurrence of normal storage, and also if an extreme event necessitates the storage of additional material. The transport contractor's *Facilities and Transport Management Plans* will detail additional controls, such as the location of containers within the facility and stacking arrangements, which can be enacted to reduce gamma doses.

The dose to member of the public, during movement of product material by road or rail, is assessed to be negligible as it is one-hundred times less than the member of public limit.

9.6.4 RESIDUAL IMPACTS

Radiological impacts to members of the public, due to the transportation and interim storage of product material, are assessed to be low given the conservative dose assessment, and the control procedures.

9.7 CHARACTERISATION OF PROJECT MATERIALS WITH REFERENCE TO EPBC ACT

9.7.1 PROCESS STREAMS

The Project will be implemented across three phases with varying process streams. The phases and process streams are shown in Figure 29. The Project will also mine two areas, with Area 1 ore having higher uranium and thorium concentrations than Area 3 ore.

During processing, uranium and thorium can concentrate in materials, and secular equilibrium can be disturbed. Sections of the processing facility will contain radioactive materials and will require radiation protection controls and management.

The radionuclide activity concentrations for product material (produced from Area 1 ore) are listed in Table 32. Where materials are not in secular equilibrium, the concentration of the decay product has been included.

Table 32: Radionuclides in Products and Waste Stream for Area 1 Ore

Phase	Material	Activity Concentration (Bq/g)						
		U-238	Pb-210	U-235	Ac-227	Th-227	Th-232	Ra-228
	Ore	0.28					0.54	
1	REMC	40.7					156	
	Zircon Titania HMC	2.98					1.13	
1a	MREC	< 0.07			1.77	1.77	< 0.023	
	Zircon Titania HMC	2.98					1.13	
2	MREC	< 0.07			1.77	1.77	< 0.023	
	Low Chrome Ilmenite	0.50	0.53	0.02			0.64	
	HiTI/Rutile	1.0		0.08			0.48	
	Leucoxene	0.92	awaiting further analyses				0.88	
	Zircon	7.6	6.9	0.31			1.6	
	Zircon concentrate	8.2	awaiting further analyses				3.0	
	Tailings Phases 1a & 2	0.14					0.54	

9.7.2 WASTE STREAMS

The waste streams from all circuits of the processing plants will be homogenized, and radionuclides will be in chemically stable forms, before being returned as a Tailings Stream to the ore zone of the mine pit void. Test work has indicated that the activity concentration mined material and subsequent tailings waste streams of ore and tailings are less than 1 Bq/g.

The tailings produced in Phase 1 will contain lower uranium and thorium concentrations than Phases 1a and 2, due to the high concentration of uranium and thorium in the REMC product. The concentrations of uranium and thorium in the Phase 1a and Phase 2 Tailings stream is listed in Table 32, and are less than those of the ore.

9.7.3 Product Storage

There will be interim contained storage of products onsite prior to transportation offsite. The Victorian Radiation Regulations [Vic Govt 2017] provide activity limits which, in conjunction with the activity concentration of the product (Table 32) enable calculation of the maximum quantities of each material that can be stored on site before exceeding the levels provided in the EPBC Act. The calculated maximum quantities of materials to be stored on site prior to shipping, the EPBC Act Level - material quantity, and the on-site storage methods are detailed in Table 33.

Table 33: Material Storage Quantities, and Storage Method

Phase	Material	Product Storage (t)		Storage Method
		Maximum to be Stored at Project	EPBC Act Level - Material Quantity	
1	REMC	300	5.1	Surge bin and in bulka bags in lined shipping containers
	Zircon Titania HMC	5,625	243	Stockpile in buildings and lined shipping containers
1a	MREC	300	513	Product bin and bulka bags in lined shipping containers
	Zircon Titania HMC	5,625	243	Stockpile in buildings and lined shipping containers
2	MREC	300	513	Product bin and bulka bags in lined shipping containers
	Low Chrome Ilmenite	1,525	854	Product bins and lined shipping containers
	HiTI/Rutile	500	676	
	Leucoxene	100	556	
	Zircon	1,525	109	
	Zircon concentrate	300	89	

During storage these materials are contained as detailed in Table 33. Buildings will be secured, with restricted access, and designed to ensure no emission of products. Any dust extraction systems will have bag-house arrangements to collect any fugitive material.

9.8 RADIOACTIVE SOURCE CATEGORY AND ADDITIONAL SECURITY REQUIREMENTS

Sealed radioactive sources will be used in density gauges throughout the processing plant. Plant design includes seventeen 5 – 20 mCi (0.19 – 0.74 GBq) Cs-137 sealed source fixed density gauges. Assessment of these sources, as per ARPANSA 2019b, gives and A/D ratio of 0.13, which equates to Category 4. The A/D range for Category 4 is 0.01 - 1.

There are no additional security requirements under the Security of Radioactive Sources Code. This will be reassessed at the time of final plant design and equipment procurement.

9.9 SUMMARY OF RESIDUAL IMPACTS

Assessment has indicated that there will be no residual radiation impact during construction, operation, decommissioning and closure.

10.0 SUMMARY OF CONTROL, MONITORING AND CONTINGENCY MEASURES

Control, monitoring and contingency measures will be detailed in the operational Radiation Management Plans, in accordance with relevant State Radiation Protection Regulations and consistent with the requirements of the Mining Code [ARPANSA 2005]. The operational Management Plans are the:

- Radiation Management Plan (RMP),
- Radiation Waste Management Plan (RWMP), and
- Radiation Environmental Plan (REP).

