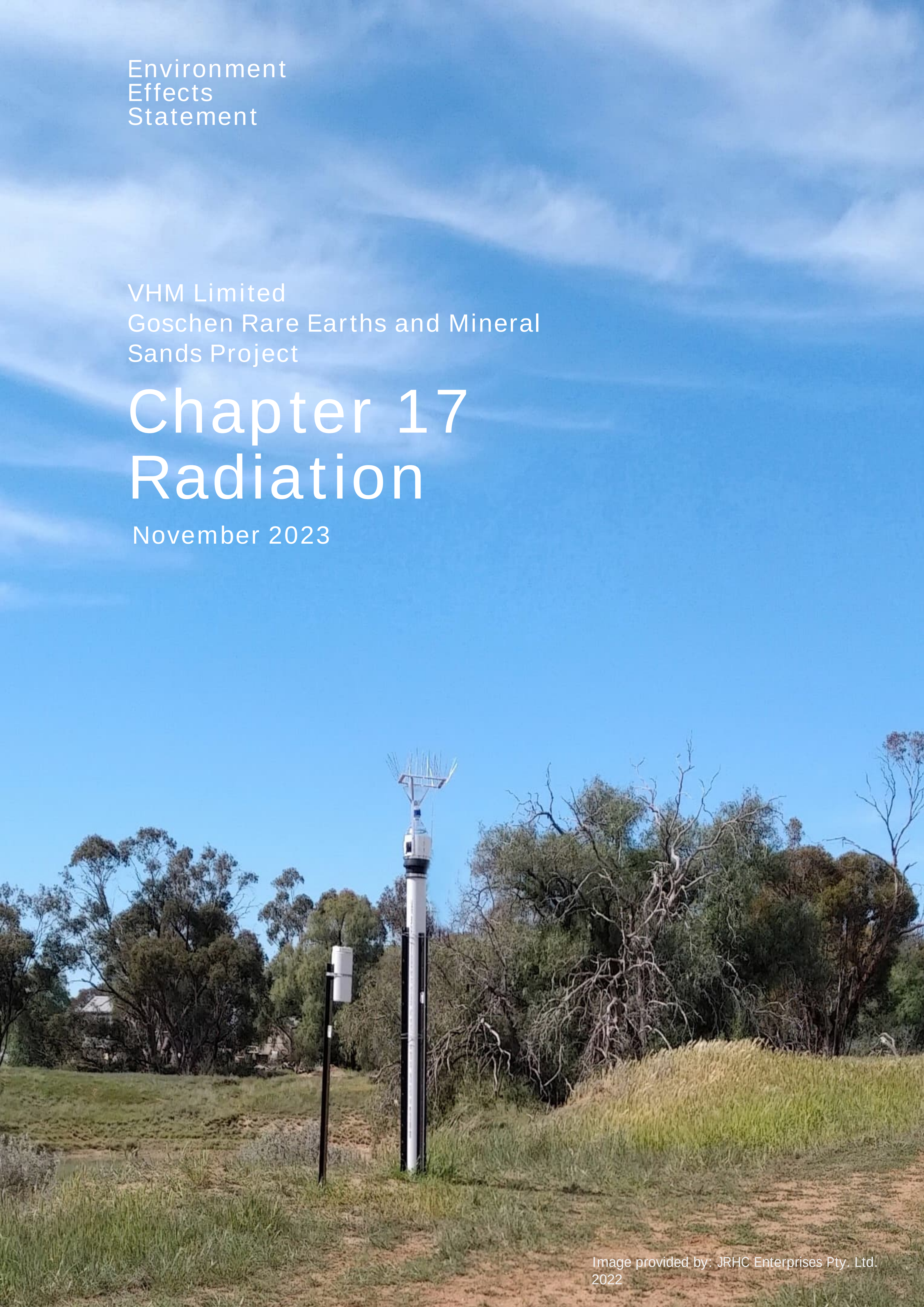
Environment
Effects
Statement

VHM Limited
Goschen Rare Earths and Mineral Sands Project

Chapter 17 Radiation

November 2023



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17. Radiation

This chapter provides an assessment of the radiation impacts associated with the construction and operation of the Goschen Rare Earths and Mineral Sands Project (the Project).

This chapter summarises the outcomes of the radiation impact assessment prepared in support of the Environment Effects Statement (EES). This technical report is shown in EES Technical Report N: Radiation.

Overview

The defined study area for the Project's radiological risk assessment is characterised by 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 characteristics, though it should be noted that radon-220 concentrations are higher than in areas where lower geological thorium concentrations are present. Additionally, groundwater radium levels are elevated.

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 radiation impact assessment is presented in EES Technical Report N: Radiation found the following key impacts:

- The conservative maximum dose to humans as a results of the Project is 0.19 mSv/y which is well below the member of the public 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 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 would 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 by train is 0.006 mSv/y. All doses are below the member of the public dose limit of 1 mSv/y.

Potential radiological risks due to the Project would 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.

EES evaluation objective

The scoping requirements for the Goschen Mineral Sands and Rare Earths Project Environment Effects Statement ('scoping requirements') 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 is relevant to the radiation 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.*

Evaluation Objective under Section 4.3 of the scoping requirements is also relevant to the radiological assessment. This includes:

- *To minimise effects on water resources and on beneficial and licensed uses of surface water, groundwater and related catchment values (including the Kerang Wetlands Ramsar site) over the short and long-term.*

A stated requirement of the Minister is for the EES is to address the effects of project construction and operation on public health and safety and diminished social wellbeing due to a range of factors including radiation on nearby sensitive receptors (particularly residences). This includes the requirement to assess the likely radiation effects associated with the Project during operations, decommissioning and post-closure.

17.1 Methodology

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.
- 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.

As discussed in Section 6.0 of EES Technical Report N: Radiation, the radiological impact assessment aims to quantify the impacts of radiation that originate from the Project and to compare the results to existing and accepted standards. For people, the radiological impact is determined as a potential radiation *dose*. For non-human biota, an *absorbed dose rate* is calculated which provides a measure of the relative radiological risk. Potential doses to the public are calculated for critical groups of people at locations of interest (receptors). The same locations of interest were used to quantify the impacts to people and non-human biota.

The assessment methods are based on the internationally and Australian recognised recommendations and standards:

- International Atomic Energy Agency (IAEA).
- International Commission on Radiological Protection (ICRP).
- Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

A simplified assessment framework is presented in the following steps:

- Identify exposure receptors.
- Identify exposure pathways.
- Calculate the increase in radioactivity levels due to the Project.
- Calculate exposures and doses.
- Compare results to standards.

