AUSTRALIAN ZIRCONIA LTD

(A wholly owned subsidiary of Alkane Resources Ltd)

Dubbo Zirconia Project

Radiation Assessment

Prepared by

JRHC Enterprises Pty Ltd

August 2013

Specialist Consultant Studies Compendium
Volume 1, Part 3

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Radiation Assessment

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Dubbo Zirconia Project

Radiation Technical Report

August 2013

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FOREWORD

AIM OF THIS DOCUMENT

Australian Zirconia Limited (the Applicant) is proposing to develop the Dubbo Zirconia Project (the Proposal), a deposit containing zirconium, hafnium, niobium, tantalum, yttrium and rare earth elements, near Dubbo in NSW.

The deposit also contains naturally occurring uranium and thorium at concentrations of 80 to 160ppm uranium and 250 to 500ppm thorium.

The Applicant has commissioned JRHC to undertake an assessment of the occupational and environmental radiological impacts of the Proposal, and the results of the assessment are contained in this document.

Previous radiological work associated with the Proposal includes;

- Report on Preliminary Radiological Assessment of the Dubbo Zirconia Project [Hewson 2002], and
- Hydrogeological and Hydrological Investigations and Environmental Impacts, Dubbo Zirconia Project [Golder Associates, 2002].

The Applicant commissioned the Australian Nuclear Science and Technology Organisation (ANSTO) to undertake various radiation related assessments, including;

- a radionuclide balance of the proposed flow sheet [ANSTO 2012a], and
- a preliminary radiation dose assessment [ANSTO 2012b].

The Applicant also commissioned Pacific Environment Limited [PEL 2013] to undertake air dispersion modelling, the results of which are used for radiological impact assessment.

These reports will be referred to in this document where appropriate.

CONTENTS OF THIS DOCUMENT

This document is structured as follows:

Foreword

1. Radiation & Radiation Protection

A brief introduction to radiation, radiation protection and an overview of the International, National and New South Wales framework for radiation protection are presented.

2. **Radiological Implications for Dubbo Zirconia Project**

An overview of the Proposal its radiological considerations are provided. Potential radiation doses to workers, the public and non-human biota are also calculated and provided.

3. **Management of Radiation**

This section provides an overview of the proposed radiation protection and management systems that the Applicant would implement.

4. **Closure Considerations**

5. **Summary**

Appendices

References, glossary, assumptions, and radiological information are provided in the appendices.

1. RADIATION & RADIATION PROTECTION

1.1 OVERVIEW OF RADIATION

This document assumes a basic understanding of radiation protection and general occupational health and safety and an overview of key concepts is provided here for contextualization of the radiation assessment. For a more detailed discussion on radiation and radiation safety, refer to the *Radiation Workers Handbook* (http://www.aua.org.au/Content/RadiationSafety.aspx) and the Technical Note in **Appendix A**.

1.1.1 WHAT IS RADIATION?

"Radiation" is a term used to describe the movement or transfer of energy through space or through a medium. It occurs when unstable atoms (isotopes) give off the radiation to move to a lower energy state. The unstable isotopes are known as "radionuclides" and when they exist in a material (such as rocks), above a prescribed concentration, the material is classified as "radioactive". For the radioactive elements of uranium and thorium, a series of radiation emissions occur as the atoms "decay" to stable isotopes and these are depicted below in **Table 1** as "decay chains".

Table 1: U^{238}, U^{235} and Th^{232} Decay Chains

Uranium-238 Decay Chain (ARPANSA 2008)

Radionuclide	Half-life	Decay
Uranium-238	4.5 x 109 a	α
Thorium-234	24.1 d	β, γ
Protactinium-234m	702 s	β, γ
Uranium-234	2.5 x 105 a	α
Thorium-230	7.5 x 104 a	α,
Radium-226	1.6 x 10^3 a	α, γ
Radon-222	3.82 d	α
Polonium-218	183 s	α
Lead-214	1608 s	β, γ
Bismuth-214	1194 s	β, γ
Polonium-214	1.6 x 10-6 s	α
Lead-210	22.3 a	β, γ
Bismuth-210	5.0 d	β, γ
Polonium-210	138.4 d	α
Lead-206	stable	□

Uranium-235 Decay Chain (ARPANSA 2008)

Radionuclide	Half-life	Decay
Uranium-235	7.0 x 108 a	α, β, γ
Thorium-231	1.1 d	β, γ
Protactinium-231	3.3 x 104 a	α, γ
Actinium-227	21.8 a	β, γ
Thorium-227	18.7 d	β, γ
Radium-223	11.4 d	α, γ
Radon-219	3.96 s	α, γ
Polonium-215	1.8 x 10-3 s	α γ
Lead-211	2166 s	β, γ
Bismuth-211	128 s	β, γ
Polonium-211	0.5 s	α, γ
Thallium-207	286.2 s	β, γ
Lead-207	stable	□

Thorium-232 Decay Chain (ARPANSA 2008)

Radionuclide	Half-life	Decay
Thorium-232	1.41 x 10^{10} y	α, β, γ
Radium-228	5.57 a	β
Actinium-228	6.13 h	β, γ
Thorium-228	1.91 a	α
Radium-224	3.66 d	α, γ
Radon-220	55.6 s	α
Polonium-216	0.145 s	α
Lead-212	10.6 h	β, γ
Bismuth-212	3630 s	α, β, γ
Thallium-208	186 s	β, γ
Lead-208	stable	□

The key observations from a radiological protection perspective for the U^{238} decay chain are:

- The chain contains 14 radioactive decays.
- There are 5 long lived alpha emitters and one longer lived beta emitter. The remaining radionuclides are short lived and come into equilibrium with their parent relatively quickly.
- One of the decay products is an inert gas Rn^{222} (known as radon) that has a 3.8 day half-life meaning that it can escape from material before decaying. It is therefore able to move in air before decaying to the more hazardous shorter lived radon decay products (RnDP).
- Rn^{222} eventually decays to the longer lived Po^{210} and Pb^{210} decay products which can deposit in the environment.
- Po^{210} and Pb^{210} are volatile at high temperatures (ie in a smelter).

The key observations from a radiological protection perspective for the U^{235} decay chain are:

- The chain contains 12 radioactive decays.
- U^{235} co-exist with U^{238}, at a relative mass percentage of 0.7%. Its impact is therefore small compared to the more prevalent U^{238}.
- The decay chain contains Ac^{227} which is one of the more radiotoxic naturally occurring radionuclides.

The key observations from a radiological protection perspective for the Th^{232} decay chain are:

- The chain contains 10 radioactive decays.
- One of the decay products is an inert gas Rn^{220} (known as thoron) that has a short half-life of approximately 1 minute. This means that it is able to move short distance, and possibly into the atmosphere before decaying. However, its short half- life means that it does not travel far in air before decaying to the thoron decay products (ThDP).
- All of the decay products of Rn^{220} have short half-lives, meaning that there are no long term decay products (unlike Rn^{222}).
- Th^{232} has a half-life of 14 billion years, with the next longest being Ra^{228} with 6.9 years and Th^{228} with 1.9 years. All other radionuclides are less than a few days. This means that the shorter lived radionuclides grow back into equilibrium with their parents relatively quickly. (For example, the processing may extract Th^{228} by itself at 1Bq/g. After a week or two, the total activity could be up to 7Bq/g due to the ingrowth of the Th^{228} decay product radionuclides).
- Approximately one third of the decays of Bi^{212} result in Tl^{208}, which is a high energy gamma emitter (which contributes much of the decay chain’s gamma radiation).

1.1.2 DESCRIBING THE IMPACTS OF RADIATION

Radioactive materials occur naturally in soils, water and the air, and are responsible for much of the naturally occurring radiation known as "background radiation". Naturally occurring background radiation is variable and causes radiation exposure to people everywhere.

When discussing impacts of radiation on people, it is usual to say that people are "exposed" to radiation resulting in a "dose". The term "dose" is a standardised measure of radiation impact, reported as "Sieverts" (Sv), which takes into account the different types of radiation and the way that exposure occurs.

The effects of radiation depend upon the size of the dose received. At high doses, above 1Sv, a range of radiation effects are *immediately* observable in individuals. At doses between 0.1 and 1Sv, effects are observable in populations or groups of people, and there is a *probability* that the dose may result in an impact to an individual. Below a dose of 0.1Sv, it is difficult to observe any effects, however, it is assumed that the probability of an effect still exists.

Background radiation produces doses ranging from 1 to 10mSv/y in different parts of the world. In Australia, the average dose from background radiation is about 2.3mSv/y (ARPANSA, 2012)

In the past, it was assumed that protecting humans from the harmful effects of radiation would also ensure the protection of the environment. This approach has been improved upon and the now preferred approach is to quantify the radiological impact on flora and fauna, known as Non-Human Biota Assessment.

1.2 FRAMEWORK FOR RADIATION PROTECTION

1.2.1 INTERNATIONAL APPROACH

Radiation and its effects have been studied for almost 100 years and there is International consensus on its effect and controls. The main organisations that oversee radiation and radiation protection and provide guidance and standards are:

- The United National Standing Committee on the Effects of Atomic Radiation (UNSCEAR) which provides a consolidated overview of the effects of radiation by regularly reviewing leading research and publishing the summaries.
- The International Atomic Energy Agency (IAEA) which develops and publishes industry "codes of practice" and provides broad advice on basic safety precautions when dealing with radiation.

- The International Commission on Radiological Protection (ICRP) which is recognised as the pre-eminent authority on radiation protection and regularly publishes specific guidelines and recommendations on radiation protection.