An outline of the content of these plans in included in Appendix D:

The Transportation Contractor will be responsible for the Transportation Facilities and Transport Management Plans which will detail control, monitoring and contingency measures with regards to radiation management, and will report regularly to VHM on performance.

10.1 CONTROL MEASURES

The overall radiological impacts of the Project are expected to be low, and controls will be implemented, consistent with the magnitude of the radiological risks to the public and to the environment.

The management plans will be developed to ensure that radiation related impacts and risks remain well controlled.

Both engineered and administrative controls will be implemented for the Project, and Table 34 provides an overview of the specific controls and how they would be implemented.

Table 34: Control measures relevant to Radiation Impact

Measure ID	Description of Control	Phase
R-ENG01	Project to be operated in accordance with a management licence addressing radiation safety in accordance with the provisions of the Radiation Regulations, including likely conditions such as compliance with the Radiation Protection Series No. 9 and preparation of a radiation sub-plan for all operations. The plan would account for any special conditions or exemptions from specific provisions of the Radiation Regulations that might apply to the project.	All phases
R-ENG02	Minimise radiation effects: Engineering design • A wheel wash and vehicle washdown bay would be established to minimise the spread of potential contamination around the site and off the site • The processing facility will be constructed with spillage containment. This includes all tanks having concrete bunds, as secondary containment, to store at least the volume of the tank [Vic EPA 2018]. • Provision for hose down facilities and sumps, access ways and sufficient room for bobcats for clean up under conveyors • Tailings pipelines will be fitted with a leak detection system that will turn off pumps if a pipe failure is detected–with a schedule of preventative maintenance and inspection to be established for pipelines carrying radioactive process materials • Dust minimisation and suppression system within process plant - with a schedule of preventative maintenance and inspection to be established for areas with radioactive process materials	Construction Operation
R-ENG03	Minimise radiation effects: Product packing • All product packing will occur within buildings, including the use of a packing booth for REMC.	Operation
R-ADM01	Minimise radiation effects: Administrative • Safe operating procedures to be developed to ensure the safe and environmentally responsible operation of the Project • All employees and contractors would receive training in the radiological aspects of the Project and provided instruction on prevention of contamination release from the Project. • A qualified and experienced Radiation Safety Officer will be available to undertake radiation monitoring, advise management on measures to reduce radiation, exposures and regulatory reporting. • Site access controls would be implemented to ensure that: o unauthorised access is restricted o intentional or inadvertent removal of radioactive material from the operation is prevented	Construction Operation
R-ADM 02	Minimise radiation effects: Rehabilitation • Radiological input to the closure plan will occur, based on approved radiological closure criteria of return to pre-operational radiological conditions, with monitoring to confirm compliance.	Closure

10.2 MONITORING AND CONTINGENCY MEASURES

The Project will undertake a range of environmental monitoring annually, to;

- assess doses to the public at the Receptors,
- assess any impacts to flora and fauna at the Receptors, and
- identify radiological changes in groundwater.

An overview of the environmental monitoring program is included in Table 35.

Table 35: Monitoring and contingency measures relevant to Radiation

Environmental Pathway	Measurement Method	Typical Location and Frequency
Direct (external) gamma	Handheld environmental gamma monitor, OSLDs	Annual survey and passive detectors at ERMLs.
Rn-220 and Rn-222 concentrations	Long term passive monitors	Placed at the ERMLs and changed quarterly
Dispersion of dust containing long-lived, alpha-emitting radionuclides	Dust deposition gauges	Sampling at off-site ERMLs. Samples composited for one year then analysed for radionuclides.
	HiVol sampling	Analysis of routine air quality samples for radionuclides.
Seepage of contaminated water	Groundwater sampling from monitoring bores	Sampling from monitoring bores and analyses for radionuclides.
Run off contaminated water	Surface water sampling	Opportunistic surface water sampling will occur following significant rainfall events.
Radionuclides in potable water supplies	Sampling and radiometric analysis	Annually

The monitoring will include:

- The use of recognised sampling methodologies that are documented, and regularly reviewed.
- The requirement for appropriately trained and qualified personnel to undertake monitoring.
- The use of appropriate monitoring equipment.
- Routine instrument calibration programs, including auditing of calibration sources.
- Instrument maintenance and repair programs.
- Regular external audits of the monitoring program and system.

The results of the monitoring will be used to ensure that the radiation controls are effective and operating properly. The results would also provide information to ensure that impacts are ALARA.

Dust particle size monitoring will be conducted to determine the activity median activity diameter (AMAD) of dust once operations commences and mineralized material is being routinely handled. Results will be used to optimize air sampling strategies.

The results of the environmental radiation monitoring, public dose estimates and assessment of radiological impacts to flora and fauna will be compared to standards to ensure compliance. Table 36 list the action levels and the contingencies. Note that the action levels are set well below the regulatory limits.

Table 36: Action Levels and Controls

Radiation Measurement Type	Action Level	Contingency Measure
Public annual dose at closest receptor	0.3 mSv/y above natural background	Identify major exposure pathway and immediately mitigate
Dust Deposition	U-238 0.61 Bq/m^2.month Th-232 1.15 Bq/m^2.month	Investigate and identify source. Eliminate emission Redesign workplace or tasks to reduce emissions.
Annual Assessment of Radiological Impacts to Flora and Fauna	5µGy/h (to any reference species)	Identify emissions source and reduce emissions

11.0 SUMMARY OF IMPLICATIONS UNDER RELEVANT LEGISLATION

This Radiation Impact Assessment has assessed the potential radiological impacts of construction, operation and closure of the Project to the public and to the environment. The assessment has used International and National standards to determine potential impacts.