The full assessment methodology is presented in Section 6.0 of EES Technical Report N: Radiation.

17.2 Study area

17.2.1 Project Study Area

The study area for the radiological impact assessment was chosen and defined to consider the existing radiological environment closer to the ore zones and project developments, and receptors. A 5 kilometre buffer around the project, as shown in Figure 17-1, was identified as the appropriate study area. The Project's radiological emissions would be airborne and the Air Quality Technical Assessment (see Section 9.0 of EES Technical Report G: Air Quality), has demonstrated that natural deposition and dispersion processes are negligible beyond the study area.

The defined study area 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.

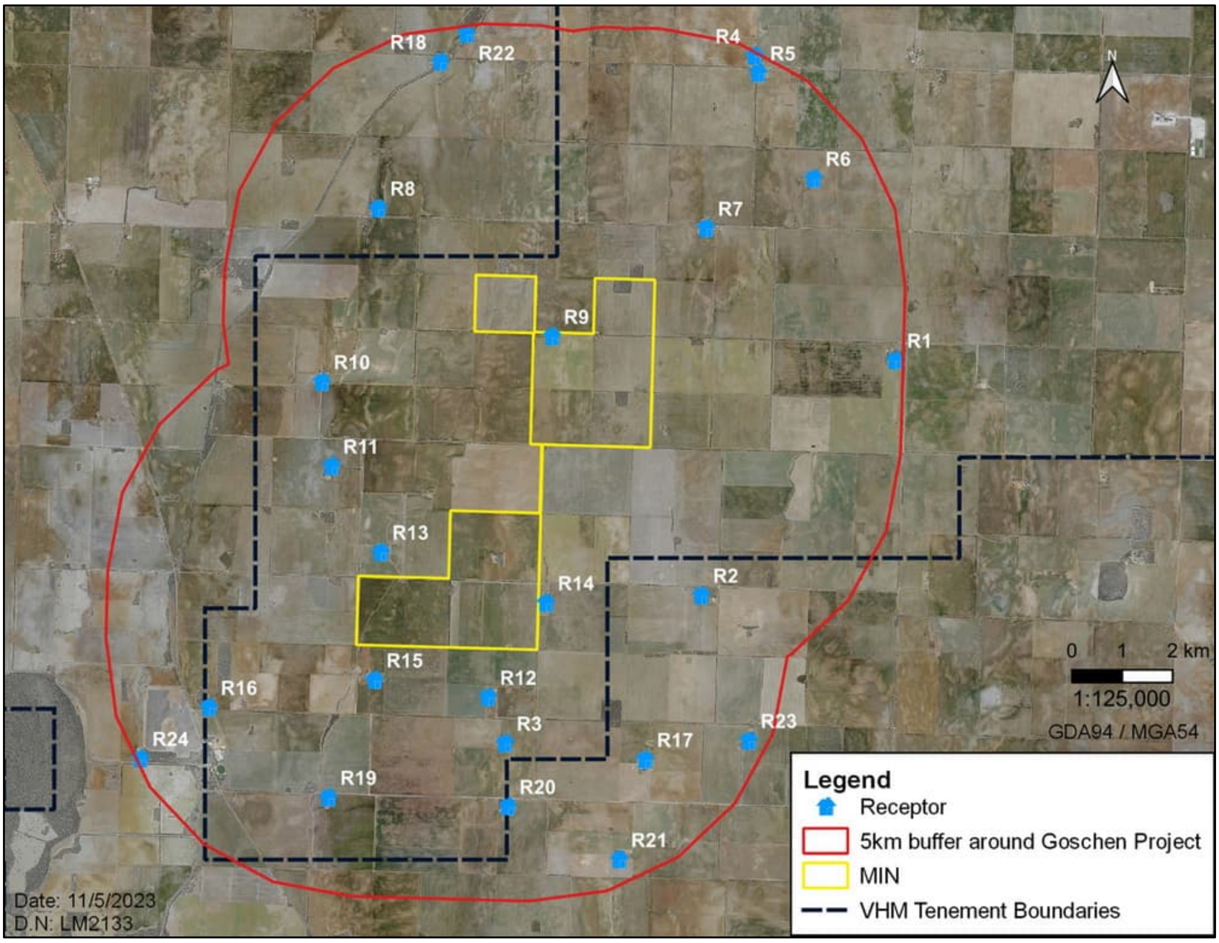

Figure 17-1 Receptor location

17.2.2 Transport Study Area

All product from the Project would be packed on site and transported in shipping containers via road and rail. The study area for transportation includes:

- The approximately 47km road route from the Project to the Ultima intermodal facility.
- The storage facility at Ultima.
- The rail route from Ultima to the Port.
- The port facilities.

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 17-2. The transportation assessment also considers, as receptors, residences backing onto the rail line and vehicles stopped at rail crossings.

Figure 17-2 Receptors in the vicinity of Ultima Intermodal

17.3 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 Earth's crust, with an average concentration of about three parts per million (ppm). Since radionuclides exist naturally in all 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 natural occurring radioactive elements of uranium and thorium.

The defined study area is described in Section 17.2.

17.3.1 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 Project study area. The location of the ERMLs in relation to the Project and Receptors is shown in Figure 17-3.