In Publication 26 [ICRP 1977], the ICRP recommended a “system of dose limitation” which has become the internationally accepted foundation for radiation protection and is universally adopted as the basis of legislative systems for the control of radiation and as the basis for standards. It is made up of three key elements as follows:

- “Justification” – this means that a practice involving exposure to radiation should only be adopted if the benefits of the practice outweigh the risks associated with the radiation exposure.
- “Optimisation” – this means that radiation doses should be As Low As Reasonably Achievable, taking into account economic and social factors. This is also known as the ALARA principle.
- “Limitation” – this means that individuals should not receive radiation doses greater than the prescribed dose limits.

Within the “system of dose limitation”, the ALARA principle is generally regarded as the most important and the most effective of these elements for the control and management of radiation. In the design stage of a project, ALARA means identifying radiation hazards and making design and engineering and infrastructure decisions to ensure that potential doses are as low as reasonably achievable. In operation, ALARA is similar to continuous improvement, where ongoing efforts are made to ensure that practices, procedures and systems are monitored and reviewed to ensure that radiation exposure in minimised.

While the ALARA principle is the foundation for radiation protection, radiation dose limits have been established to provide an absolute level of protection. The limits apply to the total radiation dose, as a result of a “practice”, from all exposure pathways (excluding natural background radiation), and are;

- 20mSv/y for a worker (at work), and
- 1mSv/y for a member of the public (total year).

When assessing compliance with the limits, occupational doses may be averaged over a five-year period and there is an absolute annual limit of 50mSv in any one year for workers. [ICRP 2007]

1.2.2 AUSTRALIAN NATIONAL APPROACH

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is the Australian national authority on radiation protection. ARPANSA develops National Codes of Practice based on the IAEA and the ICRP standards.

The primary national Codes of Practice in Australia related to radiation protection in the mining or processing of radioactive materials are;

- Recommendations for Limiting Exposure to Ionising Radiation. [ARPANSA 2002],
- The Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing 2005. [ARPANSA 2005],
- The Code of Practice for the Safe Transport of Radioactive Material 2008. [ARPANSA 2008b], and
- Safety Guide for the Management of Naturally Occurring Radioactive Material (WA Govt 2010). [ARPANSA 2008].

1.2.3 New South Wales Approach

In NSW, the primary controlling legislation is the Radiation Control Act (1990) and associated legislation. Recent amendments to the Act recognise the requirements of the National Directory for Radiation Protection, which covers the regulation of radioactive ores at mine sites.

2. RADIOLOGICAL IMPLICATIONS FOR DUBBO ZIRCONIA PROJECT

2.1 PROJECT CHARACTERISTICS

The Applicant intends to undertake mining and processing activities at its Toongi deposit near Dubbo in NSW to extract rare earth ores and produce zirconium, hafnium, niobium, tantalum, yttrium, light rare earth and heavy rare earth products.

The mine would be open cut with a final area of approximately 40.3ha and a depth of 55m, producing approximately 1Mtpa of mineralised material for 20 years.

The main surface facilities will include;

- a crushing and milling circuit,
- a leaching and filtration circuit,
- a solvent extraction circuit,
- roasting kilns,
- a waste rock disposal facility, and
- a tailings disposal facilities.

Ancillary facilities include; reagent storage area, sulphuric acid plant, water treatment plant, warehouse, workshops, offices, change-rooms and control rooms.

The mining and processing of the ore requires radiological considerations due in part to the presence of low levels of uranium and thorium and the chemical processing which indirectly concentrates radionuclides in various processes. However, the general processing methods are not new and the radiological aspects are manageable through effective design controls and management measures.

2.1.1 RADIOLOGICAL CHARACTERISTICS OF THE ORE

The mineralised material contains between 80-160ppm uranium and between 250-500 thorium and contains radionuclides from the U^{238}, U^{235} and Th^{232} decay chains. For reference, the world average for soils is 3ppm for uranium and 6ppm for thorium. These levels of uranium and thorium necessitate the consideration of radiological impacts on workers, the public and the environment.

2.1.2 RADIONUCLIDE DEPORTMENT THROUGH PROCESSING PLANT

Radionuclides from the U^{238}, U^{235} and Th^{232} decay chains will behave in accordance with their elemental state, for example, U^{238} and U^{235}, have identical process properties.

In the processing facility, the ore undergoes a range of chemical and metallurgical processes, as seen in **Figure 1**, which affect the various elements differently. The Applicant commissioned ANSTO to undertake a radionuclide deportment study of the processing facility [ANSTO 2012a]. For the main radionuclides, the activity concentration deportment is shown in **Table 2** and percentage deportment is shown in **Table 3**.

Figure 1: Process Flow Sheet [TZMI]

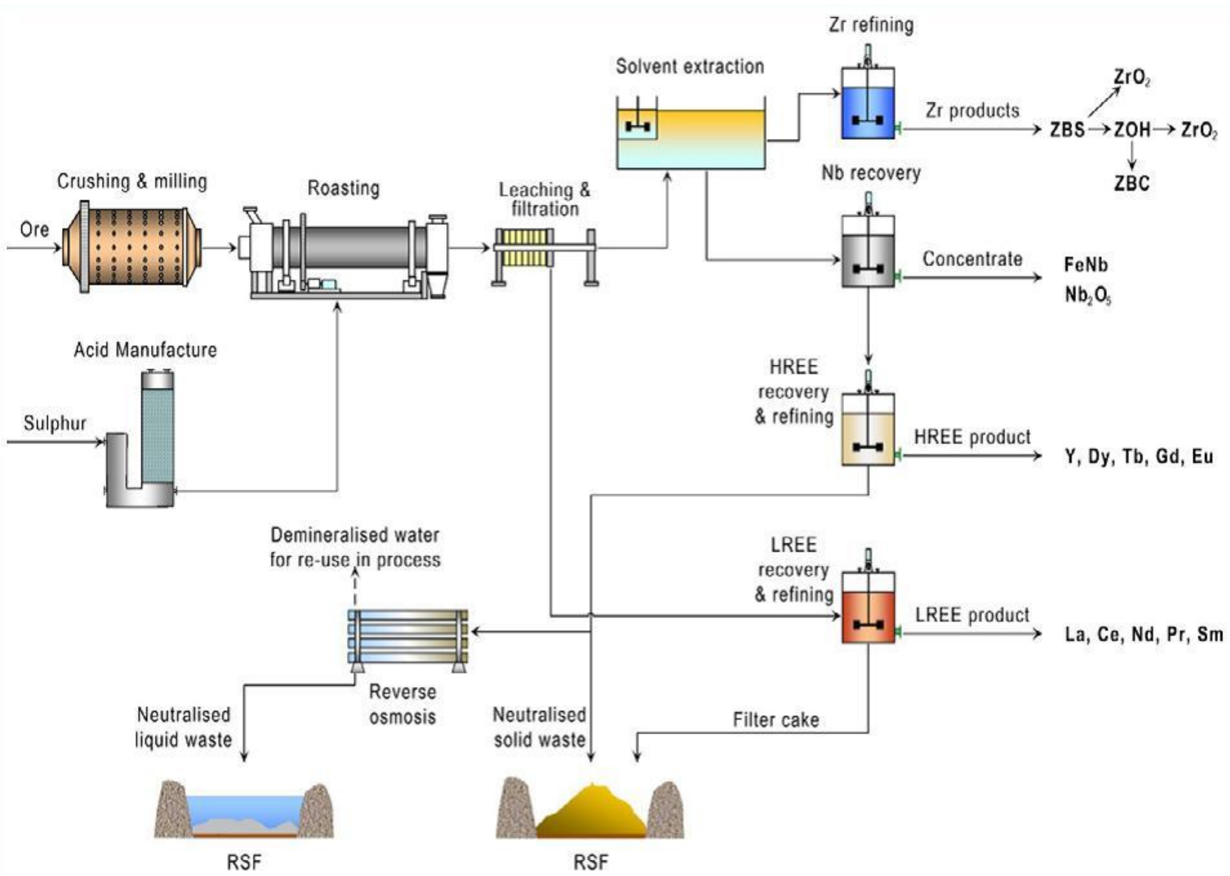


Table 2: Predicted Activity in Summary Process Streams (Solids Bq/kg, Liquors Bq/L)

Material		^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po	^{232}Th	^{228}Ra	^{231}Pa	^{227}Ac
FEED	Ore (S)	1480	1480	1480	1480	1480	1950	1950	71	71
PRODUCTS	LRE Chloride Liquor (L)	0.092	5.3	13.8	780	1.7	7.0	18.2	0.24	609
	ZOH (35% Zr) (S)	270	5	12	29	410	6	15	75	0.2
	FeNb (S)	6	10	1	540	500	14	1	64	5
	HRE Chloride Liquor (L)	2.3	144	1.4	0.47	0.35	189	1.8	0.26	376
WASTES	Combined Residues (S)	45	1040	1130	1080	1090	1400	1500	25	37
	FeNb Slag (S)	420	3500	370	470	350	4600	490	8700	660
	Combined Waste Liquor (L)	266	21.2	0.11	10.1	3.7	27.9	0.14	0.37	0.74
	Evaporated Waste Liquor Combined Salt (S)	4500	360	2	170	62	470	2	6	13

Table 3: Overall Deportment of Radionuclides from Ore (%)

Material		^{238}U	^{230}Th	^{226}Ra	^{210}Pb	^{210}Po	^{232}Th	^{228}Ra	^{231}Pa	^{227}Ac
FEED	**Ore**	100	100	100	100	100	100	100	100	100
PRODUCTS	**LRE Chloride Liquor**	0.0001	0.007	0.02	1.0	0.002	0.007	0.017	0.006	16
	ZOH (35% Zr)	0.66	0.01	0.03	0.07	1.0	0.01	0.03	3.8	0.008
	FeNb	0.001	0.002	0.0002	0.10	0.09	0.0018	0.0002	0.24	0.02
	HRE Chloride Liquor	0.002	0.10	0.001	0.0003	0.0003	0.10	0.0010	0.0040	5.7
WASTES	**Combined Residues**	4.0	91	99.8	95	96	91	99.8	47	69
	FeNb Slag	0.11	0.9	0.093	0.12	0.09	0.9	0.093	46	3.5
	Combined Waste Liquor	95	7.6	0.039	3.6	1.3	7.6	0.039	2.80	5.6

As can be seen in **Table 3**, the majority of the radionuclides report to waste and the final products.

