Radionuclide Mass Balance

For

Thunderbird Mineral Sands Project

Sheffield Resources

8/12/2016

Document Information

Document Number	SFX161122	Revision	1

Revision History

Revision Number	Issue Date	Prepared By	Approved By	Approval Date	Revision Description
0	6/12/2016	Ben Sambell	Anthony O'Brien	7/12/16	Issued for client comment
1	8/12/2016	Stuart Parr	Anthony O'Brien	8/12/16	Including client comments

Record of Approval:

Role	Name	Signature	Date
Prepared by	Stuart Parr		8/12/16
Reviewed by	Ben Sambell		8/12/16
Endorsed by	Anthony O'Brien		8/12/16

Contents

1 Executive Summary

Deposits of mineral sands can contain levels of Naturally Occurring Radioactive Material (NORM). For this reason, the Thunderbird Mineral Sands Project must adopt stringent and internationally accepted radiation management standards to minimise the potential risk to human health or the environment from NORM during its proposed activities.

This document presents the Radionuclide Mass Balance for the Project. The mass balances are given for the Uranium and Thorium radionuclides in Bq/g and in ppm, which will be used to support the Human Heath impact assessments for the Mine Site. Transport and Derby Port Operations; and therefore, supplement the Public Environmental Review (PER) documents being submitted to the Environmental Protection Agency (EPA). The base data has been supplied by the Proponent, Sheffield Resources Limited.

A preliminary Radiation Management Plan (RMP) will be developed for the first phase of the mine site development, future processing, transport operations and export operations. The RMP is a requirement under Western Australian legislation and regulations for the production, operation, storage or transport of radioactive substances.

2 Introduction

Radiation Professionals Pty Ltd (RadPro) have been engaged to update the Radionuclide Mass Balance in support of the Thunderbird Mineral Sands Project on behalf of Sheffield Resources Limited (the Proponent).

The Thunderbird mineral sands deposit was discovered by Rio Tinto Exploration Pty Ltd (Rio) in 2003. Rio conducted limited drilling and scoping metallurgical work between 2003 and 2009. In September 2011, Sheffield Resources Ltd was granted an Exploration Licence E04/2083 covering the Thunderbird deposit. Sheffield has carried out extensive drilling and metallurgical testing, completed a Pre-Feasibility Study in 2015 and is currently engaged in a Bankable Feasibility Study.

The project is a greenfield project and will comprise of:

- The mining of heavy mineral sands over a 40+ year period from the Thunderbird deposit. The initial rate of mining will allow excavation of up to 7.5 million tonnes per annum (mtpa) (nominal) of ore for the first five years, before increasing to 15 mtpa (nominal) of ore for the remainder of the project life. The details will change with each iteration of the mine schedule and the mine plan.

- The onsite primary and secondary processing of ore to produce a range of saleable mineral products (ilmenite, zircon, a zircon concentrate, HyTi88 Leucoxene, and a titanomagnetite product). Construction of the processing facilities will be staged with production and doubled to 15 mtpa (nominal) after year five.

- The abstraction and injection of groundwater from the Broome Aquifer to allow mining and supply ore processing needs.

- The development of the infrastructure needed to support the project including power generation facilities, an accommodation village, administration and maintenance buildings, internal roads, communications infrastructure, and waste storage and disposal facilities.

- The upgrade and extension of an existing pastoral road (the Mount Jowlaenga Road) from the Great Northern Highway to form a 30km site access road to the Mine Site.

- The transport of mineral products from the Mine Site via the site access road and Great Northern Highway to Derby Port for storage prior to export by barge and ship.

- The export of bulk mineral products from Derby Port via King Sound, and, as required by customers, packaged mineral products from Broome Port to international customers.

- The construction of the project is scheduled to commence in Quarter 3 of 2017, with mining and production scheduled to commence in around 2018 to early 2019. The project will be fully operational in early 2019, with first export of product being anticipated to be in 2019.

This document presents the preliminary uranium and thorium radioactivity concentration mass balance of raw, intermediate and waste products. The establishment of preliminary uranium and thorium activity concentrations will determine whether Sheffield would be expected to comply with radiation regulations specific to the mining and processing of minerals sands containing concentrations of radionuclides. A summary of potential applicable state and Commonwealth regulations are described below. This report provides the Proponent with the current uranium and thorium radioactivity balances based on the latest metallurgical test data.

3 Regulatory Framework

The regulatory framework for the mining and processing of mineral sands in Western Australia applicable to the Thunderbird Mineral Sands Project is summarised below in Table 1.

In support of the PER submission, RadPro have prepared Human Health impact assessments for the Mine Site and Processing Plant Operations, Transport Operations, Derby Port Operations and packaged mineral products to Broome Port; to demonstrate that the Proponent's arrangements will ensure that any potential radiation doses to workers, the public and the environment will be monitored, controlled and minimised to ensure that all legal requirements are met, that radiation doses are below limits and that doses are managed to be As Low As Reasonably Achievable (ALARA).

Table 1 - Western Australian Radiation Regulatory Summary

Aspect of Regulation	Legislation	Agency	Documentation Required	Guidelines
Radiation management and protection of workers and the public Radioactive Waste Management Use, possession and storage of radioactive materials	*Radiation Safety Management Act 1975*	Radiological Council	Radiation Management Plan Radioactive Waste Management Plan Application for a licence of authorised persons and registered premises. Nomination of a licensed Radiation Safety Officer	www.radiologicalcouncil.wa.gov.au *RPS 1. Code of Practice for Radiation Protection in Planned Exposure Situations as Applied to Workers, the Public and the Environment (2014).* *RPS 9. Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste management in Mining and Mineral Processing (2005).*
	Part 16 *Mines Safety and Inspections Regulations 1995* under the *Mines Safety and Inspections Act 1994*	Department of Mines and Petroleum	Radiation Management Plan	NORM Guidelines in Mining and Mineral Processing (DMP 2010)
Radioactive Transport Management	*Radiation Safety Management Act 1975*	Radiological Council and ARPANSA	Radioactive Transport Management Plan	www.radiologicalcouncil.wa.gov.au *RPS 2, Code of Practice for the Safe Transport of Radioactive Material 2001, as amended, 2001*

The Australian National Radiation Dose Register (ANRDR) was established in 2010 for the uranium industry to ensure that records of worker's radiation doses were maintained regardless of where the individual are working. The ANRDR is managed by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). By 2013, all of the then four operating uranium mines were reporting worker's radiation doses to the ANRDR. The next phase of the development of the ANRDR is to expand into the mineral sands industry. ARPANSA have been engaging with mineral sands operators across Australia and has been negotiating with State regulators regarding the mandating of reporting radiation doses to the ANRDR in each jurisdiction. By the time that the Thunderbird project is in commissioning phases, it is considered possible that the Proponent must report occupational radiation doses on a quarterly basis to the ANRDR.

In 2015, ARPANSA published the '*Guide on Radiation Protection of the Environment* (Radiation Protection Series G-1)'. The document describes the approach to assess the radiation doses to wildlife from industrial processes. The WA regulatory requirement for mineral sands operations to undertake radiation dose assessments of local wildlife is uncertain. It is possible that the regulator may require that such a dose assessment is undertaken as part of a wider environmental impact assessment. The likelihood of any requirement is increased if the mining operation is in particularly environmentally sensitive area, if the local area is used by indigenous peoples for the collection of bush foods, or if located in a sensitive / important agricultural or tourist area.

4 Radioactivity Mass Balance

4.1 Mine and Processing Plant Overview

The Thunderbird Mineral Sands Project will produce an upgraded ilmenite, titano-magnetite, zircon concentrate and primary zircon, and Hi Titanium (HiTi) product. Mining will consist of open cut extraction followed by various physical and chemical treatments of the ore. Several process streams are required to produce the three product types.

The Project is suitable for bulk mining techniques, employing heavy earthmoving equipment to achieve the modelled mining rate of —7.5-15 mtpa. The current study has assumed dry mining using large dozers pushing ore into dozer traps where the sand is screened of coarse oversize material and the remaining undersize is slurried and pumped for further scrubbing and screening prior to wet concentration.