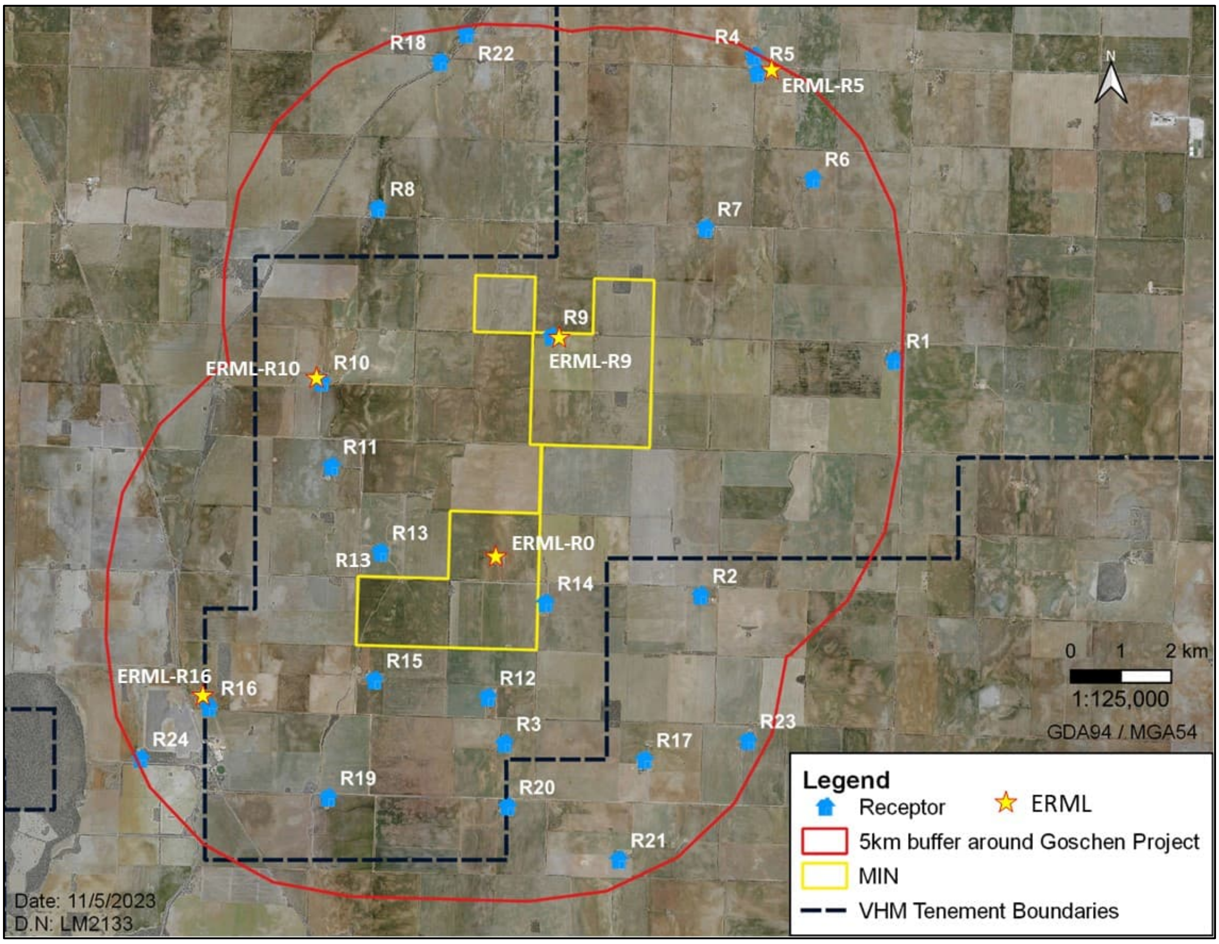

Figure 17-3 Location of ERMLs and Receptors with Study Area

Background radiation levels

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 17-1. For a comparison, Table 17-2 shows the Gamma Does Rates across Australia.

Table 17-1 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

Table 17-2 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.

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 17-4.

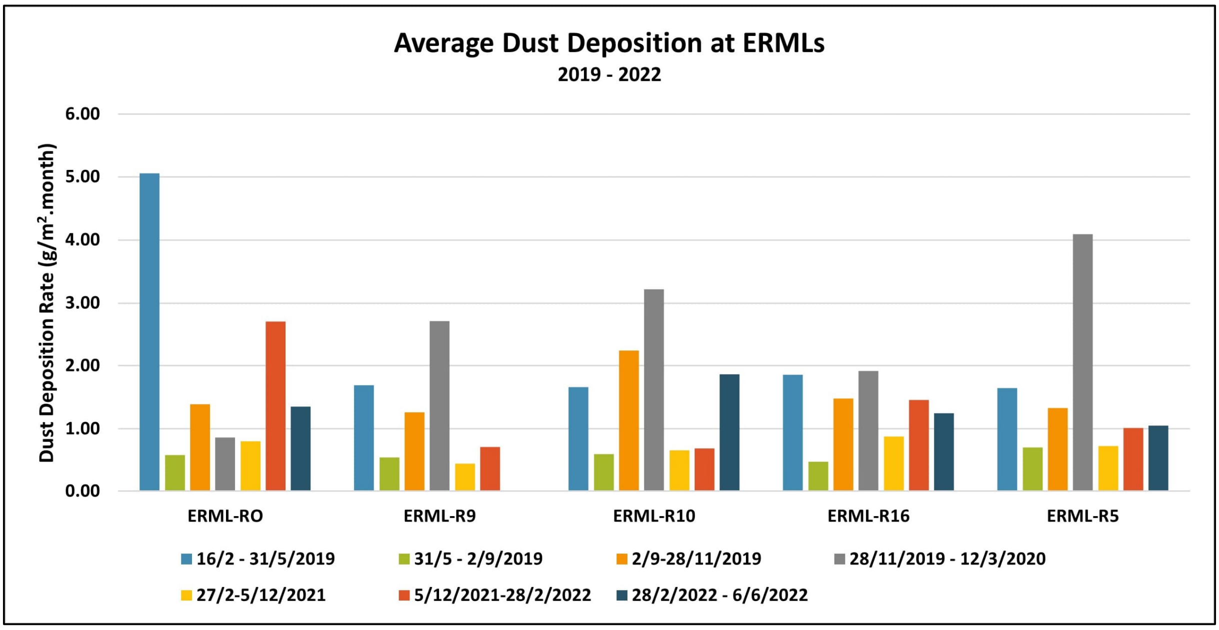

Figure 17-4 Average Baseline Dust Deposition Rates at ERMLs

The activity concentrations of radionuclides in dust and the radionuclide deposition rates, for the samples collected in Year 1 (16/2/2019 to 12/3/2020) and Year 2 (27/2/2021 to 6/6/2022), are shown in Figure 17-5 and in Figure 17-6.