2.1.3 AIR EMISSIONS

The Applicant commissioned Pacific Environmental Limited (PEL) to undertake air quality modelling to quantify the impacts of dust emissions from the Proposal. This modelling was based on estimated emissions and provided "impact contour plots" outputs [PEL 2013], which have been used as the basis for the radiological assessment. Details on the methodology and assumptions are provided in PEL 2013.

Impacts from radioactive air emissions were determined for;

- radioactive particulate emissions (leading to increased radionuclide concentrations in air and radionuclide deposition to soils), and
- radon emissions (leading to potential increases in RnDP concentrations).

The assessments conducted in PEL 2013 were at year 5 and year 15 of operations. It is noted that emission rates for these years are very similar and were chosen as they represent the worst case (ie maximum emission rates) for the Proposal. For this radiological assessment, radioactive dust impacts at year 5 and radon impacts at year 15 were used.

Particulate Emissions

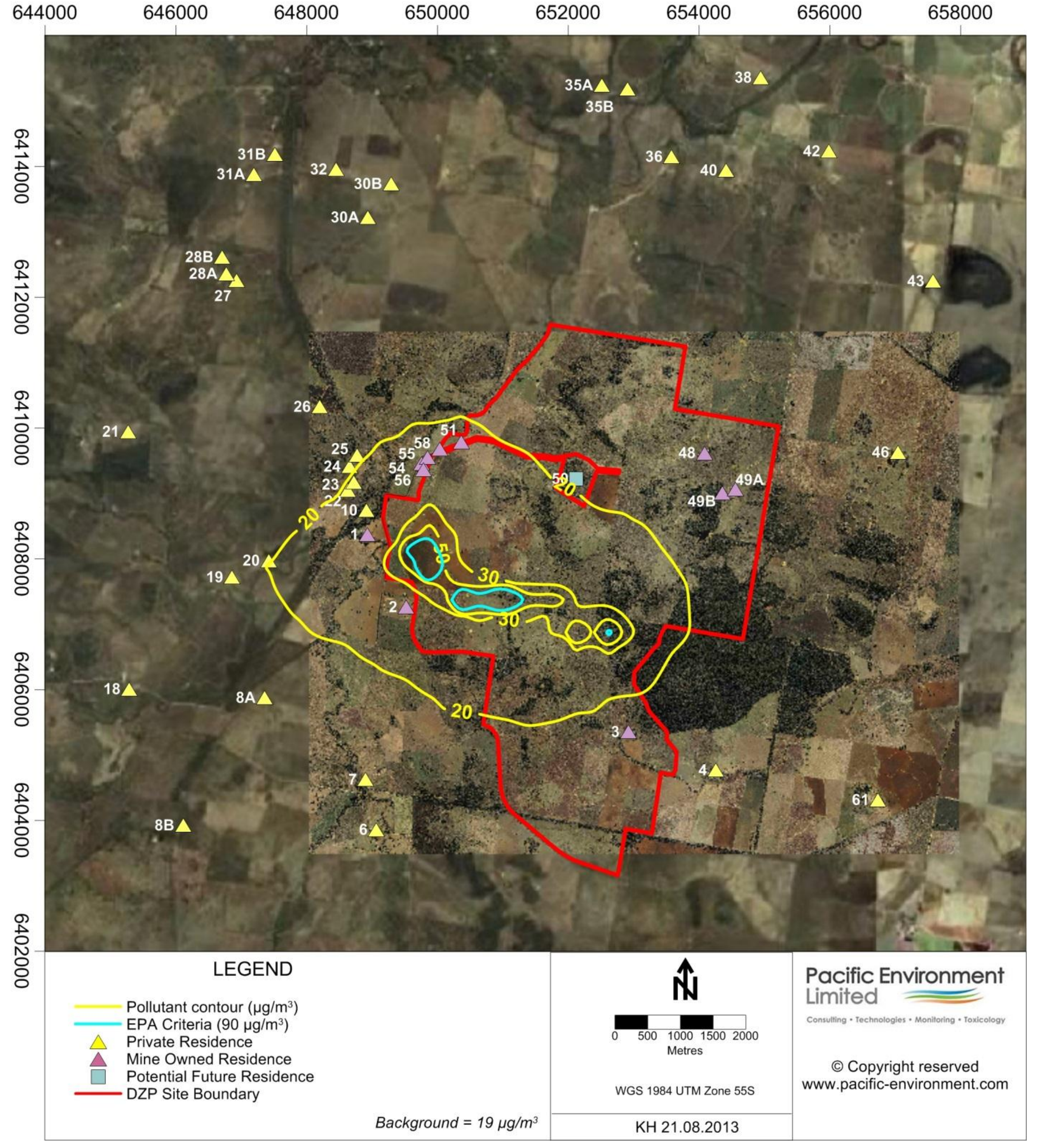
The main sources of radioactive particulate emissions are;

- mining,
- material stockpiles (during material movement and from wind erosion), and
- the processing plant.

The impact assessment calculated the concentration of Proposal originated dust at various distances from the Proposal as a result of emissions from both area sources and point sources (such as stacks).

The calculated concentrations are in µg/m^3 of total suspended solids (TSP) and can be seen in **Figure 2** as a contour plot. (Note that TSP is usually used for radiological assessments).

Figure 2: Modelled TSP Concentrations (µg/m^3) at Year 5



Source: Pacific Environment Limited – Figure 28

The Proposal originated radionuclide concentrations can then be calculated from the dust concentrations by using the radionuclide content of the dust. The dust emissions from the Proposal are from various sources as shown in **Table 4**. A conservative estimate is to assume that all dust is ore dust.

Table 4: Relative Composition of Dust Emissions at Year 5 [PEL 2013]

Dust Source	%
Soil/Overburden	4
Ore	87
Waste Materials	4
Plant Emissions	4

Table 2 shows the concentration of radionuclides in the ore (in Bq/kg). Therefore, an activity concentration can be determined by multiplying the calculated dust concentrations by the radionuclide concentrations.

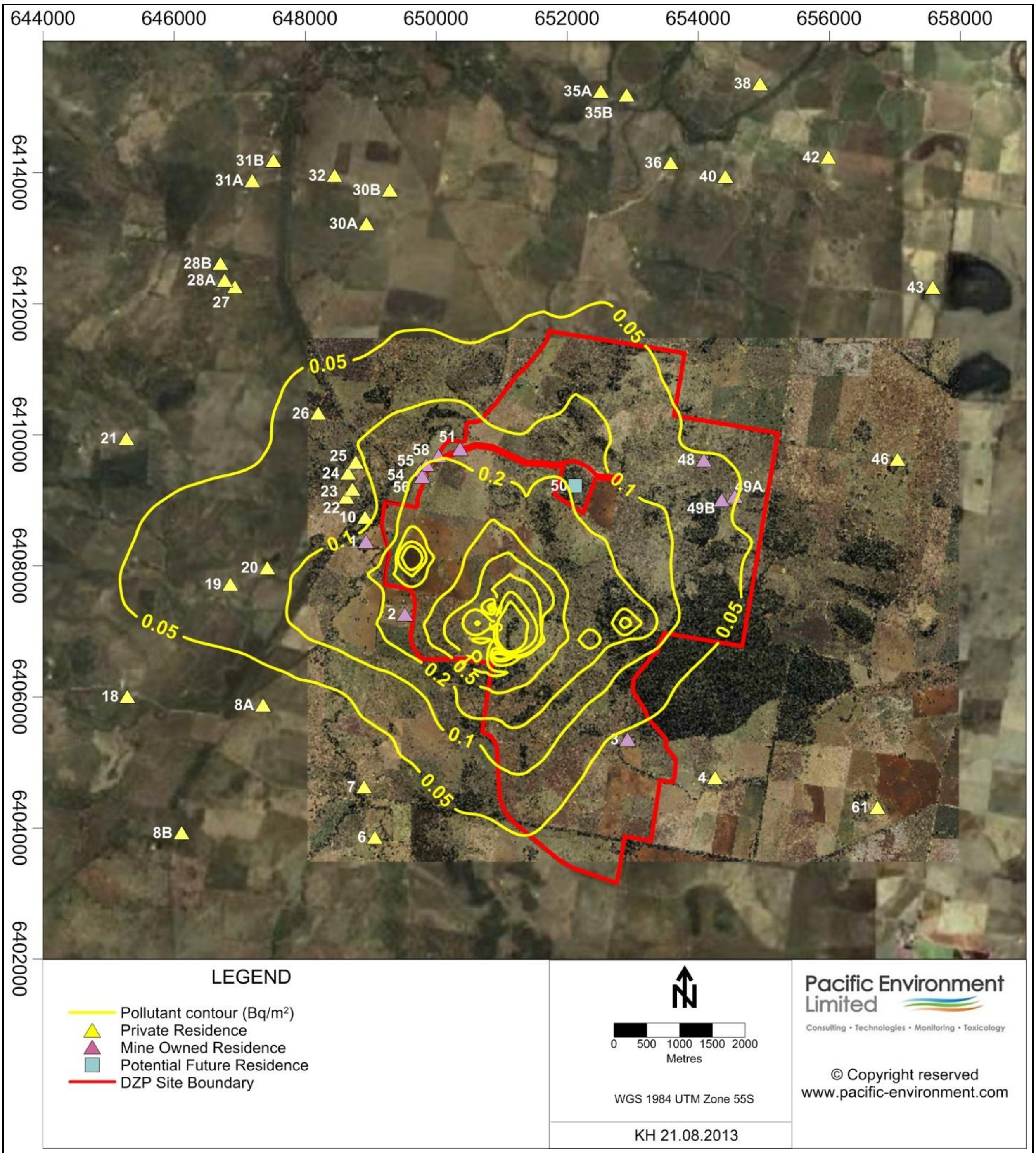
Radon Emissions

Radon is not a significant source of radiation exposure. However, it is a transport mechanism for the potentially more hazardous decay products. There is a direct relationship between the radon concentration and the decay product concentration, therefore an understanding of the radon concentration from the air quality modelling provides a basis for calculating the potential decay product concentrations.