A high-level scheduling and extraction logic was defined that would allow for the resultant optimisation of the mine pit shells to be quickly scheduled and developed whilst still maintaining practically achievable results. The key criteria for defining the scheduling logic was to focus initial mining on a high value core to bring early high cash-flow, and constrain mining to a radial Area of Influence (AOI) around proposed WCP locations and mine these locations consecutively.

Initially, the ore is fed into feed preparation and wet concentration processes to produce Heavy Mineral Concentrate (HMC). A Concentration Upgrade stage separate magnetic from non-magnetic minerals from the HMC. A Hot Acid Leach (HAL) stage is used on the non-magnetic concentrate. The ilmenite is produced by processing of the magnetic concentrate stream, whilst zircon products and HiTi result from processing of non-magnetic concentrates. Waste products in the form of oversize particles, tails and rejects are produced at each at stage of production. The waste products are combined together and are returned to the mine void.

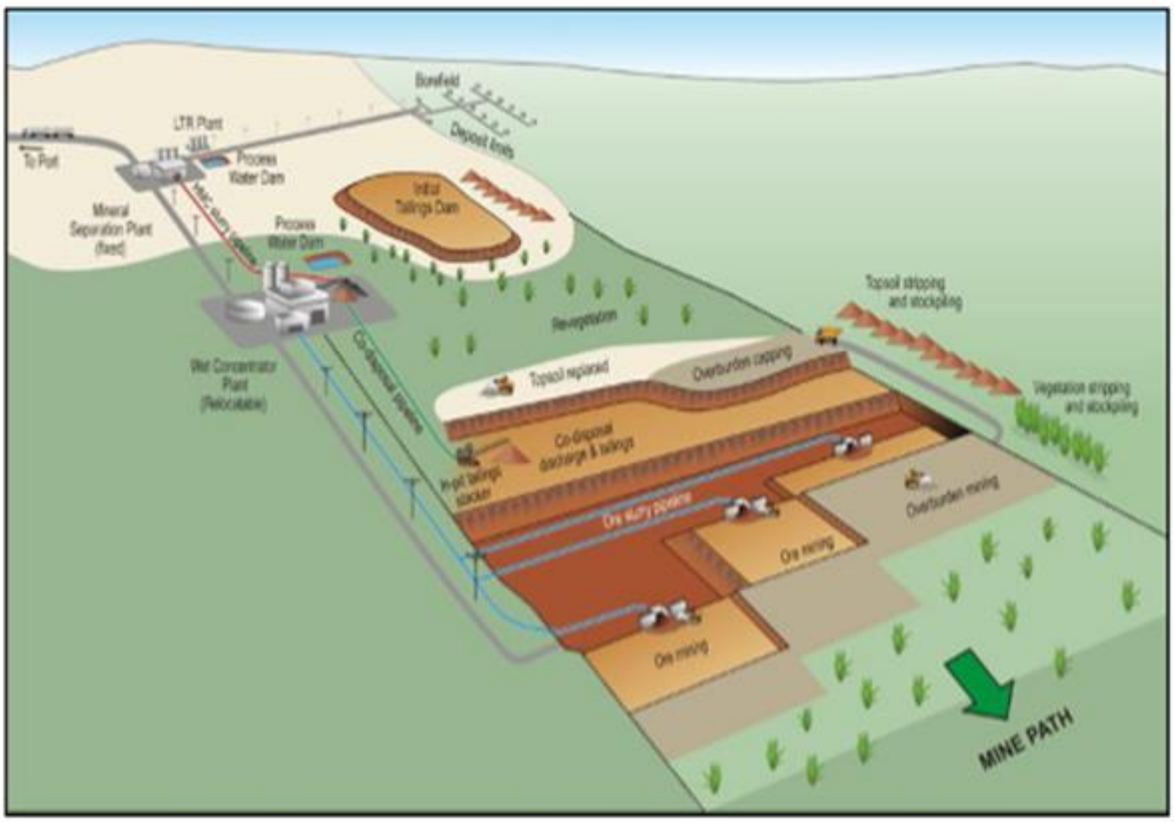


Figure 1 - Schematic of Mining Site

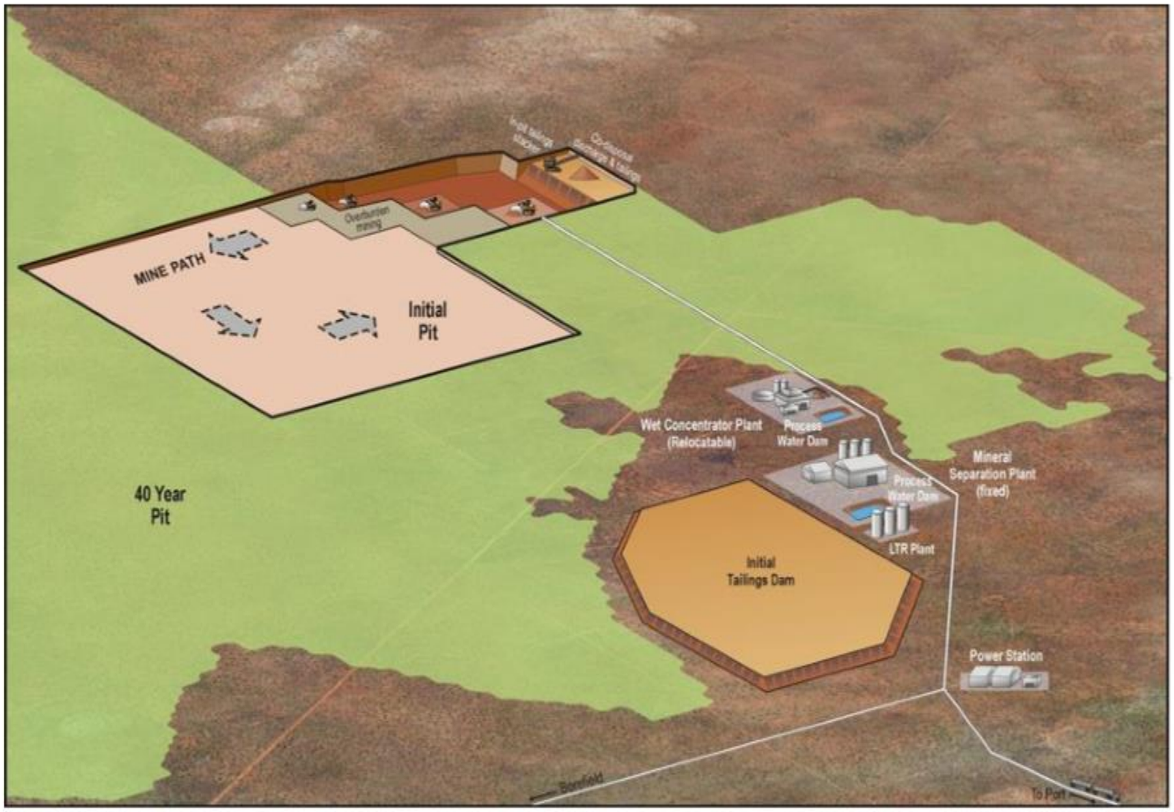


Figure 2 – Schematic Mine layout with Initial Pit and part of 40-year Life of Mine Shell

The process flow sheet comprises the following key elements:

- Mining Units
- Wet Concentrator Plant (WCP)
- Mineral Separation Plant (MSP), incorporating
  - A Concentrate Upgrade Plant
  - A HAL plant
  - A Primary Dry Circuit (HTR) plant
  - A Zircon Processing Plant
  - An Ilmenite Dry Plant
  - A Low Temperature Roasting Plant
  - An Ilmenite Magnetic Separation Plant
  - Product Load Out Sections
  -

All processing will be located at the Mine Site. All final products will be trucked to the ports at Derby or Broome where they will be stored prior to export. An option exists for all products to be transported in bulk, with zircon and a single HiTi product repackaged at a distribution centre offshore.