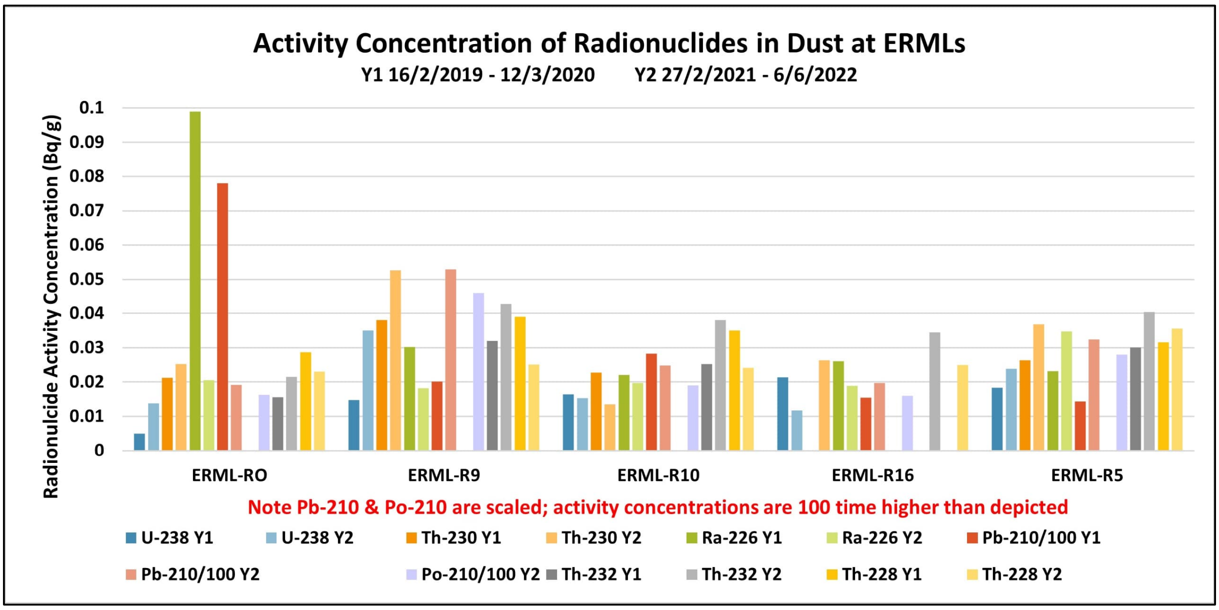

Figure 17-5 Baseline Activity Concentrations of Radionuclides in Dust

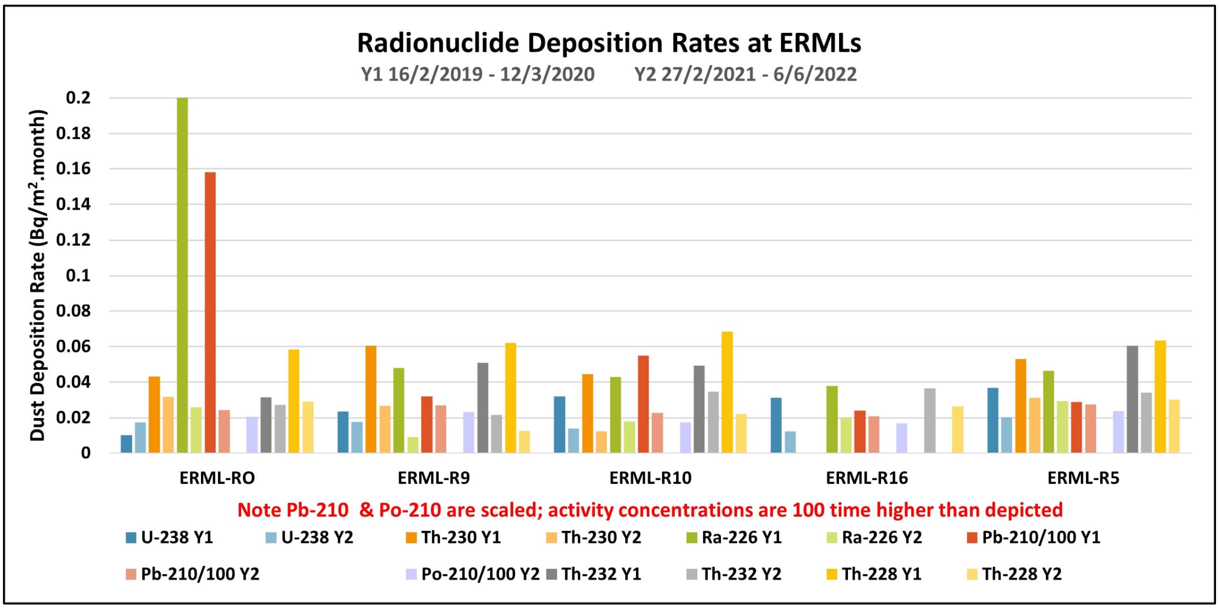

Figure 17-6 Baseline Radionuclide Deposition Rate

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 17-3.

Table 17-3 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

Measured baseline Pb-210 deposition rates with a range of 2.1 – 15.8 Bq/m^2.month and median of 2.7 Bq/m^2.month, in the study area, are comparable to global Pb-210 deposition rates.

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 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.
- 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 17-7 and Figure 17-8.