The radon sources from the Proposal have been calculated and can be seen in **Appendix B**

The contour plot of Proposal originated radon from the air quality modelling can be seen in **Figure 3**. This shows the annual average radon concentrations in Bq/m^3.

Figure 3: Contour plot of Rn^{222} Concentration from proposed activities (Bq/m^3) at Year 15



Source: Pacific Environment Limited – Figure 43

Thoron Emissions

Thoron emissions are difficult to predict. Recent research indicates that thoron emanates at a rate of 69Bq/m^{2}s per 500ppm Th, from thorium mineralised material, (Todd R et al, 1998).

The very short half-life (55.6s) of thoron means that even if it is able to emanate from ore, then it will not travel far before decaying [UNSCEAR 2000]. In addition, the relatively short half-life of its decay products mean that they decay away quickly. Therefore it has been assumed that the environmental and public impacts are negligible.

Radionuclide Deposition

Dusts containing radionuclides from the Proposal may deposit from the air. Deposited radionuclides can potentially lead to radiological impacts on flora and fauna.

The air quality modelling provides predicted contours of dust deposition from the proposed activities and can be converted to radionuclide depositions using the same factors that converted dust mass concentration to dust activity concentrations. **Figure 4** and **5** show the modelled dust deposition in Years 5 and 15 in g/m^2/month.

2.2 OCCUPATIONAL DOSE ASSESSMENT

Potential doses have been calculated for mine workers and processing plant workers, and these have been based on determining the doses from the following exposure pathways;

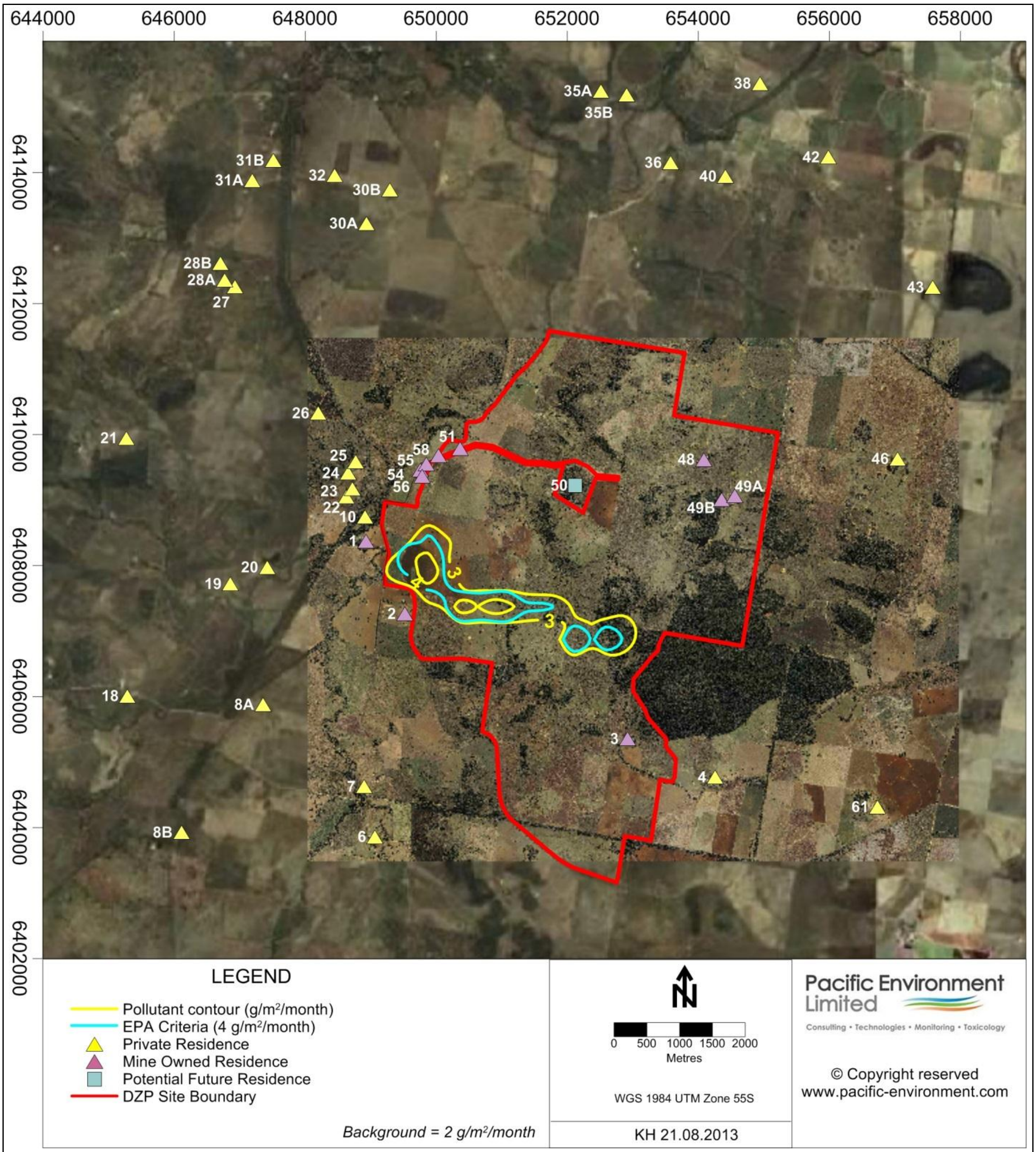
- Gamma irradiation,
- Inhalation of the decay products of radon, and
- Inhalation of radioactive dust.

For the processing plant, initial dose estimates were made by ANSTO and these have been refined where appropriate.

2.2.1 EARLIER WORK

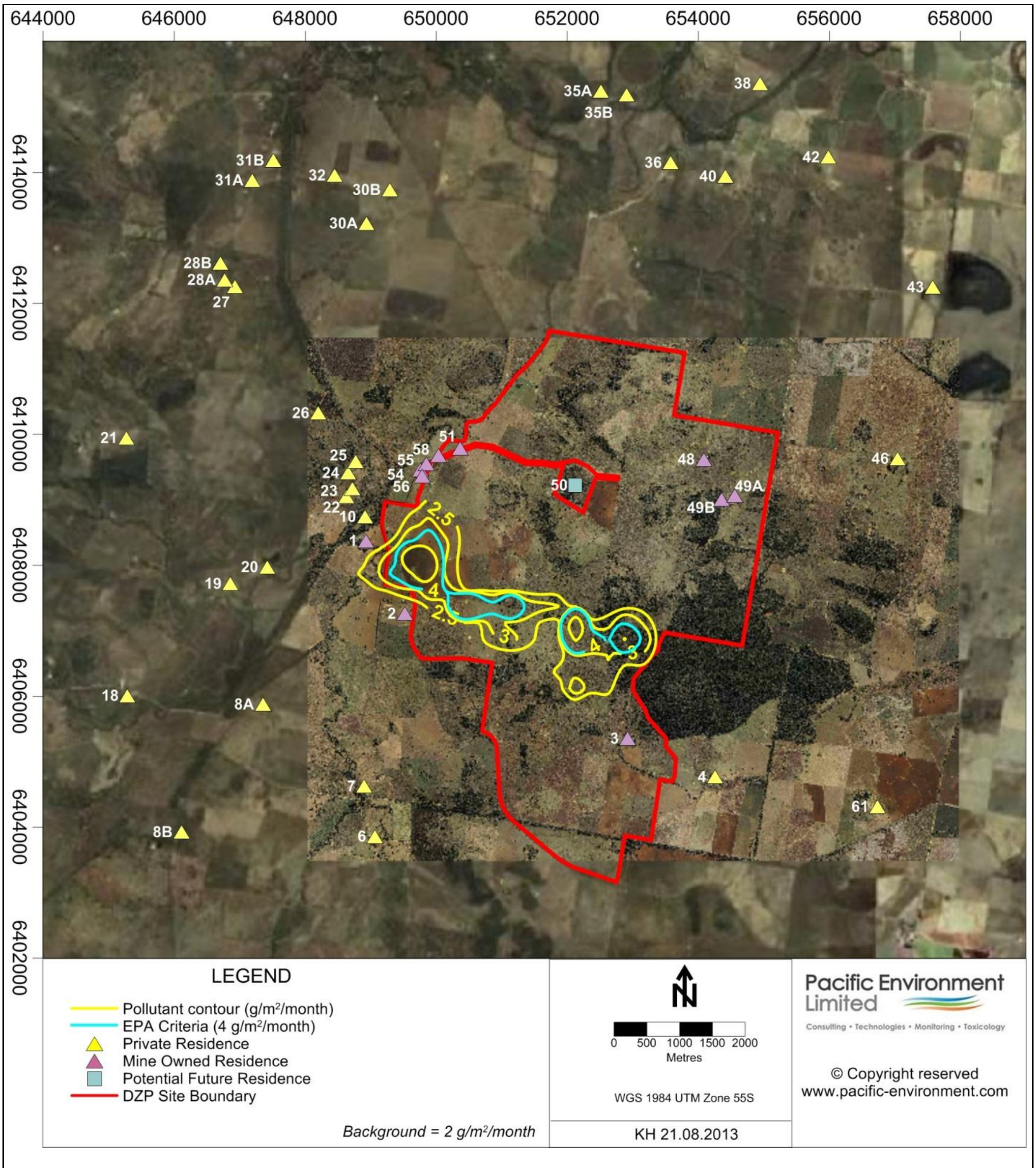
An initial conservative assessment by Hewson [Hewson 2002] indicated that occupational radiation doses for miners could be up to 4mSv/y, with 75% of the dose coming from the thorium radionuclides. It was also noted that by using more realistic factors in the dose assessment, that doses would most likely be lower at approximately 2mSv/y. The assessment also estimated that potential doses to processing plant workers will be less than 1mSv/y, however, this was for dust exposure only and no gamma contribution.