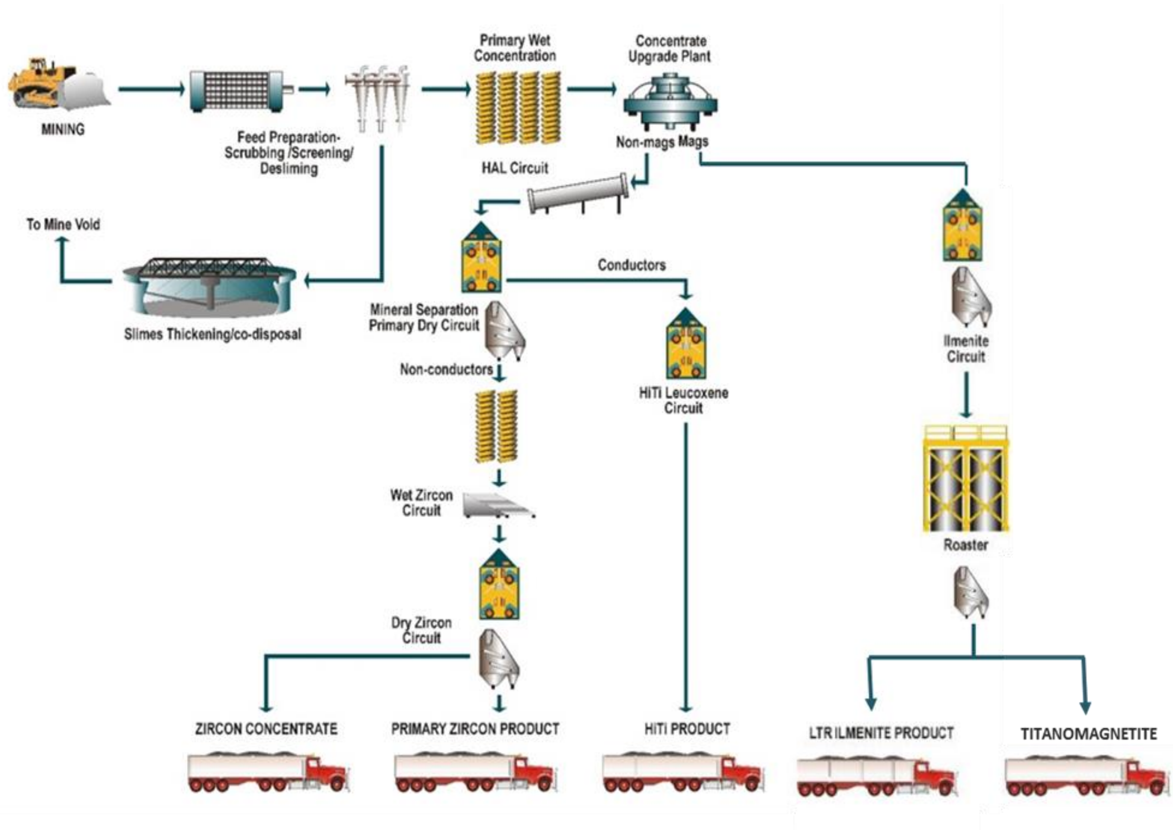


Figure 3 - Schematic of Mineral Separation Flowsheet

4.2 Radioactivity Mass Balance Assessment

The metallurgical data, as provided by the Proponent, was based on the predicted production tonnes per annum years 1-4. Radioactivity concentration for the mass balance is determined in Becquerel per gram (Bq/g) and parts per million (ppm) for Uranium and Thorium concentrations (see Figure 4).

The radioactivity concentrations of each sample have been determined using the specific activity of a gram of each radionuclide. The specific activity of natural uranium is 12445 Bq/g and for natural thorium is 4059 Bq/g. The total radioactivity is calculated as the sum of the individual uranium and thorium activity concentrations. The total radioactivity of a substance needs to be qualified to compare against prescribed total radioactivity quantities of radioactive material for the purposes of determining compliance with radiation protection regulations and the transport of radioactive material regulations.

The radioactivity balance is presented in Tables 2 to 5. The radioactivity balance is separated into ilmenite and zircon / HiTi product streams, plus the respective waste streams.

Table 2 - Uranium and Thorium Mass and Activity Balance - Ilmenite Stream

Description	Material quantity per year	Uranium	Thorium
	Tonnes per annum (tpa)	**Bq/g (ppm)**	**Bq/g (ppm)**
	1-4years	1-4years	1-4years
Ore	7,446,000	0.17 (14)	0.26 (64)
Feed Preparation Process			
Sand	5,189,862	0.10 (8)	0.18 (44)
Wet Concentration Process			
HMC	783,932	1.11 (89)	2.20 (541)
Concentrate Upgrade Process			
Mag Concentrate	282,691	0.32 (26)	1.56 (385)
HAL Process			
HAL Mags	92,239	0.61 (49)	2.34 (576)
Ilmenite Process			
Ilmenite Product	291,781	0.00 (0)	0.59 (146)
LTR Process			
Titano-Magnetite	64,192	0.39 (31)	0.25 (62)
Ilmenite Product LTR 450	225,481	0.00 (0)	0.50 (123)

Table 3 - Uranium and Thorium Mass and Activity Balance - HiTi and Zircon Streams

Description	Material quantity per year	Uranium	Thorium
	Tonnes per annum (tpa)	**Bq/g (ppm)**	**Bq/g (ppm)**
	1-4years	1-4years	1-4years
Concentrate Upgrade Process			
Non-Mag Concentrate	266,537	0.32 (26)	1.56 (385)
HAL Process			
HAL Non-Mags	108,459	2.85 (229)	4.93 (1,215)
Non-Magnetic Rougher Process			
Conductors	15,636	1.03 (85)	1.14 (280)
Non-conductors	82,736	5.50 (442)	3.93 (968)
Wet Zircon Process			
Wet Zircon Concentrate	70,236	6.17 (496)	3.80 (936)
HiTi Process			
HiTi Product	13,244	0.68 (55)	0.84 (207)
Dry Zircon			
Zircon Concentrate	44,685	5.40 (430)	3.70 (901)
Primary Zircon	44,094	4.13 (332)	0.97 (231)

Table 4 - Uranium and Thorium Mass and Activity Balance – Waste Products from Production of Ilmenite

Description	Material quantity per year	Uranium	Thorium
	Tonnes per annum (tpa)	**Bq/g (ppm)**	**Bq/g (ppm)**
	1-4years	1-4years	1-4years
Feed Preparation Process			
Oversize	1,012,656	0.82 (66)	1.11 (64)
Slimes	1,243,482	0.12 (10)	0.04 (10)
Wet Concentration Process			
Tails	4,405,930	0.04 (3)	0.06 (15)
Concentrate U*pgrade Process*			
Tails	234,705	0.10 (8)	0.40 (99)
HAL Process			
Blend Tails	7,000	0.06 (5)	0.09 (23)
Tails	58,839	0.06 (5)	0.09 (23)
Ilmenite Process			
Rejects	83,149	3.97 (319)	11.36 (2,799)
LTR Process			
Rejects	2,108	0.04 (3)	0.50 (124)
Return to Mining Void	6,955,911	0.17 (14)	0.22 (54)

Table 5 - Uranium and Thorium Mass and Activity Balance – Waste products from Production of Zircon and HiTi

Description	Material quantity per year	Uranium	Thorium
	Tonnes per annum (tpa)	**Bq/g (ppm)**	**Bq/g (ppm)**
	1-4years	1-4years	1-4years
Non-Magnetic Rougher Process			
Rejects	10,086	16.84 (1,353)	95.99 (23,644)
HiTi Process			
Rejects	2,391	2.41 (194)	2.42 (595)
Wet Zircon Process			
Tails	12,410	2.59 (208)	2.61 (643)
Dry Zircon Process			
Magnetic Rejects	3,376	11.63 (935)	38.12 (9,392)
Dry Zircon Rejects	22,856	8.80 (707)	5.50 (1,355)
Return to Mining Void	98,719	5.46 (439)	20.69 (5,097)

5 Conclusions

The radioactivity concentrations are generally greater in the zircon and HiTi process streams (Tables 3 & 5) than in the ilmenite process stream (Tables 2 & 4). There are generally higher concentrations of Thorium than Uranium throughout the process. The implications of the radioactivity concentrations are discussed further in following sections.