The following sections summarise these identified impacts under the relevant Commonwealth and Victorian legislation.

11.1 COMMONWEALTH

The assessment shows that the concentrations of radionuclides in the mined materials and tailings do not exceed the levels prescribed for a nuclear action under the EPBC Act.

The assessment shows that the concentrations in some of the products, which are to be temporarily stored on site, will exceed the levels prescribed for a nuclear action under the EPBC Act. As noted, these materials will be subject to control under the operational Radiation Management Plan.

The Project's sealed radioactive sources do not require additional security measures [ARPANSA 2019b]. As noted, this will be reassessed at the time of final plant design and equipment procurement.

The radiological impact assessment indicates that the potential impacts to the environment are very low.

11.2 VICTORIAN

The impacts to people, conservatively assessed as potential annual doses, are low and well below the established dose limit of 1mSv/y, with the highest dose being 0.19 mSv/y.

The impact to flora and fauna was assessed to be very low at 0.47 µGy/h, and well below the recognised reference dose rate of 10 µGy/h for individual species.

The impact to soil and crops was assessed to be very low, with the modelled project increment radionuclide change to soil and crops within analysis error bands, and an order of magnitude below current activity concentrations.

The impact to groundwater is assessed to be low due to the inert nature of the tailings and the lower-than-ore activity concentration.

12.0 CONCLUSION

The purpose of this report is to assess the potential radiological impacts associated with the Project to inform the preparation of the EES required for the project. A summary of the key assets, values or uses potentially affected by the project, and an associated assessment of radiation impacts and recommended mitigation measures, are summarised below.

With the implementation of the control measures included in this assessment, potential adverse radiological impacts as a result of the Project, on the health and wellbeing of residents and local communities and the environment are shown to be minimised.

Existing environment

The defined Study Area for the Project's radiological risk assessment is predominantly cleared flat land dissected by dirt roads (bordered by remnant vegetation verges), with scattered farming residences. The land is predominately used for mixed cropping purposes with occasional livestock grazing. Groundwater is not consumed or used for cultivation due to its high salinity.

The Study Area's radiological environment has been assessed by monitoring that commenced in 2018 and is on-going. The radiological environment is consistent with general Australian and world radiological characteristic, though it should be noted that Rn-220 concentrations are higher than in areas where lower geological thorium concentrations are present. Additionally, groundwater radium levels are elevated.

Impact assessment findings

An iterative assessment was undertaken to evaluate potential impacts associated with the project, considering the existing environment within the Study Area and associated construction, operational and decommissioning activities.

The assessment found the following key impacts:

- The conservative maximum dose to humans, as a result of the Project, is 0.19 mSv/y which is well below the dose limit of 1 mSv/y.
- The radiological impact to flora and fauna, as assessed using the ERICA Tool is considerably below the screening level of 10 µGy/h, with the highest being 0.044 µGy/h for lichens and bryophytes.

- The radiological impact to grain crops is assessed to be minimal, as the project originated soil radionuclide increments are within the analytical error bands for existing soil radionuclide levels, and the calculated project increment radionuclide activity concentration is one to two orders of magnitude less than current calculated crop radionuclide activity concentrations.
- The radiological impact to groundwater is assessed to be low due to the inert nature of the tailings and also because the radionuclide concentration of tailings will be less than that of the ore.
- The conservative maximum dose to members of the public as a result of the interim storage of product material at the Ultima intermodal facility is 0.80 mSv/y for Phase 1 of production, reducing to a maximum of 0.12 mSv/y for Phases 1a and 2 of production. The conservative maximum dose to members of the public during the transportation of product material is 0.010 mSv/y. All doses are below the dose limit of 1 mSv/y.

Control measures

Potential radiological impacts, due to the Project, will be avoided or minimised, and managed to required standards and to the ALARA principle. This will be achieved by;

- minimising radiological emissions to the environment, through best practice dust mitigation,
- design of plant and buildings with bunding and sumps to contain materials,
- controlled access to the Project, and
- routine radiological monitoring.

Mitigation measures

Potential radiological risks, due to the Project, will be avoided, or minimised and managed to required standards through the Radiation Management Plans, and by routine monitoring to identify any exceedances, with procedures to minimise impact.

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Appendix A: Risk Register

Risk Register

Risk ID	Risk pathway for all Receptors	Causes / Background	Initial risk level			Final mitigation	Residual risk level		
			Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
Construction									
##R01	Mineralization exposed during mining pre-strip and site preparation activities leading to exposure of people and the environment	The construction of the mine and associated processing facilities is not expected to result in any radiological impact above natural background. Potential impacts may occur when ore is uncovered and processing commences. Incorrect ore characterisation may lead to uncovering of ore during construction.	Possible	Minor	Medium	Geological assessment of area used as guidance for site planning to ensure mineralized areas are not blocked by infrastructure. Radiation management controls to be in place well before intersection with mineralisation.	Unlikely	Minor	Low
Operation									
##R02	Airborne emissions of dust and radon, above modelled levels, resulting in radiological exposure to people and the environment.	The Radiation Impact Assessment is primarily based on the outputs of the air quality modelling. Errors or omissions in emission estimates could lead to incorrect outputs and affect the radiological assessment	Unlikely	Minor	Low	Environmental radiation monitoring conducted during operations to confirm results of modelling	Rare	Minor	Low
##R03	Public radiation exposure greater than predicted due to errors in modelling methods.	The Radiation Impact Assessment is primarily based on the outputs of the air quality modelling. Errors in the air quality modelling could lead to incorrect outputs and affect the radiological assessment	Possible	Minor	Medium	Environmental radiation monitoring conducted during operations to confirm results of modelling	Unlikely	Minor	Low