Figure 4: Modelled Dust Deposition Contours (g/m^2/month) at Year 5



Source: Pacific Environment Limited – Figure 27

Figure 5: Modelled Dust Deposition Contours (g/m^2/month) at Year 15



Source: Pacific Environment Limited – Figure 31

2.2.2 OCCUPATIONAL RADIATION DOSES - MINERS

The assumptions for calculating doses to miners are as follows;

- the pit is at its maximum size with an area of 40.3 Ha and depth of 55m,
- the base of the mine is all mineralised material,

- the walls contain inert (non-radioactive) material,
- the activity concentrations of uranium and thorium grades of the ore are estimated to be 1.5 and 2Bq/g, and
- a work year consists of 2,000 hours.

Gamma Radiation

Estimates of gamma radiation exposure are based on the work of Thomson and Wilson [1980] for gamma from radionuclides in the uranium decay chain and from IAEA 2006 for gamma radiation from radionuclides in the thorium decay chain. These references provide factors to convert an average uranium and thorium grade into a gamma dose rate at one metre above an infinite plane of that material. **Table 5** shows the respective factors and the calculated dose rate for the estimated grades of the mineralised material.

Table 5: Gamma Dose Rate and Calculation factors for Miners

Decay chain	Conversion factors (µSv/h *per* %)	Estimated Grade (%)	Dose rate (µSv/h)
U^{238}	65	0.012	0.8
Th^{232}	16	0.050	0.8

The total dose rate is the sum of the dose-rate from the U^{238} and Th^{232} decay chains, being approximately 1.6µSv/h.

This corresponds to an annual calculated dose of 3.2mSv/y. This estimate does not take into account any shielding factor from equipment and assumes that all work hours are spent in mineralised areas. Experience shows that in practice, measured gamma doses are usually less than the calculated doses. Accordingly, the estimated average gamma dose for miners is 2mSv/y (assuming that not all work time is spent on mineralised material and that mining equipment provides some shielding of the gamma radiation).

RnDP and ThDP Exposure

The estimated occupational doses from RnDP and ThDP are based on the radon and thoron emanation rate into the mine and the ventilation rate of the mine. This provides information for calculating the average RnDP and ThDP concentrations in the working areas. For RnDP, occupancy estimates and standard dose conversion factors (DCFs) have been used to estimate the dose. For ThDP, due to the difficulties of estimating the impacts of the short half live of thoron, reference is made to factors provided in WA Govt 2010.

Radon Emanation

For this assessment, it has been assumed that the whole of the base of the mine is exposed ore (a total of 40.3Ha) and that broken mineralised material is removed from the mine for processing. The emanation figures provided in **Appendix B**, show that the total emanation into the mine void is $0.6Bq/m^2.s \times 40.3 \times 10^4 m^2 = 0.24MBq/s$.

Thoron Emanation

It has been assumed that the whole of the base of the mine is exposed (a total of 40.3Ha) and that broken mineralised material is removed from the mine for processing. Based on the emanation figures provided in **Section 2.1.3**, the total emanation into the mine void is 28MBq/s.

Mine Ventilation Rate

The ventilation rate or the number of air changes per hour, in an open cut mine can be calculated using a formula of Thompson 1993 as follows;

$$T = 33.8 \times (V/U_rLW) \times (0.7\cos Z+0.3),$$

where;

T = air residence time (h),

V = mine volume (m^3),

L and W = mine length and width (m),

U_r = the surface wind speed (m/h), and

Z = angle of the wind relative to the longer mine dimension. (Note that the modelling assumes a square pit, making (0.7cosZ + 0.3) equal to 1 in the calculation).

The average wind speed in the region is 6m/s [PEL 2013] and using the assumptions above gives an air residence time of 0.08h, giving 12 air changes per hour.

Mine Equilibrium Radon and Thoron Concentrations

The equilibrium concentration of radon and thoron in the mine is then calculated as follows [Cember 2009]:

Rn Bq/m^3 = Radon generation rate (Bq/h) /(Mine volume x number of air changes per hour), giving an equilibrium concentration of $0.04Bq/m^3$.

Th Bq/m^3 = Thoron generation rate (Bq/h) /(Mine volume x number of air changes per hour), giving an equilibrium concentration of $3.8Bq/m^3$.

Note that these concentrations are the Proposal originated concentrations, that is, they do not include natural background.

Doses

Converting radon and thoron concentrations to doses requires the use of conversion factors.

For radon, UNSCEAR 2000b provides a DCF for radon concentration of 9nSv/Bqh.m^3 for an equilibrium equivalent concentration of radon. If a worst case is assumed and the mine radon levels are on average 1Bq/m^3 (compared to the calculated 0.04Bq/m^3), then for 2,000 working hours in a year, the annual dose from RnDP would be 18µSv/y.

For thoron, 3.8 Bq/m^3, is equivalent to a full year exposure of 8.0µSv/y (using the factors provided in WA Govt 2010).

The combination of low grade and relatively high wind speed means that RnDP and ThDP do not constitute a significant risk.

Airborne Dust

The assessment of radioactive dust dose is based on an estimated total suspended dust concentration in the mine of 1mg/m^3 [(1)] and the assumption that all dust is from ore material.

The ore dust is expected to contain 1.5Bq/g of radionuclides from the U^{238} decay series and 2Bq/g of radionuclides from the Th^{232} series. The activity concentration can be calculated by multiplying the anticipated airborne concentration by the dust activity. This gives the following airborne radionuclide concentrations;

- U^{238} decay series – 1.5mBq/m^3, and
- Th^{232} decay series – 2mBq/m^3

ARPANSA 2005 provides DCFs that are used to convert an inhalation exposure to dose. The respective DCFs are;

- U^{238} chain – 7.2µSv/αdps, and
- Th^{232} chain – 11µSv/αdps

The DCFs are in units of alpha decays per second (αdps), and there are 5 long lived alpha emitters in the U^{238} decay series and 3 longer lived alpha emitters in the Th^{232} decay series. Note that in dose assessment, it is usual to consider the radiological impacts of the longer lived radionuclides which take into account impacts of any shorter lived decay products.

[(1)] There is a general lack of data on dust concentrations in open-cut mines. A long term study, presented in HSE2006, notes that 1% of measured respirable dust concentrations, in UK quarries, exceed 3mg/m^3, although the average is not provided. For this report 1mg/m^3 has been inferred as the average dust concentration.

Dose is calculated by multiplying the airborne activity concentration by the amount of air breathed in while working in one year (2,000h/y x 1.2m^3/h = 2,400m^3/y) by the number of αdps by the DCF for each of the decay chains. This gives approximately 0.14mSv/y from U^{238} radionuclides and 0.16mSv/y from Th^{232} radionuclides, giving a total estimate of 0.30mSv/y from radionuclides in dust.

Summary of Occupation Radiation Doses for Miners

A summary of the estimated doses is provided in **Table 6**.

Table 6: Occupational Dose Estimates - Miners

Work Group	Average Annual Dose (mSv/y)				
	Gamma	RnDP	ThDP	Dust	Total
Miners	2.0	0.018	0.008	0.30	2.3

2.2.3 PROCESSING PLANT WORKER DOSES

In 2012, ANSTO [ANSTO 2012b] calculated potential doses for processing plant workers based on actual measurements from a pilot plant established at the ANSTO facilities in NSW and radionuclide deportment work. Total doses estimates included; gamma exposure, inhalation of various processing plant dust and ingestion of materials. The ANSTO dose assessment was conducted using conservative factors and exposure conditions and the report noted this and stated that dust exposures were based on estimates and that they should be updated.

Accordingly, the ANSTO results have been reviewed and updated or revised as required. Where a change has been made to an ANSTO estimate, the reason for the modification is provided.

For gamma radiation, ANSTO concluded that dose rates would be low and close to background levels, being 0.5 to 2.0mSv/y, with the higher gamma doses being associated with working close to the ore stockpile.

The assessment of the airborne radionuclide inhalation dose was made based on 8 potential exposure scenarios. Assumptions were made about exposure conditions including; estimates of dust concentrations, radionuclide concentrations of the various process stream, exposure time, characteristics of the dust and whether respiratory protection might been used during the tasks. The estimated doses from dust inhalation ranged between 1 to 8mSv/y, with highest exposures occurring in the ore milling area, the Light Rare Earth (LRE) leach residue area and the FeNb slag dumping area.