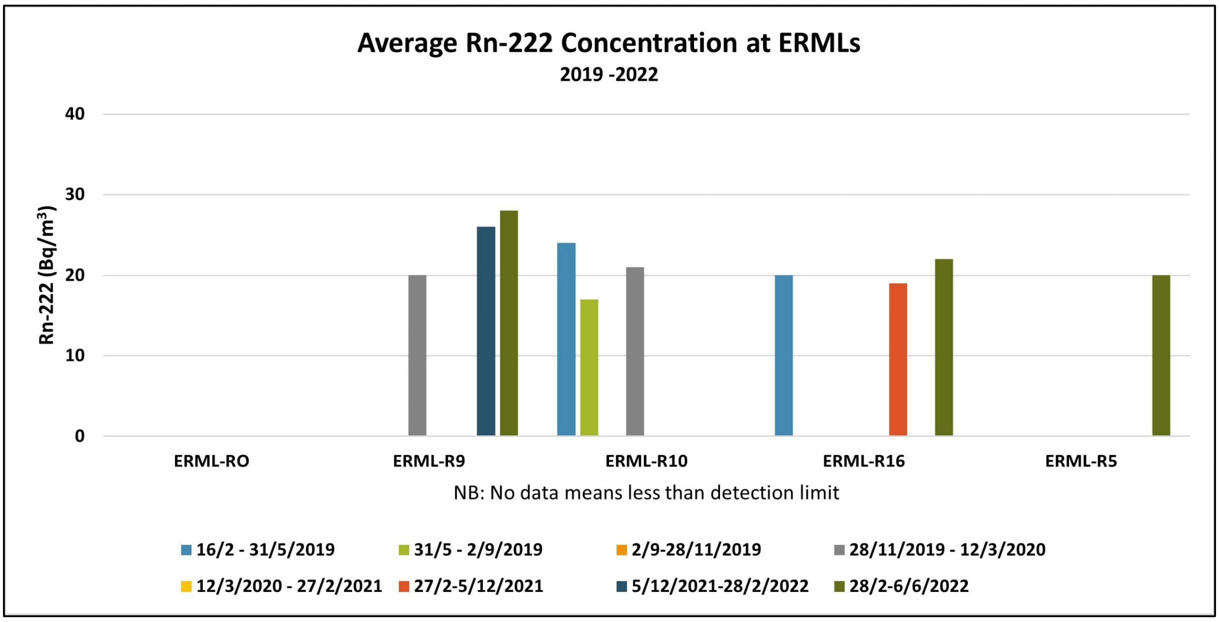

Figure 17-7 Average Rn-222 Concentration at ERMLs

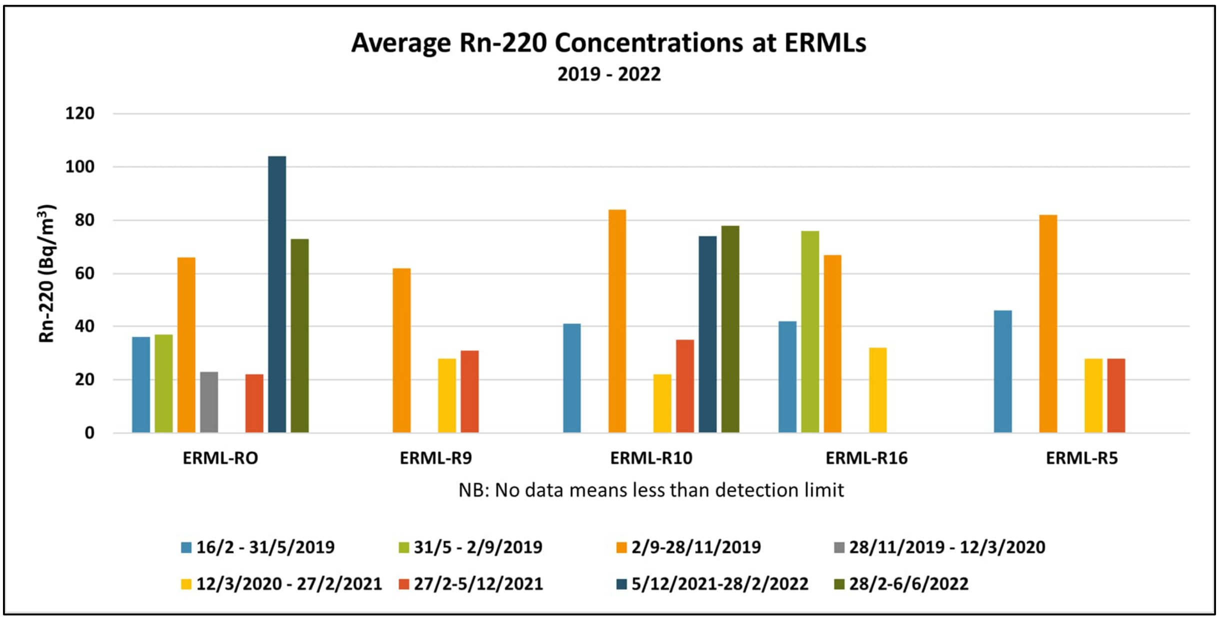

Figure 17-8 Average Rn-220 Concentrations at ERLMs

Australian and world Rn-222 and Rn-220 levels are presented in Table 17-4, noting that there is little published data on outdoor Rn-220 levels.

Table 17-4 Australian and World Rn-222 and Rn-220 Concentrations

Location	Rn-222 (Bq/m3)	Rn-220 (Bq/m3)	Reference
World	1 -100 average 10	average 10	United Nations Scientific Committee on the Effects of Atomic Radiation (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

Location	Rn-222 (Bq/m3)	Rn-220 (Bq/m3)	Reference
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

The Rn-222 concentrations in the study area are consistent with naturally occurring Australian Rn-222 radon concentrations.

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 (Feq - 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 determined by the simultaneous measure of:

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

Simultaneous monitoring was undertaken at the Project in September 2022 and the results are shown in Figure 24 and in Figure 25 of EES Technical Report N: Radiation. The calculated equilibrium factors along with other equilibrium factors are listed in Table 17-5.

Table 17-5 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

As shown in Table 17-5, 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.

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 17-9.

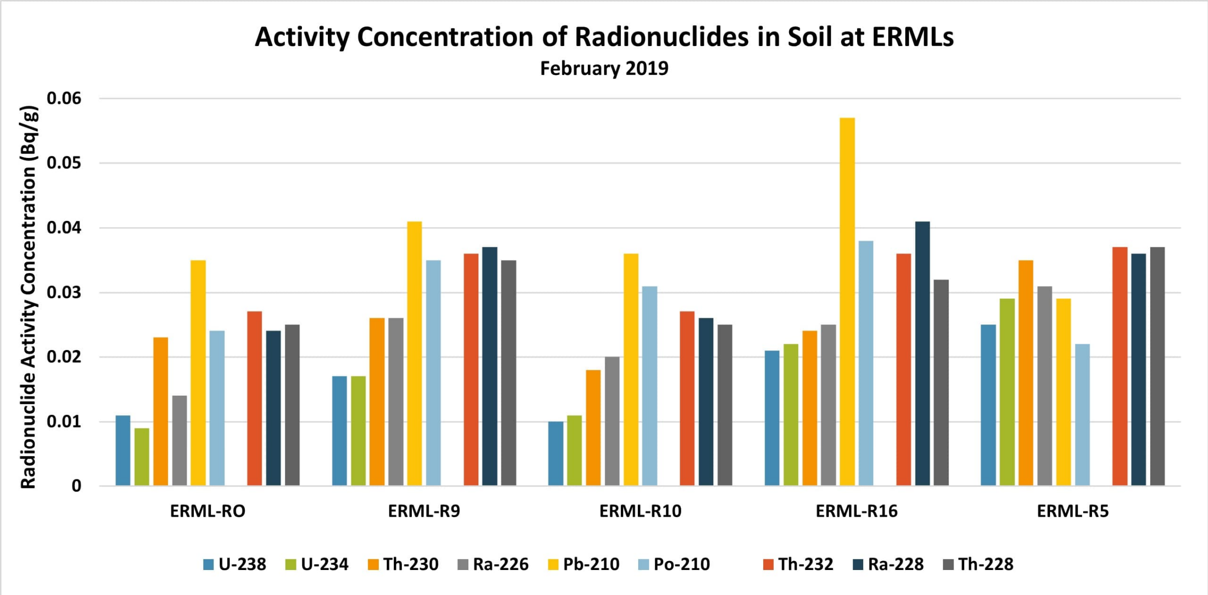

Figure 17-9 Baseline Soil Radionuclide Activity Concentrations

Australian and world soil radionuclide concentrations are presented in Table 17-6.