Risk ID	Risk pathway for all Receptors	Causes / Background	Initial risk level			Final mitigation	Residual risk level		
			Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
##R04	Radioactively contaminated equipment and materials leaving the site.	Materials and equipment that have come in contact with radioactive materials (such as pumps, pipes or vehicles) may be contaminated with the radioactive materials and when removed from the operational area, may transfer the contamination resulting in accidental exposure to the people or the environmental.	Possible	Minor	Medium	Procedures for the cleaning and then radiometric testing of equipment leaving an area where radioactive material is present to be developed and included in the Radiation Management Plan which is to be approved by regulatory authority.	Unlikely	Minor	Low
##R05	Process and material spills resulting in release of material into the environment.	Spillage of radioactive materials outside of controls (such as bunds) may lead to radioactive material uncontrollably entering the environment. Similarly, spillage that are left and allowed to dry may become additional sources of dust.	Possible	Minor	Medium	Procedures for the prompt clean-up of all spillages to be developed and included in worker training and the Radiation Management Plan which is to be approved by regulatory authority.	Unlikely	Minor	Low
##R06	Failure of process material or tailings pipelines resulting in release of slurries into the environment.	Uncontrolled spillages from pipeline failures can result in release of higher volumes of radioactive material into the environment.	Possible	Minor	Medium	Design controls (such as bunding and pipeline pressure sensors linked to pump operations) limit release from any failure. Designs to include bunds to contain spillages from potential failures for identified high flow pipelines	Unlikely	Minor	Low

Risk ID	Risk pathway for all Receptors	Causes / Background	Initial risk level			Final mitigation	Residual risk level		
			Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
##R07	Increased dust emissions from dust control equipment leading to elevated emissions from the project and higher than predicted impacts.	Failure of dust controls or emission controls, such as scrubbers, or failure to properly maintaining air scrubbing equipment results in increased emissions to the environment.	Possible	Minor	Medium	Management and maintenance programs of equipment to minimise occurrence. Environmental monitoring network to identify increase and rectification.	Unlikely	Minor	Low
##R08	Seepage/run-off from stockpile and processing areas leading to radiological impacts on the environment	Failure to collect and contain water run off results ongoing seepage from mineralised stockpiles into groundwater system or surface water systems.	Possible	Minor	Medium	Design of facilities to prevent any seepage. Management plans to manage and maintain facilities. Groundwater monitoring program would identify any changes in concentrations.	Unlikely	Minor	Low
##R09	Extreme rainfall event leading to potentially contaminated water leaving site	Extreme weather events resulting in flooding or run off from ore stockpiles, resulting in entrainment of radioactive materials which leads to increases in radionuclide concentrations in off-site surface soils.	Unlikely	Minor	Low	Identification, quantification and cleanup. .	Unlikely	Minor	Low
##R10	Bushfire destroying processing plant	Fires leading to radioactive material in smoke and dispersion into the environment	Unlikely	Moderate	Medium	Facility designed for fire management	Rare	Moderate	Medium

Risk ID	Risk pathway for all Receptors	Causes / Background	Initial risk level			Final mitigation	Residual risk level		
			Likelihood	Consequence	Risk		Likelihood	Consequence	Risk
Decommissioning and Closure									
##R11	Radioactively contaminated equipment and materials leaving the site.	During demolition and dismantling, radioactive materials or contaminated equipment is removed from the operational area, and may transfer the contamination resulting in accidental exposure to the people or the environmental.	Likely	Minor	Medium	Radiation management plan specifically developed for closure to be approved by regulatory authority	Unlikely	Minor	Low
##R12	Release of radioactive materials from closed out operation	Failure of post closure long term control mechanisms leading to release of radioactivity from rehabilitated working areas leading to environmental exposures above the recognised standards.	Possible	Minor	Medium	Development and implementation of the closure plan.	Unlikely	Minor	Low
##R13	Higher than predicted post closure public doses.	Emissions from the closed out project exceed predicted doses.	Unlikely	Minor	Low	On-going monitoring post closure.	Unlikely	Minor	Low
Transportation									
##R14	Incident during transport and release of radioactive material to soil	Road or road accident resulting in damage to containers and product release to soil	Possible	Minor	Medium	Radiation management plan specifically developed for accidental release clean-up	Possible	Minor	Medium
##R15	Incident during transport and release of radioactive material to air and waterway	Road or road accident resulting in damage to containers and significant product release to air and waterway	Unlikely	Moderate	Medium	Radiation management plan specifically developed for accidental release clean-up	Unlikely	Minor	Low

Risk Assessment Parameters

Likelihood

Likelihood	Explanation
Almost Certain	Expected to occur many times each year
Likely	May occur every year
Possible	May occur in any single year
Unlikely	May occur in life of project
Rare	Examples have occurred historically - but it is not anticipated