5.1 Product Streams

From the ilmenite product stream (Table 2), the products have relatively low radioactivity, The HMC, Magnetite Concentrate, and HAL Magnetite radioactivity concentrations all exceed the 1Bq/g definition of a radioactive substance. From the zircon and HiTi process streams (Table 3) all products have radioactivity concentrations that exceed 1 Bq/g limit, except for the HiTi product. It is also noted that none of the products exceed the radiation transport limit of 10 Bq/g and therefore will be exempt from the transport regulations.

5.2 Waste Streams

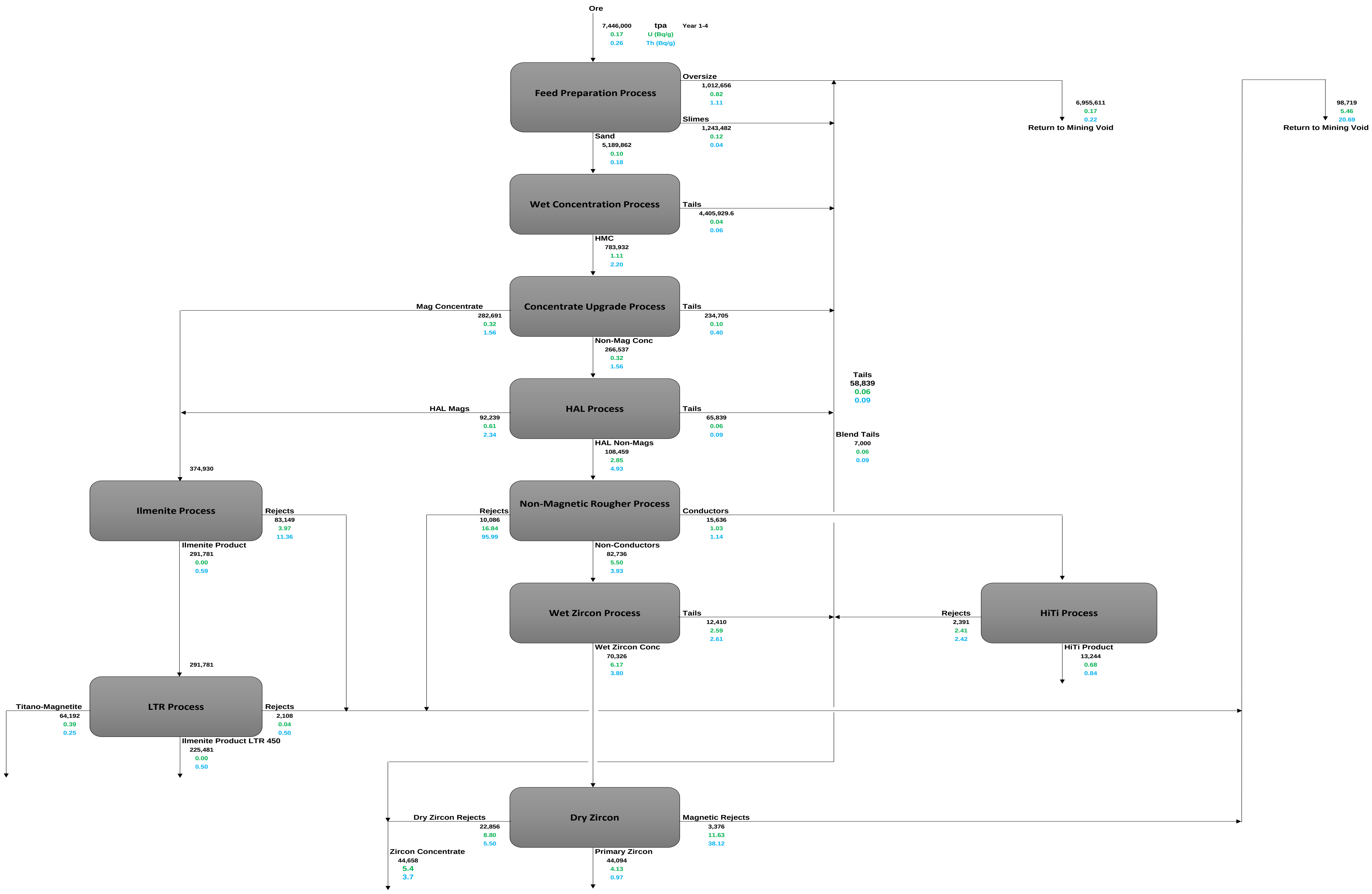
From the ilmenite waste stream (Table 4), the waste products have relatively low radioactivity, except for Ilmenite Rejects at 3.97 Bq/g uranium and 11.36 Bq/g thorium. From the zircon and HiTi waste streams (Table 5) all waste products have radioactivity concentrations that exceed 1 Bq/g definition of a radioactive substance, notably the non-magnetic rougher process rejects at 16.84 Bq/g uranium and 95.99 Bq/g thorium. It is also worthy of note that the waste product returned to the mining void has 5.46 Bq/g uranium and 20.69 Bq/g thorium. The higher level radionuclide waste streams will be diluted with low activity tails as part of a tailings and radiation management process. As a consequence, the combined waste streams returned to the mining void from the initial wet concentration stream, and the MSP waste streams contain 0.24 Bq/g uranium and 0.50 Bq/g Th.

All waste disposals will be in accordance with DER licence requirements to minimise contamination of the surrounding environment.

5.3 **Prescribed Radioactive Material**

Natural substances with a specific radioactivity of >30 Bq/g constitute prescribed radioactive material under the *Western Australian Radiation Safety Regulations (1983)*. Whilst these regulations will apply and take precedence, it is highly probable that regulatory conditions imposed on the project will mandate the Project complies with Radiation Protection Series 9 (RPS 9) *Code of Practice on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (ARPANSA 2005),* henceforth referred to as the 'Code'. The Code does not have specific concentration limits for radioactive materials, however the Safety Guide to the Code does refer to the IAEA Basic Safety Standards (IAEA 1996) that sets exclusion levels of 1 Bq/g (1000 Bq/kg) for Uranium or Thorium in bulk materials containing natural radionuclides. The Code recommends this limit as a reasonable criterion for decisions by the relevant regulatory authority on the extent of application of the Code. Based on the radioactivity calculations, the uranium-238 and the thorium-232 concentrations in the majority of intermediate, final and waste products are expected to exceed exclusion limit of 1 Bq/g and, as such, it is anticipated that certain requirements of RPS 9 Code will be applicable to the Project. Such requirements include, conducting baseline radiation monitoring, working within an approved Radiation Management Plan, Radiation Waste Management Plan (RWMP) and Radiation Transport Management Plan (RTMP) and establishing an occupational radiation monitoring and environmental dose assessment program.

Figure 4 - Process Flowsheet for Thunderbird Mineral Sands Project



Radiation Professionals

Promoting Informed Decisions

Human Health Assessment Derby Port and Transport Operations

For

Thunderbird Mineral Sands Project

Sheffield Resources

6/01/2017

Document Information

Document Number	SFX160802	**Revision**	1

Revision History

Revision Number	**Issue Date**	**Prepared By**	**Approved By**	**Approval Date**	**Revision Description**
1	24/10/2016	Stuart Parr	Anthony O'Brien	27/10/2016	Including client comments

1.1 HUMAN HEALTH – DERBY PORT AND TRANSPORT OPERATIONS

The EPA's objective in relation to human health is "*to ensure that human health is not adversely affected*".

1.1.1 Key Statutory Requirements, Environmental Policy and Guidance

Refer to Section xxx for a general summary of key statutory requirements, environmental policy and guidance for this factor.