Table 17-6 Radionuclide Concentrations in Soil

Source	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.

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 17-10 in August/September 2021 and April 2022.

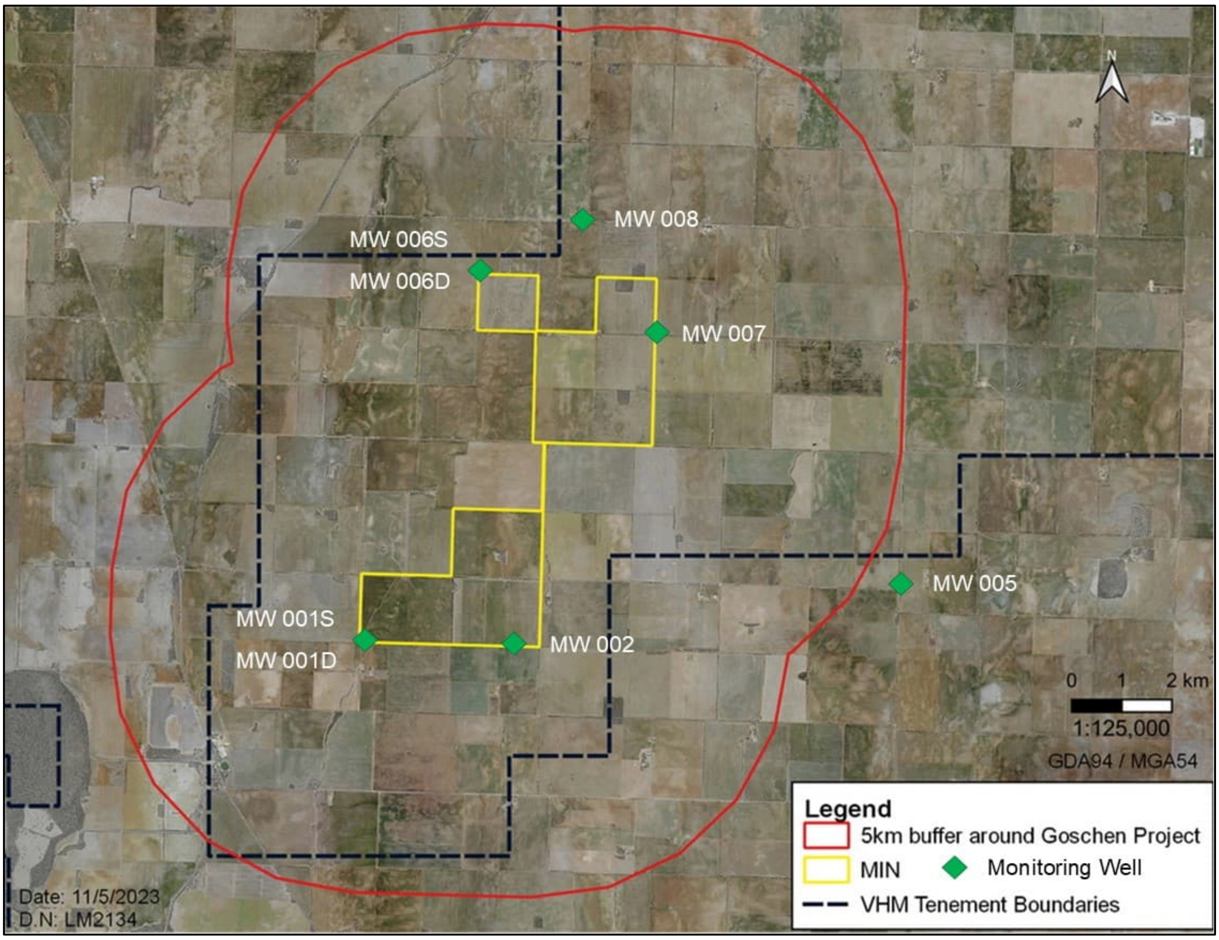

Figure 17-10 Location of Groundwater Monitoring Wells

The baseline activity concentrations of the ground water samples are shown in Figure 17-11. Both U and Th were below detection limits of 0.01 mg/L which equated 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.

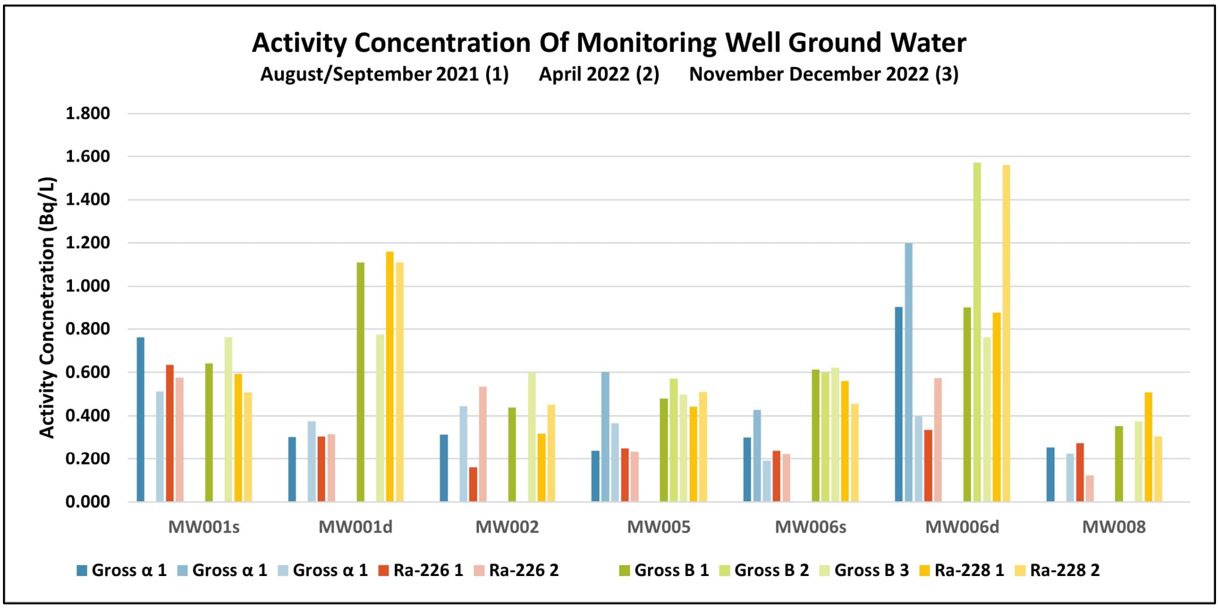

Figure 17-11 Baseline Groundwater Activity Concentration 2021

The groundwater in the study area contains elevated radium concentrations exceeds Australian Drinking Water guidelines as shown in Table 15 of EES Technical Report N: Radiation, however due to its high salinity, groundwater is not used for human consumptions, stock watering or irrigation.