Consequences

Consequence	Public Impact	Environmental Impact
Insignificant	No increase in dose expected	No impact expected
Minor	Measurable increase in dose, but below dose limit	Event leads to temporary increase in natural background levels
Moderate	Individual dose exceeds public dose limit of 1mSv/y	ERICA assessment indicates species exposed above reference level
Major	Ongoing or multiple individual doses exceeding dose limit of 1mSv/y	Event leads to significant long term increase in natural background levels
Critical	Public dose exceeds 5mSv/y	Event leads to widespread contamination making areas unusable due to radiation

Risk Rating

Likelihood	Almost Certain	Medium	High	Very High	Very High	Very High
	Likely	Medium	Medium	High	Very High	Very High
	Possible	Low	Medium	Medium	High	Very High
	Unlikely	Low	Low	Medium	High	High
	Rare	Low	Low	Medium	Medium	High
		Insignificant	Minor	Moderate	Major	Critical
		Consequence				

Appendix B: SLR Air Quality Modelling for Inputs to Radiation Impact Assessment

DESCRIPTION OF MODELLED SCENARIOS

Scenario 1 – Area1 Y1Q1
Although the amount of material to be mined during the initial stages of the mining schedule in Area 1 (year 1, quarter 1 (Y1Q1)) is relatively moderate, all of the material is required to be transported by truck to the topsoil, clay and overburden stockpiles or to the MUP. The distance between the mining blocks (101 and 102) and the stockpiles is relatively far, which together with the intensity of haulage required has the potential to generate the most dust emissions due to wheel generated dust.
Scenario 2 – Area1 Y6Q2
The mining schedule indicates that the maximum amount of material to be mined in Area 1 will occur during year 6. During year 6, quarter 2 (Y6Q2) the distance between the mining blocks (127 and 126) and the stockpiles is relatively far, increasing the potential for the generation of wheel generated dust, however the percentage of material sent to stockpile is reduced as a significant amount is used to backfill block 125. Being near the southern boundary of Area 1, the distance to the nearest sensitive receptors is reduced and the activities in this area will therefore be limited to daytime hours only to manage noise impacts. This will require increased intensity of mining activities during daytime hours to achieve the necessary material movement rates.
Scenario 3 – Area3 Y11Q3
The amount of material to be mined during the initial stages of the mining schedule in Area 3 (year 11, quarter 3 (Y11Q3)) is relatively moderate, however the distance between the mining blocks (112 and 111) and the stockpiles and MUP is relatively far, increasing the potential for the generation of wheel generated dust. The percentage of material used to backfill block 110 is relatively low (approximately 20%). Being near the northern boundary of Area 3, the distance to the nearest sensitive receptors is reduced and activities in this area will therefore be limited to daytime hours only to manage noise impacts. This will require increased intensity of mining activities during daytime hours to achieve the necessary material movement rates.
Scenario 4 – Area3 Y15Q2
The amount of material to be mined during the year 15, quarter 2 (Y15Q2) is relatively high and all of it is to be transported by truck to the topsoil, clay and overburden stockpiles or to the MUP. The distance between the mining blocks (101 and 102) and the stockpiles is relatively far, which together with the intensity of haulage required, has the potential to generate the most dust emissions due to wheel generated dust.

MODELLED DUST DEPOSITION RATES

These emission sources have been modelled as a large volume source representing the significant sources (ore production, processing and tailings areas) with an initial horizontal spread of 500 m, located near the centre of Area 1 and Area 3.

Receptor ID	Dust Deposition Rate (g/m^2.year)			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
R1	0.084	0.10	0.21	0.20
R2	0.31	0.39	0.24	0.27
R3	0.48	0.73	0.11	0.13
R4	0.056	0.065	0.18	0.13
R5	0.058	0.067	0.19	0.14
R6	0.066	0.072	0.25	0.2
R7	0.10	0.10	0.76	0.45
R8	0.10	0.08	0.11	0.14
R9	0.22	0.2	0.97	1.5
R10	0.19	0.14	0.09	0.092
R11	0.32	0.19	0.093	0.1
R12	1.08	1.5	0.12	0.14
R13	0.96	0.44	0.12	0.14
R14	2.6	6.4	0.26	0.34
R15	0.59	0.38	0.092	0.10
R16	0.11	0.086	0.044	0.046
R17	0.19	0.28	0.10	0.10

MODELLED TSP CONCENTRATIONS

These emission sources have been modelled as a large volume source representing the significant sources (ore production, processing and tailings areas) with an initial horizontal spread of 500 m, located near the centre of Area 1 and Area 3.

Receptor ID	TSP Concentration ($\mu g/m^3$)			
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
R1	0.071	0.054	0.12	0.17
R2	0.26	0.22	0.14	0.24
R3	0.44	0.47	0.074	0.12
R4	0.052	0.036	0.1	0.13
R5	0.053	0.037	0.1	0.14
R6	0.061	0.042	0.14	0.18
R7	0.09	0.058	0.42	0.42
R8	0.092	0.047	0.072	0.13
R9	0.22	0.11	0.61	1.4
R10	0.17	0.08	0.061	0.11
R11	0.29	0.12	0.065	0.11
R12	0.94	0.97	0.081	0.14
R13	0.82	0.28	0.083	0.15
R14	2.1	3.4	0.17	0.31
R15	0.59	0.27	0.062	0.10
R16	0.12	0.065	0.032	0.051
R17	0.18	0.18	0.06	0.10

MODELLED RADON

This estimate of radon (Rn-222 and Rn-220) source terms for the Project will consider the radon released from the surface of;

- the ore in the active area of the Pit (6 blocks) totalling 3.9×10^5 m^2, and
- a nominal HMC intermediate stockpile totalling 700 m^2.