In some cases the ANSTO assessment identified higher activity process materials and calculated potential doses to highlight the need for good practice and design in the particular area of the processing plant. These have been excluded from the assessment in this report because it is expected that exposures to these materials would be limited in practice. For example, doses were assessed for maintenance in the FeNb smelting baghouse, however, the following controls would be incorporated into the design and operation of this process..

- Since, the assessment, AZL has included a pre-treatment step for the Niobium concentrate (Nb_2O_5) prior to smelting to produce a FeNb final product.
- Niobium concentrate that is produced as the underflow from the niobium precipitation circuit contains an array of trace contaminants, including Polonium 210 and Lead 210. High temperature roasting and calcination prior to sintering in the presence of a flux, has been shown to remove a significant quantity of the contaminants, resulting in a clean intermediate product that is more suitable for final smelting.
- Exhaust gases and fumes from the roasting, calcination and sintering stages would be scrubbed in a venturi scrubber, the exhaust of which would be finally cleaned in a wet electrostatic precipitator (ESP) prior to release to the atmosphere. Residues from the scrubber and ESP would be slurried and mixed with the process waste stream going to the solid residue storage facility. The majority of the Polonium 210 and Lead 210 is therefore captured by the venturi scrubber and ESP, rather than the smelter baghouse and similarly disposed of to tailings.
- Following the pre-treatment, the clean niobium concentrate would be pelletised and sintered for smelting to produce FeNb. The clean niobium concentrate is expected to contain only minor quantities of Polonium 210 and Lead 210, which would be collected and disposed of via the smelter baghouse.

For this assessment, a weighted average of radionuclide concentrations of products in the particular part of the plant was determined [ANSTO 2012a] and these can be seen in **Table 7**.

Table 7: Weighted Average Radionuclide Concentrations [ANSTO 2012a]

	Average Radionuclide Concentration in Area of Processing Plant (Bq/g)		
Radionuclide	**Niobium Processing**	**Light Rare Earth Processing**	**Heavy Rare Earth Processing**
U^{238}	0.3	0.0	0.5
Th^{230}	2.4	35.9	11.3
Ra^{226}	0.3	0.1	0.0
Pb^{210}	2.8	15.0	0.0
Po^{210}	20.5	0.3	0.0
Pa^{231}	5.8	0.1	0.1
Ac^{227}	0.5	1.6	0.2
Th^{232}	3.1	47.3	14.9
Ra^{228}	0.3	0.1	0.0
Th^{228}	3.1	47.3	14.9
Ra^{224}	0.3	0.1	0.0

Using the DCFs provided in IAEA 1996, and assuming an activity median aerodynamic diameter of 1µm, a breathing rate of 1.2m^3/h and a working year of 2,000 h/y, the relative inhalation doses for a 1mg/m^3 dust cloud can be seen in **Table 8**.

Table 8: Inhalation Dose Rates in Main Plant Areas

Plant Area	**Dose Rate (mSv/y per mg/m^3)**
Ore milling	0.4
Light Rare Earth Processing	8.5
Niobium Processing	1.2
Heavy Rare Earth Processing	2.6

ANSTO 2012b also estimates potential doses of between 0.04 and 1.5mSv/y, from the ingestion of materials. However, it is expected that hygiene management practices will reduce any ingestion dose to negligible levels.

Based on these results, the dose estimates for the processing plant work areas are shown in **Table** 9.

Table 9: Processing Plant Work Area Doses

Processing Plant Work Area	Doses (mSv/y)		
	Gamma	Dust Inhalation	Total
Ore Milling/Handling /Roasting	2.0	0.4	**2.4**
LRE processing	0.5	8.5	**9.0**
HRE processing	0.7	2.6	**3.3**
Niobium Processing	0.8	1.2	**2.0**

It should be noted that these updated dose estimates are conservative and monitoring will be conducted to confirm the estimates.

2.3 PUBLIC DOSE ASSESSMENT

This section describes the offsite radiological impacts, in which emissions from the Proposal impact on receptors outside the Proposal.

Of the main exposure pathways, gamma radiation, is not considered to be significant because sources of gamma radiation are well within the mine lease area and inaccessible. Therefore, gamma radiation levels from the Proposal beyond the boundary of the proposed plant will be negligible.

For the public, the only potential exposure pathways are via the airborne pathways being;

- inhalation of radioactive dust, and
- inhalation of the decay products of Rn^{222} and Rn^{220}.

The recognised method to assess public dose is to identify a reference person to represent groups of people potentially exposed to radiation from an activity.

For this assessment, the closest potentially exposed public groups are residents of the Toongi “lifestyle blocks” (TLBs) which are located approximately 1km from the Proposal. Being the closest exposed group, it is expected that other public groups would receive less exposure.

To estimate doses to the TLB residents, the results of the air quality modelling are used. The method is as follows;

- establish the dust and radon concentrations at the TLBs from the contour plots (**Figure 2** & **Figure 3**),
- calculate an exposure based on the concentration and occupancy factors, and
- use standard DCFs to determine the doses.

For this assessment, it is assumed that the TLBs are permanently occupied (therefore the occupancy factor is 8760 hours per year) and it is also assumed that the breathing rate of an individual living there is $1.2m^3/h$.

Figure 2 shows that the annual average TSP dust concentration is approximately $1\mu g/m^3$ at the TLBs during the 5th year of operation. The air quality assessment was also undertaken at year 15 and shows that the average annual dust concentration is approximately $3\mu g/m^3$. For the radionuclide dust impact assessment, the higher concentration is used. The air quality report also notes that the majority of the dust produced from the operation is ore dust, with the majority of the remainder being inert soil or overburden material. For this assessment, it is conservatively assumed at all dust is ore dust, with a radionuclide composition as presented in **Table 2**. ICRP2012 provides a range of DCFs for each radionuclide and these can be seen in **Appendix C.**

The dose from the dust inhalation is then calculated as follows. Firstly, each radionuclide concentration is multiplied by its respective DCF (which converts the intake into a dose), and then summing for all radionuclides. This gives the dose for every gram of material that is inhaled. Secondly the amount of material inhaled is worked out my multiplying the breathing rate by the exposure hours (being 8760 hours per year). The result of these calculations is that the average annual inhalation dose from exposure to dust from the operation at the TLBs is approximately 20µSv/y.

Figure 3 shows that the annual average radon concentration is approximately $0.1Bq/m^3$ at the TLBs during the 15th year of operation. Assuming that the radon is in equivalent equilibrium concentration, UNSCEAR [in UNSCEAR 2000 Annex B, paragraph 153] provides a DCF of $9nSv(Bq.h/m^3)^{-1}$. The DCF is then multiplied by the radon concentration to give the dose rate per hour, which is then multiplied by the exposure hours (which is 8760 hours).

Therefore for a full year exposure of 8,760hours, the radon decay product dose at the TLBs is calculated to be 7.5µSv/y.

A summary of doses to the residents of the TLBs is show in **Table 10**. Note that the public dose limit is 1mSv/y.

Table 10: Predicted Dose TLB public groups

Public Group	Dose From Pathway (mSv/y)			
	Inhalation of RnDP (Rn^{222})	Inhalation of Dust	Gamma Radiation	Total Dose
TLBs	0.0075	0.020	0	0.028

2.4 EXPOSURE TO NON-HUMAN BIOTA

In ICRP publication 103 [ICRP 2003], a system for the protection of non-human biota was outlined, which included objectives for the radiological protection of non-human species and an approach for assessing radiological impact to reference species.

A software tool, called ERICA (see Appendix D- Non Human Biota Assessment, for detail), was developed to determine a relative radiological risk factor to a species as a “dose rate” based on site specific data. The dose rate is used as part of a tiered screening mechanism to indicate the level of assessment that should be undertaken. The ERICA approach has been used successfully in Australia to assess the impact of a number of proposed uranium mining operations as part of their EIS assessment.

An assessment of the potential for radiological effects on the terrestrial environment resulting from dust emissions from the operation of the Proposal has been conducted using the ERICA assessment tool. Outside the $10g/m^2$.month dust deposition contour there is negligible risk of radiological harm to any of the “reference organisms”. Within that contour and particularly in areas (if any) where deposition exceeds $30g/m^2$.month, this assessment has indicated that dose rates may be above screening levels. However these deposition rates only occur very close to the operations and well within the Proposal boundary and therefore impacts on non-human biota outside the Proposal area are negligible.

2.5 PUBLIC DOSE FOLLOWING CLOSURE

The Applicant has developed closure and rehabilitation plans for the proposed activities. From a radiological perspective, the overall approach is to ensure that the radiation levels at the site are returned to levels consistent with those which existed prior to the Proposal (as measured and reported in Naturally Occurring Background Radiation in the Vicinity of the DZP [JRHC2012-13]). With the implementation of the closure and rehabilitation plans, there are therefore no reasonable pathways for public exposure, and doses are expected to be negligible and much less that the member of public dose limit of 1mSv/y (above natural background).

2.6 SUMMARY OF RADIOLOGICAL IMPACTS

The assessment has shown that the radiological impacts of the Proposal will be low. Conservative estimates show that doses to most workers will be less than 5mSv/y, compared to the annual limit of 20mSv/y. Special attention needs to be paid to workers in the Light Rare Earths Section of the processing plant to ensure that doses are well controlled. Public doses are expected to be well below the public dose limit of 1mSv/y, and there are expected to be no impacts to non-human biota outside of the Proposal area.