17.3.2 Radiological Modelling

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.

Using the study area soil samples radionuclide activity concentrations as reported in Figure 17-9, grain crop radionuclide activity concentrations can be calculated and these are listed in Table 17-7. These crop activity concentrations do not consider the application of fertiliser (some of which do contain uranium).

Table 17-7: 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

17.4 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. 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. The basis for the radiation impact assessment as shown in EES Technical Report N: Radiation, also required an understanding of radiological properties of the ore, process streams and product. 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.

17.4.1 Radiological Impacts to the Public at Receptors

Dose from irradiation by gamma radiation

The highest gamma dose rates would occur closest to the Project boundary as gamma energy levels decrease exponentially with distance. Gamma doses were calculated for Receptors 14 and 9 which are the closest receptors to Areas 1 and 3. The gamma irradiation results at both locations are shown in Table 17-8.

Table 17-8 Dose for Gamma Irradiation

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

Dose from the inhalation of dust containing radionuclides

Doses due the potential for 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 17-9.

Table 17-9 Dose from the inhalation of Dust containing radionuclides

Receptor	Inhalation Dose (mSv/y)	
	Area 1 ore	Area 3 ore
R1	0.0000715	0.000115
R2	0.000262	0.000162
R3	0.000473	0.0000809
R4	0.0000524	0.0000876
R5	0.0000534	0.0000943
R6	0.0000614	0.000121
R7	0.0000906	0.000283
R8	0.0000927	0.0000876
R9	0.000222	0.000943
R10	0.000171	0.0000741
R11	0.000292	0.0000741
R12	0.000977	0.0000943
R13	0.000826	0.000101
R14	0.00342	0.000209
R15	0.000594	0.0000674
R16	0.000121	0.0000344
R17	0.000181	0.0000674

Dose from ingestion of food

A standard Australia diet in accordance with the Australian Radiation Protection and Nuclear Safeguards Agency's (ARPANSA) *Doses from Average Australian Diet* Technical report (ARPANSA, 2019) was used. It was assumed that half of the ingested food, excluding milk and fish, is grown at the Receptor, where Project dust has deposited and has been taken up into plants and animals. The calculations were 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 dose coefficients. The ingestion doses are listed in Table 17-10.

Table 17-10 Doses from ingestion of food

Receptor	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

Receptor	Ingestion Dose (mSv/y)			
	1 Y	5 Y	10 - 15 Y	Adult
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

Dose from ingestion of tank water

The primary source of water at receptors is tank water which is 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 17-11.

Table 17-11 Doses from ingestion of tank water

Receptor	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

Dose from Inhalation of radon decay products

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 17-12.

Table 17-12 Doses from ingestion 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	0.00000000000102	0.0005	0.00000000342
R2	0.0009	0.000000739	0.0007	0.000000528
R3	0.0013	0.0000306	0.0004	0.000000000106

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)
R4	0.0002	0.000000000000000591	0.0005	0.00000000257
R5	0.0002	0.00000000000000138	0.0006	0.0000000437
R6	0.0003	0.0000000000000494	0.0007	0.0000000547
R7	0.0004	0.0000000000214	0.0017	0.000124
R8	0.0004	0.0000000000491	0.0006	0.00000541
R9	0.0012	0.000000306	0.0081	0.04131
R10	0.0007	0.000000128	0.0005	0.000000744
R11	0.0009	0.00000424	0.0005	0.0000000401
R12	0.0023	0.0009	0.0005	0.00000000178
R13	0.0020	0.0025	0.0005	0.0000000938
R14	0.0067	0.0259	0.0008	0.000000633
R15	0.0014	0.0006	0.0003	0.000000000224
R16	0.0004	0.0000000207	0.0002	0.0000000000000858
R17	0.0007	0.0000007	0.0004	0.0000000000437

Total Estimated Dose

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 17-13.

Table 17-13 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 member of the public dose limit of 1 mSv/y. It should be noted that Receptor R9 will not be considered a sensitive receptor during mining of Area 3 (which will commence once the Area 1 mining is complete), while Receptor R14 will not be considered a sensitive receptor during the entire Project duration. Notwithstanding, this assessment demonstrates that even the closest receptors (including Receptor R9 and Receptor R14, are exposed to radiation that is significantly below the recognised member of the public dose limit.

Realistic Dose

A number of the factors for the parameters used in the dose calculations throughout Section 17.4.1. have been identified as being overly conservative. These have been listed in Table 17-14, with the more *realistic* factors included.

Table 17-14 Conservative 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	$F_{Rn-220} = 0.004$	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 member of the public dose limit of 1 mSv/y.

17.4.2 Radiological Impacts to Flora and Fauna

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 outputs of the assessment are listed in Table 17-15.

Table 17-15 Outputs of ERICA Tool Tier Assessment for Flora and Fauna

Reference Species	Dose Rate (µGy/h)
Amphibian	0.0523
Annelid	0.0657
Arthropod – detritivorous	0.0734
Bird	0.0110
Flying insects	0.0172
Grasses & Herbs	0.123
Lichen & Bryophytes	0.466
Mammal – large	0.0246
Mammal – small-burrowing	0.276
Mollusc – gastropod	0.0160

Reference Species	Dose Rate (µGy/h)
Reptile	0.0525
Shrub	0.134
Tree	0.00903

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. The potential impact to all reference species is very low.

For comparison purposes, the estimated additional 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.

17.4.3 Radiological Impacts to crops

Soil samples from the study area have been samples and analysed with the results reported in Figure 17-9 and detailed in Table 17-16. The conservative calculated maximum change in soil radionuclide activity concentration at the end of the Project life, is also included in Table 17-16, as head of chain, with decay products in secular equilibrium.