Radon emissions from the processing plant and tailings are not considered, as emissions from wet processes are low, due to the increased diffusion time for radon through the liquids.

The equation used is:

$$J = [\lambda_{Rn} . De]^{0.5} \times E \times R \times \rho$$

Where:

Symbol	Parameter	Units	Value
J	emanation rate	$Bq/m^2.s$	
λ_{Rn}	radon decay constant	s^{-1}	Rn-222 2.1×10^{-6}
			Rn-220 1.25×10^{-2}
De	radon diffusion coefficient	m/s	2.0×10^{-6}
E	radon emanation coefficient for soil grains		0.2
R	specific activity of Ra-226 or Ra-224 in material	Bq/kg	
ρ	material density	kg/m^3	2,000

This provides the following emissions from the Project for input to the AQM:

- Rn-222: 9.0×10^4 Bq/s
- Rn-220: 1.35×10^7 Bq/s

It should be noted that these are still conservative as they are based on Area 1 ore grades, the HMC stockpile (which contributes 1.3 % Rn-222 and 2.5% Rn-220) is included in the Area 3 modelling, and because the mine pit will be damp as a dust mitigation method.

The modelled radon concentrations are shown below.

Receptor ID	Area 1		Area 3	
	Rn-222 (Bq/m3)	Rn-220 (Bq/m3)	Rn-222 (Bq/m3)	Rn-220 (Bq/m3)
R1	0.0046	1	0.0078	1.2
R2	0.014	2.1	0.010	1.5
R3	0.020	2.9	0.0056	0.84
R4	0.0035	0.52	0.0079	1.2
R5	0.0035	0.52	0.0082	1.2
R6	0.0041	0.62	0.010	1.5
R7	0.0062	0.93	0.025	3.8
R8	0.0061	0.91	0.0083	1.2
R9	0.018	2.7	0.12	18
R10	0.010	1.5	0.0078	1.2
R11	0.014	2.2	0.0073	1.1
R12	0.034	5.2	0.0075	1.1
R13	0.030	4.5	0.0075	1.1
R14	0.10	15	0.012	1.8
R15	0.021	3.2	0.0051	0.76
R16	0.0065	1.0	0.0030	0.46
R17	0.010	1.5	0.0054	0.81

Appendix C: Calculation Parameters

GAMMA IRRADIATION DOSE CALCULATIONS

Calculation Parameters

Parameter	Value	Unit	Reference
Dose Factor U	65	µSv/h per %U	ARL 1980
Dose Factor Th	16	µSv/h per %Th	IAEA 2006

- For gamma radiation absorbed dose (Gy) is considered to be equal to effective dose (Sv). [Cember 2009].
  Note dose rate instruments are usually calibrated for Sv, and dose limits are specified as Sv.
- Material is considered an *area* source up to 10 times the distance of its largest dimension - area source intensity is 1/distance.
- Material is considered a *point* source beyond 10 times the distance of its largest dimension - area source intensity is 1/distance squared.
- Distance used is from Project boundary to receptor.
- No consideration of material shielding.

Project Parameters

<table>
<tr><th>Receptor</th><th>Gamma Source</th><th>Source type and dimension (m)</th><th>Exposure time (h)</th></tr>
<tr><td>9</td><td>1Mt stock-pile of Area 3 ore</td><td>Area
100 x 100 x 100</td><td rowspan="3">8760</td></tr>
<tr><td rowspan="2">14</td><td>1Mt stock-pile of Area 1 ore</td><td>Area
100 x 100 x 100</td></tr>
<tr><td>300 t unshielded REMC</td><td>Area
12.5 x 8 x 3</td></tr>
</table>

Transport Parameters

Shipping container internal dimensions (m): 5.71 x 2.35 x 2.38 (L x W x H)

Receptor	Exposure time
TR1	8760 hours/year
TR2	300 hours/year
TR3	8760 hours/year
Residence adjacent to transport route	4.9 hours/year
Vehicle stopped at railway crossing-one train	0.0474 hours/train
Vehicle following truck from Ultima to Port	4.5 hours per journey
Vehicle parked beside stopped truck between Ultima to Port	0.5 hours per journey

		Gamma source configuration (A=Area P=Point)					
		Normal Storage			10 days storage		
	Product material	TR1	TR2	TR3	TR1	TR2	TR3
Phase 1	REMC	P	A	P	P	A	P
	Zircon Titania HMC	P	A	A	A	A	A
Phase 1a	MREC	P	A	P	P	A	P
	Zircon Titania HMC	P	A	A	A	A	A
Phase 2	MREC	P	A	P	P	A	P
	Low Chrome Ilmenite	P	A	P	P	A	A
	HiTI/Rutile	P	A	P	P	A	P
	Leucoxene	P	A	P	P	A	P
	Zircon	P	A	P	P	A	A
	Zircon concentrate	P	A	P	P	A	P

Inhalation of Dust Dose Calculations

TSP Concentrations Used (from AQM)

Receptor ID	Area 1		Area 3	
	Modelled Scenario	TSP Concentration (µg/m³)	Modelled Scenario	TSP Concentration (µg/m³)
R1	1	0.071	4	0.17
R2	1	0.26	4	0.24
R3	2	0.47	4	0.12
R4	1	0.052	4	0.13
R5	1	0.053	4	0.14
R6	1	0.061	4	0.18
R7	1	0.09	3 & 4	0.42
R8	1	0.092	4	0.13
R9	1	0.22	4	1.4
R10	1	0.17	4	0.11
R11	1	0.29	4	0.11
R12	2	0.97	4	0.14
R13	1	0.82	4	0.15
R14	2	3.4	4	0.31
R15	1	0.59	4	0.1
R16	1	0.12	4	0.051
R17	1 & 2	0.18	4	0.1

- Assumption that all dust is ore, and contains all radionuclides of the U-238 and Th-232 decay chains in equilibrium.