The transport of substances is also regulated by the State through the Radiation Safety (Transport of Radioactive Substances) Regulations 2012 which requires any person who transports radioactive substances to be licensed or work under the direction and supervision of a licensee.

The Code of Practice for the Safe Transport of Radioactive Material (RPS C-2, December 2014) stipulates that the '…radiation level under routine conditions of transport shall not exceed 2 mSv/h at any point on, and 0.1 mSv/h at 2 m from, the external surface of the conveyance…'. Consideration should be given to providing an appropriate distance between the driver and the consignment to ensure that the dose rate levels at the driver location are <20 mSv/hour.

As the Derby Port will receive significant quantities of product material transported from the Mine Site, and as the product will be classed as a radioactive material under the RSA, the material received by the Port for unloading, for storage and for loading onto ships; must be regulated accordingly.

1.1.2 Assessment of Potential Impact

The mineral products transported to, stored and exported at the Derby Port will be classed as a radioactive material under the RSA. Given the radioactive nature of the mineral product, there is the potential to impact upon human health. Potential worker and public exposures to radiation include:

- Workers transporting product material from the Mine Site to Derby Port;
- Public exposure along the transport route;
- Port workers associated with Product loading, unloading and storage; and
- Public exposure at the Port.

1.1.2.1 Radiation Exposure of Transport Workers

The final product is to be trucked to the Derby Port for export by ship. The product will be appropriately contained in sealed containers during transports and therefore shall not present a potential dust issue to transport workers and the public. The main exposure pathway during routine transport operations will be from potential external gamma radiation.

Transport workers may potentially be exposed to gamma radiation from the product. The expected dose rate from standing on mineralised material can be expressed as 0.0058 µGy/h/ppm of uranium and 0.0025 µGy/h/ppm of thorium in the material at 1 m and 0.7 Sv/Gy (UNSCEAR 2008).

The average concentration of uranium and thorium for all products is 79.48 ppm and 170.25 ppm respectively, from the 'Revised Radionuclide Mass Balance and Regulatory Summary' (SGS 2016). Therefore, the calculated dose rate is 0.0058 x 0.7 x 79.48 + 0.0025 x 0.7 x 170.25 = 0.62 µSv/h at 1 m.

Truck drivers are more likely to be exposed to radiation doses from the product for the greatest duration. The dose rate to a truck driver will reduce approximately according to the following geometric function. It has been assumed that the load is, symmetrical, with a radius of 2.5 metres.

$$I = I_0 \Big/ \left[\frac{ln\left(\frac{R^2 + {d_0}^2}{{d_0}^2}\right)}{ln\left(\frac{R^2 + d^2}{d^2}\right)} \right]$$

Where:

- ***I*** = the radiation level at a point ***d*** metres from the source;
- $\boldsymbol{I_0}$ = the radiation level at a point $\boldsymbol{d_0}$ metres from the source;
- $\boldsymbol{d_0}$ = dose rate assumed at 1 metre from the source (0.62 µSv/h); and
- ***R*** = the radius of the source area (assumed as 2.5 m)

It has been assumed that the driver will be seated 1.5 m from the load, and therefore the dose rate will reduce to <0.5 µSv/h.

A truck driver would be expected to have a product load only in one direction of the journey between the Mine Site and the Derby Port, and therefore based on a nominal working year of 2,000 hours, the truck driver may be exposed to the product for up to 1,000 hours. Therefore, the truck driver's estimated annual dose would be <0.5 mSv/year.

This is a conservative estimate as it does not take into account shielding that is provided by the product container and that drivers will not necessarily spend their whole time transporting the product. Actual doses are expected to be lower.

On this basis of a conservative assumption, the maximum external gamma dose to the transport workers is estimated to be 0.5 mSv/year.

1.1.2.2 Public Radiation Exposure during Transport

During the routine trucking of the product between the Mine Site and the Derby Port, there is the potential for members of the public to be exposed to gamma radiation on a short-term basis (i.e. a maximum of several hours per year). The exposure would therefore only be a fraction of the maximum external gamma dose of 0.5 mSv/year estimated for transport workers. Given that the public dose rate limit is 1 mSv/year (i.e. twice the exposure of a transport worker), there are no public impacts expected.

In the event of an accident and a release of the mildly radioactive product material, an Emergency Response Plan (ERP) would be initiated. The priorities of the ERP are first aid to any injured and containment of any product spillage. The area would be segregated from the public and any spilled product covered and contained. The potential dose from such an incident is expected to be very low due to the relatively short potential exposure period.

1.1.2.3 Radiation Exposure of Port Workers

There are three main pathways for potential radiation exposures of workers: external gamma exposure, inhalation of radionuclides in dusts and inhalation of radon decay products. This section discusses the estimated doses that may be received by the Derby Port workforce.

External Gamma Exposure

Derby Port workers may potentially be exposed to gamma radiation from the product. The expected dose rate from standing on mineralised material can be expressed as 0.0058 µGy/h/ppm of uranium and 0.0025 µGy/h/ppm of thorium in the material at 1 m and 0.7 Sv/Gy (UNSCEAR 2008).

The average concentration of uranium and thorium for all products is 79.48 ppm and 170.25 ppm respectively, from the 'Revised Radionuclide Mass Balance and Regulatory Summary' (SGS 2016). Therefore, the calculated dose rate is 0.0058 x 0.7 x 79.48 + 0.0025 x 0.7 x 170.25 = 0.62 µSv/h at 1 m.

The largest accumulation of the product material will be when the product is held within the storage facility. Therefore, based on a nominal working year of 2,000 hours, it is estimated that annual dose to a port worker would be 1.24 mSv/year. This is a conservative estimate as it assumes that the port workers will spend their whole time in vicinity of the storage facility. Actual doses are expected to be lower.

On this basis of a conservative assumption, the maximum external gamma dose to the port workers is estimated to be 1.24 mSv/year.

Inhalation of Radionuclides in Dust

During the unloading and loading process, particularly at the storage facility, the product may produce dust containing radionuclides which have the potential to result in an internal dose exposure of the port workers.

For this assessment, a conservative estimate of the long-term average dust concentrations has been made. Published data of 3,000 personal dust samples from 157 quarrying operations has been used (Creely et al., 2006). From this data 99% of the 3,000 measurements taken were of a concentration of less than 3 mg/m^3.

The average specific activities of uranium and thorium in the products is assumed to be 0.99 Bq/g and 0.78 Bq/g respectively (from the 'Revised Radionuclide Mass Balance and Regulatory Summary', (SGS

2016)). Assuming a breathing rate of 1.2 m^3/h for a nominal working year of 2,000 hours, and using the recognised dust conversion factors from ICRP 1994, the resulting dose received from inhaling dust is approximately 0.38 mSv/year.

This estimate is very conservative as port workers are unlikely to be exposed to dusty conditions for a full working day and dust levels are likely to be below the estimated concentrations for most of the annual period.

Inhalation of Radon Decay Products

Exposures to radon decay products are dependent on two main factors: the amount of radon that is being produced within the storage facility and the natural ventilation effects of the facility.

For example, the radon release rate from the Yeelirrie uranium mine deposit has been estimated to be 50 Bq/m^2/s per %U (Mason 1982, BHP Billiton 2009, ERA 2014). For an average uranium grade of ore of 1,600 ppm U, the radon emission rate was calculated to be 8 Bq/m^2/s.

By comparison, for the zircon concentrate product (the most active material), the average concentration of uranium and thorium in the product is 429 ppm U and 934 ppm Th respectively, therefore based on the above assumptions, the radon emission rate would be 2.15Bq/m2/s.

The total surface area of the proposed storage facility is 15000 m^2 with up to ~40000 tonnes of mineral products. However, the zircon concentrate will be only ~14% of the total products produced. For 429ppm U and 1096 ppm Th, and an emanation rate factor of 2.15Bq/m^2/s, the total emanation into a storage cell would be ~4500Bq/s or ~16 MBq/hour. Assuming that the storage cell is 5 metres tall, the volume of the storage cell would be ~10500m^3. The average annual wind speed in the area is 3.8m/s (based on data for Broome Airport from the Bureau of Meteorology, (http://www.bom.gov.au). As the product will be stored within a facility which is only accessed through doors to allow worker and vehicle access, it has been conservatively assumed that the air flow through the storage cell is 2m/s which will approximate to around 160 air changes per hour.