3. MANAGEMENT OF RADIATION

The ICRP is the international authority on radiation protection and has established a structured and recognised approach, which is outlined in its "system of dose limitation". The Applicant has adopted the general ICRP approach and radiation and radioactive waste will be optimally managed and controlled through good design and appropriate ongoing operational management systems.

Detailed design of the proposed mine, processing facilities and tailings management facility has yet to occur. However, the Applicant has considered radiation controls at this early stage of the Proposal through;

- the establishment of radiation design criteria for the Proposal, and
- the establishment of specific radiation related management systems and measures.

This section provides an overview of radiation controls.

3.1 GENERAL SITE CONTROLS

3.1.1 CLASSIFICATION OF WORK AREAS & WORKERS

ARPANSA 2005 provides guidance on classification of workplaces for radiological purposes, as follows:

> A "controlled area" is an area to which access is subject to control and in which employees are required to follow specific procedures aimed at controlling exposure to radiation.
>
> A "supervised area" is an area in which working conditions are kept under review but in which special procedures to control exposure to radiation are not normally necessary.

The Applicant has defined the whole of the Proposal within the fence-line as a "supervised area". Within this area, the mine will be defined as a "controlled area" as will the milling and crushing areas and the light rare earths processing area.

Employees working in the controlled areas will be defined as designated radiation workers. Other workers will be defined as "non-designated" radiation workers.

3.1.2 SITE ACCESS CONTROL

Access to the site will be through a manned gatehouse. Access will be linked to a record keeping system to ensure that all personnel accessing the site have been appropriately inducted.

Vehicle access will be through the main boom gate, and exit from site would require all vehicles to pass through the wheel wash. Water from the wheel wash and wash-down areas will be collected and settled to remove solids, then treated for re-use at the on-site water treatment plant.

3.1.3 CHANGE-ROOMS

Workers in the “controlled area” (“designated workers”) will be required to change into work clothes at the commencement of their shift and then shower and change into “street clothes” at the end of their shift. This will be a general health and hygiene requirement (not just a radiation requirement) that will be implemented once the Proposal commences and would continue for the life of the Proposal.

Dirty clothes will be laundered on site, with waste water sent to the on-site water treatment plant.

3.1.4 OTHER GENERAL CONTROLS

The Applicant will develop and implement a series of other site-wide operational and administrative controls for radiation protection including;

- pre-employment and routine medical checks,
- development of safe work procedures, which includes radiation safety aspects,
- procedures to segregate, isolate and clean up contamination or contaminated equipment,
- procedures for equipment or materials leaving the controlled area, and
- mandatory use of personal hygiene facilities (wash facilities) at entrances to lunch rooms and offices.

3.2 RADIATION CONTROL IN THE MINE

The doses to mine workers are expected to be low (<5mSv/y), and the Applicant will implement standard management controls to ensure that doses remain low. These include;

- restricting access to the main mining areas to ensure that only appropriately trained and qualified personnel are able to access the work areas,
- ensuring that all heavy mining equipment is air conditioned to minimise impacts of dust,

- minimising dust using standard dust suppression techniques and protective measures to reduce subsequent exposure,
- monitoring the levels of dust generated during tipping of material onto stockpiles and implementing standard dust control techniques as necessary, and
- a separate wash-down pad within the site area for vehicles that have come from the mine area.

3.3 RADIATION CONTROL IN THE PROCESSING PLANT

Both wet and dry process material will be handled in the processing plant, requiring specific design considerations for dust control, spillage containment and fume control. This includes;

- crushers and conveyor systems fitted with appropriate dust control measures such as dust extraction,
- use of scrubbers or bag houses where appropriate,
- bunding to collect and contain spillages from tanks containing radioactive process slurries, with bunding to capture at least the volume of the tank in the event of a catastrophic failure,
- tailings pipeline corridor bunded to control spillage from tailings pipeline failures
- sufficient access and egress for mobile equipment to allow clean-up where there is the possibility for large spillages,
- wash-down water points and hoses supplied for spillage clean-up
- suitable extraction ventilation with appropriate scrubbing systems for the smelting and processing of ferro-niobium , and
- procedures to control exposures during the maintenance of the ventilation systems and plant work.

If the monitoring shows that there are elevated levels of dust in the workplace, respiratory protection will be used until a more permanent means to reduce dust is established.

3.4 OPERATIONAL AND ADMINISTRATIVE CONTROLS

The programs outlined in this section would form part of the *Radiation Management Plan* (RMP) and the *Radioactive Waste Management Plan* (RWMP).

3.4.1 RADIATION SAFETY EXPERTISE

The Applicant would ensure that suitably qualified and experienced radiation safety professionals are available to assist during the final design, construction and the operational phases of the Proposal. During operations, the Applicant would employ a suitable qualified and resourced Radiation Safety Officer (RSO) who would influence the day to day workings of the Proposal, ensure that appropriate radiation safety advice is available to implement the RMP and RWMP and provide ongoing advice to the General Manager.

3.4.2 INDUCTION AND TRAINING

All employees and contractors will receive an induction upon commencement (with annual re-induction), informing them of the hazards associated with the workplace. The induction would include an introduction to radiation, radiation safety and responsibilities. Specific training will be provided to personnel involved in the handling of process materials containing elevated levels of radionuclides. Managers and supervisors will receive additional training in the recognition and management of situations that have the potential to increase a person's exposure to radiation.

A specific radiation safety work permit system will be developed and implemented. Before any non-routine work or maintenance work commences in a potentially high exposure area or situation, such as maintenance in the light rare earths area, a work permit will be issued, outlining the specific radiation protection measures.

3.4.3 RECORD KEEPING

A computer based data management system will be used to store and manage all information relating to radiation management and monitoring, including both occupational and environmental monitoring results and worker doses.

Periodic reports will be prepared from information stored in the electronic database. Dose reports will be provided to individuals upon request.

3.5 RADIATION MONITORING PROGRAMS

As part of the ongoing management of radiation, an occupational monitoring program will be developed and implemented. The existing Environmental Radiation Monitoring Program will continue.

The Radiation Monitoring Programs will also include;

- recognised sampling methodologies that are documented and regularly reviewed,

- appropriately trained and qualified monitoring personnel,
- the use of appropriate monitoring equipment,
- review of new equipment,
- routine instrument calibration programs, including auditing of calibration sources,
- instrument maintenance and repair programs, and
- regular external audits of the monitoring program and system.

3.5.1 Occupational Radiation Monitoring Program

An outline of the proposed occupational radiation monitoring is shown in **Table 11**.

Table 11: Dose Assessment Monitoring Program (Indicative only)

Radiation Exposure Pathway & Monitoring Method	Mine Area	Processing Plant Area	Administration Area
Gamma radiation – Personal TLD badges	Quarterly TLD badges	Quarterly TLD badges on selected workers	
Gamma radiation – Survey with hand held monitor	Monthly areas survey	Monthly area survey	Monthly area survey
Airborne dust – Sampling pumps with radiometric and gravimetric analysis of filters	Weekly personal dust sampling for; • truck driver, • loader operator, • maintenance personnel, & • miner	Fortnightly personal samples in selected work areas Weekly sampling in the Light rare Earths area	Monthly area samples
Radon Decay Products – Grab sample using the Rolle or Borak method [WA Govt 2010]	Monthly "grab" sampling in mine workings.		
Thoron Decay Products – Grab sample using the Cote method [WA Govt 2010]	Monthly "grab" sampling in mine workings.		
Surface Contamination	Monthly survey	Monthly survey	Monthly survey

Results of monitoring will be provided to operational personnel for action as necessary.

For routine management control of radiation, the Applicant would establish a series of action levels to ensure that exposures and doses remain well controlled. Exceeding the action levels would require mandatory action by operational personnel. **Table 12** provides an overview of the proposed action levels and actions.

Table 12: Exposure Action Levels and Actions

Radiation Measurement Type	Action Level	Actions
Gamma radiation	1μSv/h	Investigate and identify source. Consider redesign of workplace or tasks to reduce exposure.
TLD - (quarterly result)	1mSv	Investigate and identify source. Redesign workplace or tasks to reduce exposure. Shield if necessary.
Surface contamination in workshops, control rooms and lunchrooms	4000Bq/m^2	Immediate clean-up
Airborne Dust	5mg/m^3 1mg/m^3 in the light rare earths area	Identify source and suppress (e.g. water suppression, housekeeping and ventilation)
RnDP and ThDP	1μJ/m^3	Investigate

Table 13 provides a list of the radiation monitoring equipment that will be used to implement the radiation monitoring program.

Table 13: List of Equipment required for Occupational Monitoring

Radiation Measurement Type	Equipment
Gamma radiation	Hand held gamma radiation monitor (x1)
TLD - (quarterly result)	TLD badges (provided and analysed by service provider)
Surface contamination in workshops, control rooms and lunchrooms	Surface contamination probe and rate-meter (x 2)
Airborne Dust	2L/min personal dust pumps fitted with suitable “inhalable” filter holders (x 10) Microbalance for weighing of filters (x 1) Alpha slide drawer assembly and rate-meter (x 2)
RnDP and ThDP	2L/min personal dust pumps fitted with suitable “inhalable” filter holders (x 1) Portable alpha slide drawer assembly and rate-meter (x 1)

3.5.2 ENVIRONMENTAL MONITORING PROGRAM

The Applicant will continue with the existing environmental radiation monitoring program. **Figure 6** shows the locations of these Environmental Monitoring Locations (EMLs) and **Table 14** details the ongoing monitoring that will be undertaken at these sites.