Calculation Parameters

Parameter	Value	Unit	Reference
Exposure hours	8760	h/y	Hours in a year
Breathing rate	1	m³/h	ICRP 2006-101
AMAD	1	µm	Conservative best practice

Dose Coefficients for Inhalation (DCs) [ICRP 2017-137]

Radionuclide	Dose Coefficient for AMAD 1µm (Sv/Bq)
U-238	2.00E-05
U-234	2.30E-05
Th-230	2.50E-05
Ra-226	2.30E-05
Pb-210	1.50E-05
Po-210	2.80E-06
Th-232	1.00E-04
Th-228	3.50E-05
Ra-228	3.70E-05
Ra-224	1.60E-06

In ICRP 137 the *new* dose factors are for occupational exposures, and the ICRP is silent on the applicability of these dose factors for public exposure. In this assessment, it is assumed that the occupational factors are applicable for public exposure. Whilst ICRP72 provides age dependant inhalation dose factors, these are generally an order of magnitude lower than those of ICRP 137. The use of ICRP 137 dose factors are considered more up-to-date and best-practice for public dose calculation.

DUST DEPOSITION CALCULATIONS

Calculation Parameters

Parameter	Value	Unit	Reference
Mixing Depth	0.01	m	Kaste et al 2007
Soil Density	0.0011	kg/m^3	www.nationalmap.gov.au Soil atlas – Bulk Density Av 0-5 & 5-15cm @ERML-RO
Number of Years of Deposition	20 years = 10 y Area 1 Dust + 10 y Area 3 Dust		

INGESTION DOSE CALCULATIONS

Concentration Ratios (CRs) [IAEA 2010]

Element	Concentration Ratios				
	Grain	Leafy	Roots	Fruit	Sheep
U	0.0106	0.0200	0.0084	0.0015	0.3100
Th	0.0011	0.0012	0.0008	0.0008	0.0062
Ra	0.0097	0.0910	0.0700	0.0170	0.1800
Po	0.0002	0.0074	0.0058	0.0002	0.1400
Pb	0.0061	0.0800	0.0150	0.0150	0.0120

- *Grain* is the average of *Cereal Crop* and *Maize*.
- Not Po for *Fruit* so Po for Leafy Vege has been used.
- Pb is specifically for Sheep, all other ratios for are for *Generic Meat*.
- CR are dry weight for dry weight. It has been conservatively assumed that wet weight (ie mass consumed) is twice the mass of dry weight.

Ingestion Rates – Tank Water

Age Group	Modelled Ingestion rate (L/d)
1 Y	1
5 Y	2
10 – 15 Y	3
Adult	3

Ingestion Rates - Food [ARPANSA 2019]

Age Group	Estimated Ingestion Rate (kg/y)				
	Grains	Leafy	Root	Fruits	Meat (sheep)
1 Y	45	20	30	30	15
5 Y	90	40	55	55	35
10 – 15 Y	140	60	85	85	50
Adult	140	60	85	85	50

- Combination of ARPANSA TR181 data and author estimates
- Milk and fish products not modelled as not produced in the Study Area.
- Conservation assumption that all of the foods in the above table are grown at the Receptor
- 5 Y is ARPANSA *Child* ingestion rates.
- 10 – 15 Y is ARPANSA *Adult* ingestion rates

Dose Coefficients for Ingestion (DCs) [ICRP 1996-72]

Radionuclide	Dose Coefficient for Age Group (Sv/Bq)			
	1 y	5 y	10 - 15 y	Adult
U-238	1.20E-07	8.00E-08	6.80E-08	4.50E-08
U-234	1.30E-07	8.80E-08	7.40E-08	4.90E-08
Th-230	4.10E-07	3.10E-07	2.40E-07	2.10E-07
Ra-226	9.60E-07	6.20E-07	1.50E-06	2.80E-07
Pb-210	3.60E-06	2.20E-06	1.90E-06	6.90E-07
Po-210	8.80E-06	4.40E-06	2.60E-06	1.20E-06
Th-232	4.50E-07	3.50E-07	2.90E-07	2.30E-07
Th-228	3.70E-07	2.20E-07	1.40E-07	7.20E-08
Ra-228	5.70E-06	3.40E-06	5.30E-06	6.90E-07
Ra-224	6.60E-07	3.50E-07	2.60E-07	6.50E-08

- The ICRP 72 age dependent DCs for 10 and 15 year-olds have been combined into one age group and use the maximum DCs from two age groups.

INHALATION OF RADON DECAY PRODUCT DOSE CALCULATIONS

Calculation Parameters

Parameter	Value	Unit	Reference
Windspeed	4.4	m/s	SLR Air Quality Report
Exposure hours	8760	h/y	Hours in a year
Breathing rate	0.92	m^3/h	ICRP 2006-101
Rn-222 EF	0.6		UNSCEAR 2019
Rn222 EF constant	5.56E-03	$(\mu J/m^3) / (Bq/m^3)$	UNSCEAR 2008
Rn-222 DP DCF	2.5	Sv/J	ARPANSA 2022
Rn-220 decay constant	0.0125	s-1	decay constant = ln(2)/½ life
Rn-220 EF	0.004		Hartely et al 2010 DMIRS 2021
Rn-220 EF constant	7.56E-02	$(\mu J/m^3) / (Bq/m^3)$	UNSCEAR 2019
Rn-220 DP DCF	1.25	Sv/J	ARPANSA 2022

- Air quality modelling did not include radioactive decay. A decay factor was applied for Rn-220, due to its short half-life of 56s seconds, to calculate more accurate Rn-220 concentration at the receptor locations.