The radon equilibrium concentration is calculated using the following equation (derived from Cember 2009):

Radon concentration (Bq/m^3) = ER/ (CV x VR)

Where:

- ***ER*** = the radon generation rate for a cell in Bq/h;
- ***CV*** = the volume of the cell (m^3); and
- ***VR*** = the number of air changes per hour.

Therefore, the radon concentration was calculated to be 9.8 Bq/m^3.

In 1990, ARPANSA conducted a nationwide survey of more than 3,300 Australian homes to determine the radiation dose to the Australian population from exposure to natural background radiation, including radon. Based on this survey, the average concentration of radon in Australian homes is about 10 Bq/m^3. Therefore, using very conservative assumptions, the potential radon release is equivalent to natural background levels in Australia and therefore will have no significant impact on human health.

Total Dose

The estimated average annual dose to the port workers is 1.24 mSv from gamma and 0.38 mSv from inhalation of potentially radioactive dust (alpha), resulting in a total of conservative dose estimate of 1.62 mSv/year.

The assumptions used in this assessment are very conservative. The derived external gamma doses to the port workers do not take account of the shielding effects of the facility walls, any dust suppressions systems put in place, the workers wearing appropriate PPE. In practice, it is expected that the total dose to the port workers will be less than 1.62mSv/year. This is well below the dose rate limit for radiation workers of 20 mSv/year and therefore is unlikely to result in human health impacts.

1.1.2.4 Public Radiation Exposure at the Port

Given that the public will not have access to the product storage facility there are only two primary potential exposure pathways:

- External gamma radiation; and
- Inhalation of potential radionuclides in the dust.

External Gamma Exposure

The main source of potential external gamma radiation would be the stockpile of product within the storage facility. It has been assumed that the stockpile is, symmetrical, with a radius of 5 m.

$$I = I_0 \Big/ \left[\frac{ln\left(\frac{R^2 + {d_0}^2}{{d_0}^2}\right)}{ln\left(\frac{R^2 + d^2}{d^2}\right)} \right]$$

Where:

- ***I*** = the radiation level at a point ***d*** metres from the source;
- ***I_0*** = the radiation level at a point ***d_0*** metres from the source;
- ***d_0*** = dose rate assumed at 1 m from the source (0.62 µSv/h); and
- ***R*** = the radius of the source area (assumed as 5 m).

It has been assumed that the nearest member of the public would be 10 m away from the stockpile, and therefore the dose rate will reduce to <0.05 µSv/h. Therefore, based on a member of the public being exposed for 5 minutes every day for one year whilst walking past the storage facility, the estimated dose was calculated to be 0.002 mSv/year. This is a conservative estimate as it does not take into account shielding that is provided by the storage facility. Actual doses are expected to be lower.

Dust Inhalation

Dust emissions from the Project are expected to be primarily generated from loading and unloading materials within the storage facility and for transport by an enclosed conveyor system onto ships. Transports are unloaded within the storage facility and the facility doors are only opened when transports arrive and leave the facility. Therefore, for the majority of the operations any potential dust will be contained within the storage facility or the conveyor system. Using the assumption of an average worker inhalation dose of 0.38 mSv/year calculated previously, and equate that to a member of the public being exposed for 5 minutes per day for one year whilst walking past the storage facility, the estimated dose was calculated to be 0.006 mSv/year. Hence it is judged that any potential dust inhalation impacts on the public will be minimal.

Total Dose

The estimated average annual dose to the port workers is 0.002 mSv from gamma and 0.006 mSv from inhalation of potentially radioactive dust (alpha), resulting in a total of conservative dose estimate of 0.008 mSv/year. This is well below the public dose rate limit of 1 mSv/year and therefore is unlikely to result in human health impacts.

1.1.3 Management Measures

1.1.3.1 Transport Operations

Under Section 303 of the Code, for occupational exposures arising from transport activities, if doses are between 1 and 20 mSv in a year, a dose assessment programme via workplace and individual monitoring shall be conducted and appropriate records are kept.

The Proponent will be responsible for the health, safety and welfare of its employees and will have a duty of care to the public and the environment for all Project activities. The transport activities between the Mine Site and the Derby Port will be under ARPANSA transport regulations and the Proponent will be required to engage the services of a RSO to implement a Radiation Transport Management Plan (RTMP) on behalf of the Proponent. The RTMP must be endorsed by the Radiological Council as it will define the requirements of periodic monitoring for both personal and environmental radiation levels in the preparation of transports, the road transports themselves, and on receipt of the transports at the Derby Port; the findings of which will be formally reported to Radiological Council for consideration.

It is the Proponent’s responsibility to ensure that transport documents are generated correctly and completely and must include the following information:

- Consignment specifics;
- A declaration regarding the consignment’s contents, packaging and condition;
- Information for carriers and actions to be taken in the event of an emergency;
- Consideration of appropriate dose rate levels and the distance between the product and the driver’s seat (<20 mSv/hour); and
- Consignments shall be securely stowed.

It should be noted that a radioactive material is considered exempt from the Code of Practice for Safe Transport of Radioactive Material (RPS-C2, 2014) if specific activity of the consignment does not exceed 10 Bq/g.

Under Section 107 (f) of the Code, "*…natural material and ores containing naturally occurring radionuclides, which may have been processed, provided the activity concentration does not exceed 10 times the values specified in Table 2…*" of the Code, i.e. 10 times the specific activity concentration limits for natural uranium and thorium (1 Bq/g) or 10 Bq/g. For an exempt consignment under Section 423 b) ii) of the Code, markings are not required on the external surfaces of the consignment "…provided that such products are transported in a package that bears the marking "RADIOACTIVE" on its internal surface in such a manner that a warning of the presence of radioactive material is visible on opening the package…".

It should also be noted that as the specific activity is likely to exceed 1 Bq/g, then the product is still classified as a radioactive substance under the RSA for processing at the Mine Site and storage at the Derby Port.

Radiation Monitoring Regime

During transports from the Mine Site, periodic occupational and environmental monitoring should be initiated and agreement sought from the Radiological Council as to the schedule of the surveillance period. Monitoring may include (though not exclusively):

- Environmental gamma radiation levels for transport clearances from the Mine Site using personal and hand-held monitors;
- Environmental alpha (dust) radiation levels for transport clearances from the Mine Site using wipe tests and hand-held monitors; and
- Personal gamma external dose monitoring for workers (in particular the drivers) involved in transportation using personal and hand-held monitors.

It is intended that the product will be transported as Low Specific Activity (LSA) material, e.g. LSA-I type package, which includes uranium and thorium type ores.

1.1.3.2 Derby Port Operations

The Proponent will be responsible for the health, safety and welfare of its employees and will have a duty of care to the public and the environment for all activities associated with the Thunderbird Mineral Sands Project. The activities at the Derby Port will be registered under the RSA with the Radiological Council and Proponent will be required to engage the services of a RSO to implement a RMP on behalf of the Proponent. The RMP must be endorsed by the Radiological Council as it will define the requirements of periodic monitoring for both personal and environmental radiation levels, the findings of which will be formally reported to Radiological Council for consideration.

The Proponent will ensure that dust suppression strategies and appropriate PPE will be a priority during operations as part of an overarching occupational health and safety program.

Radiation Monitoring Regime

Radiation monitoring will be conducted periodically at the Derby Port. The first step to any periodic radiation monitoring is to undertake a background survey to establish an environmental baseline for radiation levels along the proposed transport routes, unloading/loading areas and storage areas prior to any Project operations taking place.

The principal purpose of undertaking environmental monitoring is to understand natural background variation in radiation levels and through periodic monitoring during port operations, evaluate what impacts the Project operations have upon these ambient levels. It is also necessary to establish the rehabilitation targets when the Project operations have ceased.