Figure 6: Location of Environmental Monitoring Locations

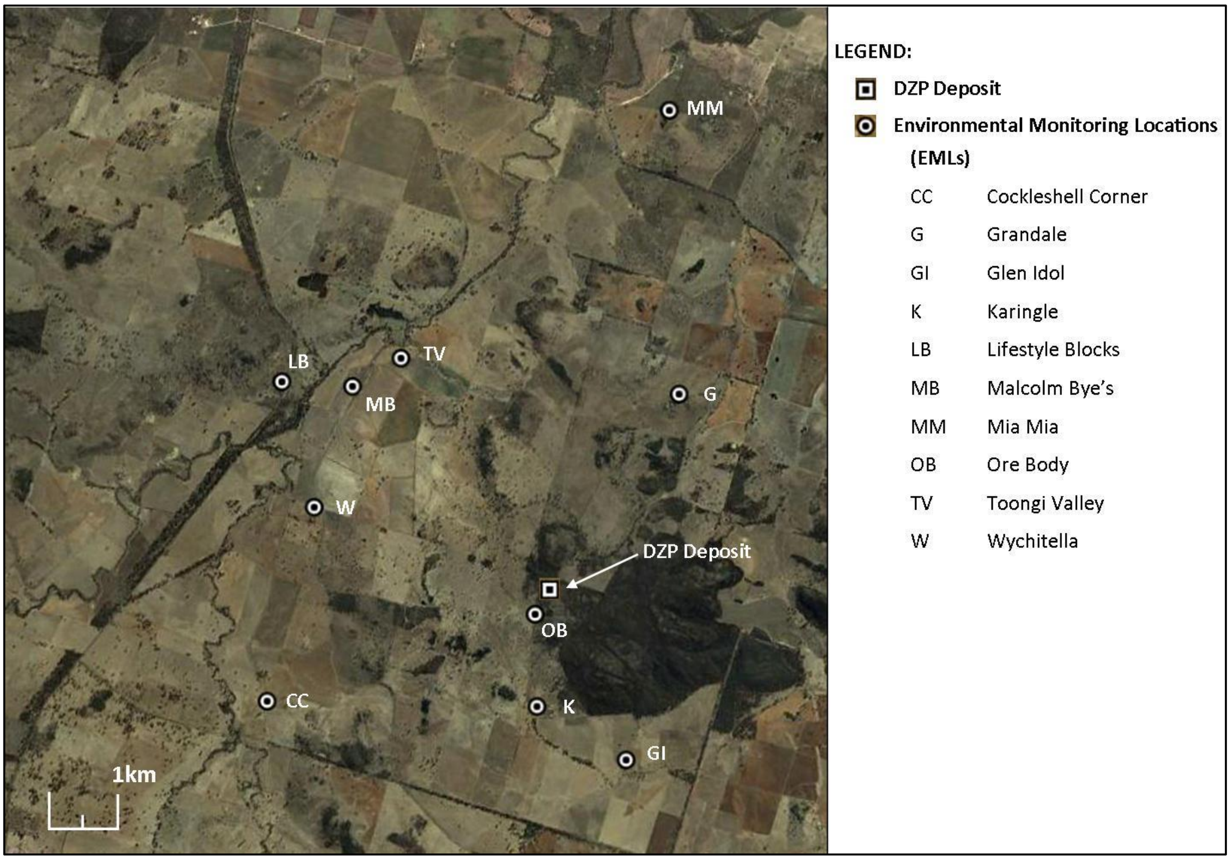


Table 14: Environmental Radiation Monitoring Program

Parameter	Monitoring	Location
Gamma radiation	Quarterly environmental TLD badges	All EMLs
	Handheld environmental gamma monitor	Annual survey at perimeter of operational area
Airborne dust	Passive dust sampling, with samples composited for one year then radiometric analysis	All EMLs
Radon Concentrations	Quarterly passive monitoring	All EMLs
Thoron Concentrations	Quarterly passive monitoring	All EMLs
Radionuclides in Soils	Sampled every 5 years	All EMLs
Radionuclides in Ground Water	Water sampled annually at monitoring bore locations	In accordance with the Groundwater Assessment (EES 2013)

3.6 RADIOACTIVE WASTE DISPOSAL

There are four main categories of radioactive waste generated by the Proposal;

- wastes from various processing streams including residue from processing that has had the valuable minerals removed,
- ferro-niobium slag,
- water that may have come into contact with radioactive materials including surface runoff, from areas which contain process material, and
- miscellaneous wastes that may have become contaminated through contact with ores and process residues (referred to as contaminated waste).

Waste rock from clearance and removal of mine overburden is not considered to be radioactive and will be disposed of on a waste rock stockpile with no radiation control measures necessary.

3.6.1 PROCESS WASTES

In general, all of the original radionuclides that enter the processing via the ore report to the processing plant waste streams.

There are three main waste streams that are treated and then disposed in the residue storage facility (RSF) as follows;

- A solids residue stream from a number of processes, consisting of filter cake with approximately 35% moisture level is produced. This material is conveyed to the RSF and stabilised by neutralisation, then transferred to a specially constructed lined disposal facility via a mobile stacker. Remnant liquid is captured in sumps and recycled or sent for evaporation. A total of approximately 1Mtpa of cake is produced from the various processes.
- A chloride waste liquor stream which is generated in the zirconium, niobium and HRE treatment streams. This stream is neutralised and then sent to dedicated lined evaporation ponds.
- A sulphate waste liquor stream, which is generated from all other process streams. This stream is recycled, with excess reporting to separate evaporation ponds.

The radionuclide deportment into the waste streams has been experimentally determined by ANSTO [ANSTO 2012a]. This shows that between 90 and 95% of the processing plant input radionuclides report to the solids in the solids residue stream, with the majority of the remaining radionuclides reporting to the liquid fraction of the solids residue stream. The exception to this is the uranium that is more soluble and reports mainly to the process liquor streams. The uranium then precipitates to salts during evaporation in the evaporation ponds. The radium isotopes (Ra^{226} and Ra^{228}) remain mainly in the solids fraction with less than 0.1Bq/L being present in liquor streams.

The RSF will be designed as a permanent, zero-discharge facility with a geo-membrane lining and leak detection system. The design would ensure that tailings are effectively contained in the long-term and that radiation doses from the tailings to the proposed workforce, members of the public and non-human biota are as low as reasonably achievable (ALARA) both during operations and following closure.

A radiological assessment of the process waste streams (see Appendix E) shows that the solid wastes are classified as restricted solid waste and the liquid waste is not classified as either a hazardous waste or a restricted liquid waste.

3.6.2 Ferro-Niobium Slag

The ferro-niobium slag is a process stream waste but has been identified separately due to its relatively small volumes (approximately 4,000tpa) and its properties.

The slag generally contains radionuclide concentrations of less than 1Bq/g, although elevated Th^{230} and Th^{232} concentrations (up to 4.5Bq/g) and elevated Pa^{231} (8.7 Bq/g) were noted in the ANSTO work [ANSTO 2012a].

The assessment in Appendix E shows that the ferro-niobium slag would be classified as a restricted solid waste if it were to be disposed by itself. Notably, the ferro-niobium slag would be slurried and mixed with the solid residue, of which it would form less than 0.5% of the total (4,000tpa of 1,300,000tpa).

3.6.3 Contaminated Water

Water that has come in contact with mineralised material, such as stormwater runoff from the ore stockpile or waste rock emplacement may contain entrained radioactive dusts and sediments. The DZP Site has been designed so that this surface water is collected and contained, and is prevented from discharging from the DZP Site or into ground-water. The method of control would involve the construction of a liquid residue storage facility for sedimentation and evaporation, and appropriate collection bunds and channels.

Waste water from wash-down areas and clean-up water would also be captured for treatment and evaporation.

3.6.4 MISCELLANEOUS WASTE CONTROL

This material includes contaminated equipment and wastes from operational areas, including discarded conveyor belts, rubber lining material, pipes, filter media and used protective equipment. This material would be disposed in an approved manner. Where practical, potentially contaminated waste would be decontaminated and disposed of via normal waste disposal methods. Where this is not possible and depending on the nature of the waste, several disposal options would be available. These include:

- encapsulation into the RSF,
- encapsulation within the waste rock emplacement,
- disposal into the open cut and encapsulation at the end of operations, and
- disposal in an on-site landfill (subject to obtaining appropriate licence from the EPA).

In all cases records of the disposal, including type of material, quantities and locations would be kept.

4. CLOSURE CONSIDERATIONS

In the event that mining ceases, or at the conclusion of the Proposal, the site will be rehabilitated in accordance with the closure plan. From a radiological perspective, this means a return to the natural background radiation levels that existed prior to the commencement of works.

Contaminated plant and equipment will be cleaned and decontaminated (where possible) and moved off site. Where this is not possible, it will be safely and securely disposed as discussed in Section 3.6.4.

It is expected that the Proposal area will be free from contamination once rehabilitated. Monitoring would occur for a period agreed to by the regulator to confirm this.

5. SUMMARY

The radiation assessment of the Proposal shows that the impacts will be manageable and well below the recognised limits. A summary of the radiological impacts of the Proposal can be seen in **Table 15**.

Table 15: Summary of Radiation Impacts During the Proposed Project

Dose Groups	Expected Dose/Impact (mSv/y)	Dose Limit/Standard (mSv/y)
Workers	<5mSv/y *	20mSv/y
Member of Public	<0.1mSv/y	1mSv/y
Non-Human Biota	No impact	-

* NOTE: Initial indications are that light rare earth plant workers may receive up to 10mSv/y. Dust controls will be implemented to minimise dose.