ERICA TOOL ASSESSMENT INPUTS

A Tier 2 assessment was conducted using version 2.0 of the software. Default parameter values were used for concentration ratios, organism occupancy and radiation weighting factors.

For Life of Mine the greatest modelled change in Soil Activity Concentration is at Receptor 14, with;

U(nat) = 0.968 Bq/kg for: U-238, Th-234. U-234, Th-230, Ra-226, Pb-210 and Po-210

Th(nat) = 1.823 Bq/kg for: Th-232, Ra-228, Th-228 and Ra-224

Appendix D: Management plans

The Project will develop a series of management plans for radiation as part of the licencing process as required by Victorian regulation and industry practice. The plans would be finalised with final Project design and the general outline of the key features of the plans is provided in this section.

The Victorian Department of Health provides guidance on the content of management plans, as does the ARPANSA Mining Code [ARPANSA 2005]. In addition, guidance on radiation management programmes is also provided by the IAEA [IAEA 2014]. The content of the final Project management plans would draw on these sources of guidance.

The management plans that would be developed are:

- Radiation Management Plan
- Radioactive Waste Management Plan
- Radiation Environment Plan

Management Plans will be developed and submitted for approval for each phase of the Project as required by the Mining Code.

Transport Management Plans

VHM will ensure that its Transportation Contractor details all radiation requirements in their Facilities and Transport Management Plans.

Radiation Management Plan (RMP)

The RMP will include:

- The roles, contact details and responsibilities of relevant staff who have responsibilities or accountabilities for radiation protection and licences
- Details of the professional radiation expertise that the Project will use.
- Description of applicable regulations and codes and how they will be complied with An overview of the Project, including a description of the radiological characteristics of the project, such as the radionuclide content of process streams and sources of radiation exposure.
- An overview of the existing radiological environment.
- A radiation risk assessment that identifies the radiation risks and mitigation measures (in this context, a *risk* is defined as an unplanned event or scenario).
- An outline of the radiation control mechanisms, including design and engineering controls administrative systems and personal protective equipment and the processes for auditing effectiveness of the control measures.
- An overview of the processes for optimisation (ALARA), including a nominated dose constraint for workers and the public.
- Information regarding worker induction, instruction and training for understanding radiation, and also for operating radiation protection controls, including reference to procedures.
- Details of the occupational and environmental radiation monitoring programme, including reference to monitoring methods, equipment, quality control processes, recording of results and reporting.
- Pre-defined action levels for monitored results, with defined actions.
- Details of how exposures are assessed and how doses are calculated.
- Register and location of any other sources of radioactivity, such as density gauges or x-ray equipment
- Procedures and measures to protect the security of radioactive sources and materials including storage, transport and disposal
- Plans for management of accidents, incidents, emergencies and near misses related to radiation, including investigation and reporting procedures.
- A description of periodic assessment, review and reporting processes.

Radioactive Waste Management Plan (RWMP)

Although the Project will not be producing radioactive tailings for disposal as waste, there may be circumstances where waste is generated that requires appropriate management due to its radioactivity levels or contamination.

The RWMP would contain a number of components that are similar to the RMP. The key additional content would include:

- A description of the waste that may be generated and the processes that may generating the waste.
- A description of the waste management practices, such as minimisation, reuse, recycling, clearing and disposal.
- A description of the final disposal options, including any dedicated disposal facility and a description of the environment into which the waste will be discharged or disposed, including the baseline radiological characteristics.
- A prediction of any environmental radiological impact of the waste disposal, including impacts to flora and fauna and members of the public.
- A demonstration that the disposal options are sustainable and appropriate both now and, in the future, as determined by the relevant regulatory authority.
- Details of the monitoring programme associated with the waste disposal and the methods for the assessment of radiation doses to members of the public arising from the waste management practices.
- Details of contingency plans for dealing with accidental releases, or circumstances which might lead to uncontrolled releases of radioactive waste.
- Details of record keeping and a schedule for reporting.
- An overview of the plans for decommissioning the operation and the associated waste management facilities and rehabilitating the site.
- A description of periodic assessment and review processes.

Radiation Environment Plan (REP)

There are no identified prescriptive requirements for the content of a REP, however, general guidance can be found in the environmental radiation protection documents of ARPANSA [ARPANSA 2015] and ICRP [ICRP 2014].

The REP would have similar components as the RMP and RWMP, with the key additional aspects being as follows:

- Characterisation of the possible situations where environmental radiation exposure may occur.
- A description of the potential radiological impacts on the environment.
- An outline of the methods to assess the magnitude of the impacts, for example through Radiation Impact Assessment of flora and fauna using measurement data.
- Detail of environmental radiation monitoring program.
- Management measures to control any potential impacts.

The REP will be developed in consultation with the DHHS.

Transport Management Plans

VHM will ensure that its Transportation Contractor details all radiation requirements in their Facilities and Transport Management Plans in accordance with relevant regulatory requirements.