During operations at the Port, periodic occupational and environmental monitoring should be initiated and agreement sought from the Radiological Council as to the schedule of the surveillance period. Monitoring may include (though not exclusively):

- Environmental gamma radiation levels for transport routes around the Port, at unloading/loading areas and around the storage facility using personal and hand-held monitors;
- Airborne dust levels for the presence of alpha radiation, for transport routes around the Port and at unloading/loading areas using static and/or mobile dust monitors;
- Radon/thoron levels during storage of the product for the presence of alpha radiation using static monitors, where appropriate ventilation is required;
- Personal gamma external dose monitoring for workers involved in transportation, unloading/loading activities and storage access using personal and hand-held monitors; and
- Personal alpha internal dose monitoring for workers involved in unloading/loading activities and storage access using personal monitors, where there is a potential for dust generation.

1.1.4 Predicted Outcome

The predicted dose to transport workers and port workers was conservatively estimated to be 0.5 mSv/year and 1.62 mSv/year respectively which are both well below the dose rate limit for radiation workers of 20 mSv/year. The predicted dose to a member of the public as a result of transport operation was considered to be extremely low and well below the public limit of 1 mSv/year.

All transport and port activities associated with the Project will be undertaken in accordance with the RSA and Radiation Safety (Transport of Radioactive Substances) Regulations 2012. The storage facility will be registered under the RSA and the Proponent will engage a RSO on the implementation of a RMP, and to implement periodic personal and environmental monitoring of radiation levels for formal reporting to the Radiological Council.

Implementation of these arrangements will ensure that any potential radiation doses to workers and the public will be monitored, controlled and minimised to ensure that all legal requirements are met, that radiation doses are below limits and that doses are managed to be ALARA.

Based on the information provided above, Project transport and port activities are not expected to result in impacts to human health. The EPA Objective for this factor can therefore be met.

Human Health Assessment Mine Site Operations

For

Thunderbird Mineral Sands Project

Sheffield Resources

6/01/2017

Document Information

Document Number	SFX160802	**Revision**	1

Revision History

Revision Number	**Issue Date**	**Prepared By**	**Approved By**	**Approval Date**	**Revision Description**
1	24/10/2016	Stuart Parr	Anthony O'Brien	27/10/2016	Including client comments

1.1 HUMAN HEALTH – MINE SITE OPERATIONS

The EPA's objective in relation to human health is "*to ensure that human health is not adversely affected*".

1.1.1 Key Statutory Requirements, Environmental Policy and Guidance

State

In Western Australia the current regulatory framework for the management of radioactive substances is the *Radiation Safety Act 1975* (RSA) with three subsidiary regulations:

- Radiation Safety (General) Regulations 1983;
- Radiation Safety (Qualifications) Regulations 1980; and
- Radiation Safety (Transport of Radioactive Substances) Regulations 2012.

The Radiological Council is an independent statutory authority appointed under the RSA to assist the Minister for Health to protect public health and to maintain safe practices in the use of radiation. The RSA regulates the possession, storage, use, handling or disposal of, or other dealing with, any radioactive substances, irradiating apparatus and certain products that use radiation, through its registration and licensing system.

The RSA states that a premise, at which radioactive substances are manufactured, used or stored, must be registered. Through subsidiary legislation like the Radiation Safety (General) Regulations 1983, specific guidance is given for Radiation Safety Officers (RSOs) on the implementation of a Radiation Management Plan (RMP), to periodically monitor radiation levels and to formal report their findings to regulators.

As a Mine Site, the Project will be regulated by the Department of Mines and Petroleum (DMP) under Part 16 of the Radiation Safety of the Mines Safety and Inspection Regulations 1995 (MSIR).

Naturally occurring radioactive elements thorium and uranium are commonly associated with heavy minerals, in particular with the mineral monazite. The concentration of thorium and uranium in Heavy Mineral Concentrate (HMC) is significantly dependent on the percentage of the undiluted mineral monazite. This mineral is a main source of possible radiation exposure, thus radiation risk is directly proportional to the percentage of monazite in the HMC, and the concentration in which it exists within the processing plant.

Monazite content in mineral sand deposits is typically ~0.1% of the bulk material and increases to approximately 0.5% within the HMC. Although the monazite typically represents less than one percent of the total volume of mineral sands processed, the DMP has deemed that the operations fall under Part 16 of the MSIR 1995. Also Regulation 16.7 of the MSIR requires that a RMP be prepared for such activities.

The Mine Site processing operations will generate significant quantities of waste material that may contain monazite:

- Oversize, tails, rejects etc. - for return to the mining voids, and
- Product material.

Both the waste and product materials must be regulated as the materials are classed as a radioactive substance under the RSA. A Radiation Waste Management Plan (RWMP) is required, which is to outline the arrangements for managing the waste material for return to the mining void under the rehabilitation programme, and to ensure the worker and public radiation exposures are managed in accordance with the legislation.

The Project falls under the provision of Part 16 of the MSIR 1995. Regulation 16.18 requires that the manager of a mine site must ensure that any employee at the mine does not receive a dose of radiation exceeding:

- Effective dose limit in a single year of 50 milli-Sievert (mSv);
- Effective dose limit over a period of 5 consecutive years of 100 mSv; and
- Therefore, the derived exposure limit is 20 mSv/year.

Regulation 16.19 requires that the manager of a mine must ensure that a member of the public does not receive a dose of radiation, as a consequence of the mining operation, exceeding an effective dose limit of 1 mSv/year.

To ensure compliance with these limits, monitoring and investigation levels will be established for Project operations and personnel. Potential exposures of surrounding communities are also monitored, and the contribution from any operations must remain very low in comparison with both public dose limits and the natural background radiation levels.

Commonwealth

The *Australian Radiation Protection and Nuclear Safety Act 1998* (ARPANS Act) complements State legislation by regulating agencies and departments which fall under Commonwealth jurisdiction. As with State legislation, the ARPANS Act creates its own regulatory authority, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). ARPANSA is recognised as the national authority on radiation protection in Australia.

The International Commission on Radiological Protection (ICRP) sets two limits for radiation exposure above that received from natural background or medical exposure. These limits are 1 milli-Sievert (mSv) per year for the public and non-radiation workers, and 20 mSv per year for radiation workers.

The exposures of surrounding communities are also monitored, and the contribution from any operations must remain very low in comparison with both public dose limits and the natural background radiation levels.

1.1.2 Assessment of Potential Impact

Waste and product materials generated by the mining and manufacturing process has the potential to impact upon human health. Potential exposures to radiation include:

- Mining Operations;
- Processing Plants;
- Mine Site Waste Product Storage, e.g. Tailings; and
- Returns of Waste Product to Mining Voids.

1.1.2.1 Radiation Exposure of Mine Workers

There are three main pathways for radiation exposures of mine workers: external gamma exposure, inhalation of radioactive dusts and inhalation of radon decay products. This section discusses the estimated doses that may be received by Mine Site workforce.

External Gamma Exposure

Mine workers may potentially be exposed to gamma radiation from the product. The expected dose rate from standing on mineralised material can be expressed as 0.0058 µGy/h/ppm of uranium and 0.0025 µGy/h/ppm of thorium in the material at 1 m and 0.7 Sv/Gy (UNSCEAR 2008).

For the mine site as a whole, the average concentration of uranium in the ore is 14 ppm and 64 ppm for thorium, from the 'Revised Radionuclide Mass Balance and Regulatory Summary', SGS (June 2016). Therefore, the calculated dose rate is 0.0058 x 0.7 x 14 + 0.0025 x 0.7 x 64 = 0.17 µSv/h at 1 m. A worker who spends 2,000 hours per year at a distance of 1 m from the ore would have a predicted annual dose of 0.34 mSv/year.

This is a conservative estimate as it does not take into account shielding that is provided by the mining equipment or the fact that miners do not spend all of their working time within 1 m of the ore. Actual doses are expected to be much lower.