Table 17-16 Measured Soil Radionuclide Activity Concentration and Project Soil Increment

ERML	Soil Radionuclide Activity Concentration - 2019 samples (Bg/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		

It can be seen that the modelled radiological changes in soil concentrations are an order of magnitude less than current concentration 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 17-16, are listed in Table 17-17.

Table 17-17 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.

17.4.4 Radiological Impacts to Groundwater

The groundwater in the study area is below the zone to be mined. The groundwater has no beneficial use due to high salinity levels. 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 would be returned to what was the ore zone, and the activity concentration of the tails would not be greater than that of the ore. It is therefore unlikely that any radiological change in groundwater would occur.

17.4.5 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 product encapsulation. The calculated dose is then compared to the accepted member of the public dose limit of 1 mSv/y. The highest gamma dose rates would occur during Phase 1 of the Project, when REMC is being transported.

Gamma Doses during interim storage at Ultima Intermodal Facility Receptors

The highest gamma doses would be received at receptors closest to the Project boundary as gamma levels decrease with distance. Gamma doses were calculated for Receptors TR1, TR2 and TR3 (see Section 17.2.2), with the conservative assumption that all containers are placed on the boundary closest to that specific receptor. 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. Scenarios for normal transportation storage, as well as normal storage with one extreme event, with Phase 1, Phase 1a and Phase 2 product materials were calculated and are listed in Table 17-18.

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 the 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 would 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* would detail additional controls, such as the location of containers within the facility and stacking arrangements, which can be enacted to reduce gamma doses.

Table 17-18 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

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 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 results are presented in Table 17-19.

Table 17-19 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

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.

17.4.6 Characterisation of Project Materials with Reference to EPBC Act

Process Streams

The Project would be implemented across three phases with varying process streams. The Project would also mine two areas with Area 1 ore having a higher uranium and thorium grade than Area 3 ore. During processing, uranium and thorium can concentrate in materials, and secular equilibrium can be disturbed. Sections of the processing facility would contain radioactive materials and would require radiation protection controls and management.

The radionuclide activity concentrations for product material (produced from Area 1 ore) are listed in Table 17-20. Where materials are not in secular equilibrium, the concentration of the decay product has been included.

Table 17-20 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	

Waste Streams

The waste streams from all circuits of the processing plants would be homogenised and radionuclides would 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 would contain lower uranium and thorium grades 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 17-20, and are less than those of the ore.

Product Storage

There would be interim contained storage of products onsite prior to transportation offsite. The Victorian Radiation Regulations provides activity limits which, in conjunction with the activity concentration of the product (Table 17-20) enable calculation of the maximum quantities of each material that can be stored on site before triggering Clause 22(1)(g). The calculated maximum quantities of materials to be stored on site prior to shipping, the limit for triggering the EPBC and the on-site storage methods are detailed in Table 17-21.

Table 17-21 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 17-21. Buildings would be secured, with restricted access, and designed to ensure no emission of products. Any dust extraction systems would have bag-house arrangements to collect any fugitive material.

17.4.7 Radioactive Source Category and Additional Security Requirements

Sealed radioactive sources would 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 would be reassessed at the time of final plant design and equipment procurement.

17.5 Residual impacts

Residual impacts are those that remain once mitigation and management measures have been implemented. This section describes potential residual impacts during the operation phase of the project once mitigation and management measures have been considered and applied.

The assessment as presented in Section 17.4 and EES Technical Report N: Radiation has indicated that there would be no residual impacts relating to radiation during construction, operation, decommissioning and closure. It is expected that the actual doses to humans at the nearest receptors will be lower than the conservative assessments that have been undertaken. Radiological impacts to non-human environmental values such as flora and fauna, crops, and groundwater from the operations are expected to be minor. Further, the 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 control procedures.

17.6 Summary of mitigation measures

17.6.1 Mitigation and management measures

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

A Radiation Management Plan (RMP), Radioactive Waste Management Plan (RWMP) and Radiation Environmental Plan (REP) would be developed to ensure that radiation related impacts and risks remain well controlled. The Transportation Contractor would be responsible for the Transportation Facilities and Transport Management Plans which would detail control, monitoring and contingency measures with regards to radiation management, and would report regularly to VHM on performance.

Three main types of control would be implemented for the Project:

- Engineered Design Controls.
- Mechanical Controls.
- Administrative Controls.

Table 17-22 provides an overview of the specific controls and how they would be implemented.

Table 17-22 Mitigation measures relevant to radiation impact

Measure ID	Mitigation Measure	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 building, including the use of a packing booth for REMC.	All phases

Measure ID	Mitigation Measure	Phase
R-ADM01	Minimise radiation effects: Administrative Safe operating procedures outlined in RMP to ensure the safe and environmentally responsible operation of the Project. RMP to specify that all employees and contractors would receive training in the radiological aspects of the Project and be 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: • Unauthorised access is restricted • Intentional or inadvertent removal of radioactive material from the operation is prevented.	• Construction • Operation
R-ADM02	Minimise radiation effects: Rehabilitation Radiological input to the Rehabilitation/Closure Plan will occur, based on approved radiological closure criteria of return to pre-operational radiological conditions, with monitoring to confirm compliance.	Closure

17.6.2 Monitoring and contingency measures

The monitoring and contingency measures that are proposed to monitor radiation impacts associated with the project are summarised in Table 17-23.

Table 17-23 Monitoring and contingency measures relevant to Radiation

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

The monitoring would 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 would be used to ensure that the radiation controls are effective and operating properly. The results would also provide information for ensuring that impacts are As Low As Reasonably Achievable (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 would be compared to standards to ensure compliance. Table 17-24 lists the action levels and the contingencies. Note that the action levels are set well below the regulatory limits.

Table 17-24 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/m2.month Th-232 1.15 Bq/m2.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

17.7 Conclusion

An 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 has shown that the construction, operation and decommissioning phases of the Project can be managed such that the objective of minimising adverse effects resulting from radiation can be met.

The radiation impact assessment as presented in EES Technical Report N: Radiation concluded:

- The conservative maximum dose to humans as a results of the Project is 0.19 mSv/y which is well below the member of the public 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 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 calculate crop radionuclide activity concentrations.
- The radiological impact to groundwater is assessed to be low due to the inert nature of the tailing and also because the radionuclide concentration of tailing would 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 by train is 0.006 mSv/y. All doses are below the member of the public dose limit of 1 mSv/y.

In response to the EES evaluation objective described at the beginning of this chapter, impacts of the Project resulting from radiation have been assessed and mitigation measures have been identified to avoid and minimise adverse effects.