Based on this conservative assumption, the maximum external gamma dose to the mine workers is estimated to be well under the derived limit of 20 mSv/yr – at approximately 0.34 mSv/year.

Inhalation of Radionuclides in Dusts

Drilling, blasting and handling of the ore and waste rock produces dust containing radionuclides, which have the potential to result in internal dose exposure of the mine workers.

For this assessment, a conservative estimate of the long-term average dust concentrations has been made. Published data of 3,000 personal dust samples from 157 quarrying operations has been used (Creely et al., 2006). From this data 99% of the 3,000 measurements taken were of a concentration less than 3 mg/m^3.

A dose received from inhaling dust is calculated to be approximately 0.11 mSv/year based on the following conservative assumptions:

- The specific activity of uranium in the ore is 0.17 Bq/g and 0.26 Bq/g thorium, from the 'Revised Radionuclide Mass Balance and Regulatory Summary' (SGS 2016);

- A breathing rate of 1.2 m^3/h for 2,000 hours per year; and
- The recognised dust conversion factors from ICRP 1994.

This estimate is considered conservative as mine site workers are unlikely to be exposed to dusty conditions for a full working day and it is likely that dust concentrations will be below the estimated concentrations for most of the year.

The Proponent will ensure that dust suppression strategies and appropriate Personal Protective Equipment (PPE) will be a priority during operations as part of an overarching occupational health and safety program.

Inhalation of radon decay products

Exposures to radon decay products are dependent on two main factors: the amount of radon that is being introduced into the mine air and the rate of ventilation.

For example, the radon release rate from the Yeelirrie uranium mine deposit has been estimated to be 50 Bq/m^2/s per %U (Mason 1982, BHP Billiton 2009, ERA 2014). For an average uranium grade of ore of 1,600 ppm U, the radon emission rate was calculated to be 8 Bq/m^2/s.

By comparison, the average concentration of uranium and thorium in the ore is 14 ppm U and 64 ppm Th respectively, therefore based on the above assumptions, the radon emission rate would be 0.07 Bq/m^2/s. (Note that the uranium grade of ore is used because it is assumed that the base of the open cell from which the radon is emitted is ore).

For a mining void area of 50 ha, the emanating surface area is 50 ha plus the wall surface area. Assuming the void is square, the walls of the void will be approximately 700 m long and the design depth is 10 m. This gives a total surface area of 528,000 m^2.

For an average ore grade of 14 ppm uranium and 64 ppm thorium, and an emanation rate factor of 50 Bq/m^2/s per %U, the total emanation into the void of 36,960 Bq/s or 133 MBq/hour.

The ventilation rate was calculated from the following expression (Thompson 1994):

T=33.8*(V/U.L.W)*(0.7cos(x) +0.3)

Where:

- T is the air residence time;
- V is the pit volume (m^3);
- U is the wind velocity (m/s);
- L and W are the pit length and width (m); and
- x is the angle between the mine axis and the wind velocity.

Assuming an average wind speed of 2.5 m/s and using the above formula, together with the mine dimensions, gives a ventilation rate approximately 30 air changes per hour.

The radon equilibrium concentration is calculated using the following equation (derived from Cember 2009):

Radon concentration (Bq/m^3) = ER/ (VV x VR)

Where:

- ER = the radon generation rate for the void in Bq/h;
- VV = the void volume (m^3); and
- VR = the number of air changes per hour.

This gives an average concentration of 0.84 Bq/m^3. If the equilibrium factor between radon decay products (RnDP) and radon is 0.4, then the resulting annual average RnDP concentration is 0.24 $\mu J/m^3$. Using the dose conversion factor in ARPANSA (2005), the RnDP dose for a miner for a full working year is approximately 0.7 mSv.

It is noted that the ICRP (ICRP 2015) has recently recommended a new dose conversion factor for RnDP, which is equivalent to 2.8 Sv/J and is an increase by a factor of 2.4 over the current dose conversion factor. While the new factor has yet to be adopted in Australia, applying the new factor to the estimated doses for the worker, results in a revised estimate of 1.7 mSv/year.

Total Dose

The estimated average annual dose to miners is 0.34 mSv from gamma, 0.11 mSv from inhalation of radioactive dust, and 1.7 mSv from inhalation of radon decay products, resulting in a total of approximately 2.15 mSv/year.

The assumptions used in this assessment are very conservative. A minimal allowance for such factors as shielding of gamma radiation by heavy equipment has been allowed for and it is expected that a lower dust exposure due to cab air-conditioning would occur.

The radiation dose history of all Australian uranium mine workers is recorded on the Australian National Radiation Dose Register (ANRDR). More than 31,700 individual workers from the uranium mining industry are recorded on the database which is maintained and managed by ARPANSA.

The register tracks a worker's cumulative dose based on data provided by the employer. It assists in minimising the possibility of a worker receiving a dose greater than the Australian dose limit when moving from one employer to another. The data is available to workers and is also used to generate annual statistics relating to exposure trends to assist in the optimisation of radiation protection.

In 2013, approximately 95% of workers received a dose less than 3.5 mSv/y and 67% of workers received a dose below 0.5 mSv/y. (ARPANSA, 2013).

1.1.2.2 Processing Plant Workers

Ore will be trucked to the Processing Plant from the mine. The Processing Plants, will incorporate:

- Wet Concentrator Plant;
- Mineral Separation Plant;
- Low Temperature Roasting Plant;
- Magnetic Separation Plant; and
- Product Load-Out Plant.

Throughout the process of extracting the required mineral products throughout the concentration, heating and separation procedure and the generation of the waste by-products; radioactive material is generated. Therefore, the process plant workers may potentially be exposed to radiation from the product and waste material.

External Gamma Exposure

The expected dose rate from mineralised material can be expressed as 0.0058 µGy/h/ppm of uranium in the material at 1 m and 0.7 Sv/Gy (UNSCEAR 2008).

The average concentration of uranium and thorium for all products is 79.48 ppm and 170.25 ppm respectively, from the 'Revised Radionuclide Mass Balance and Regulatory Summary', (SGS 2016). Therefore, the calculated dose rate is 0.0058 x 0.7 x 79.48 + 0.0025 x 0.7 x 170.25 = 0.62 µSv/h at 1 m.

The gamma dose rates will be greatest when the product material is accumulated during the process. Therefore, based on a nominal working year of 2,000 hours, it is estimated that annual dose to a process worker would be 1.24 mSv/year. This is a conservative estimate as it does not take into account shielding that is provided by the storage container walls, and that the process plant workers will not necessarily spend their whole time in vicinity of the processing equipment. Actual doses are expected to be lower.

On this basis of a conservative assumption, the maximum external gamma dose to process plant workers is estimated to be 1.24 mSv/year

Inhalation of Radionuclides in Dusts

Average annual dust concentrations of 2 mg/m^3 have been assumed to exist in the processing area. This assumption is based on dust concentrations in modern processing facilities being generally low because there is a focus on dust minimisation in design and operations and during actual operations, process materials are usually in slurry form (also known as wet processing).

For the wet processing part of the concentrator, it has been assumed that average dust concentrations are less than for the screening and ore handling parts of the concentrator area (due to process materials only being in a slurry form). The dust dose in this area is conservatively assumed to be 1 mg/m^3.

Assuming the average specific activities of uranium and thorium in the products is 0.99 Bq/g and 0.78 Bq/g respectively, from the 'Revised Radionuclide Mass Balance and Regulatory Summary' (SGS 2016). Assuming a breathing rate of 1.2 m^3/h for 2,000 hours per year and using the recognised dust conversion factors from ICRP 1994, the resulting dose received from inhaling dust is approximately 0.13-0.25 mSv/year, for concentrations of 1-2 mg/m^3.

This estimate is conservative as process plant workers are unlikely to be exposed to dusty conditions for a full working day and it is likely that dust levels will remain below the estimated concentrations for most of the annual period.

The Proponent will ensure that dust suppression strategies and appropriate PPE will be a priority during operations as part of an overarching occupational health and safety program.

Inhalation of Radon Decay Products

The estimated doses from inhalation of radon decay products for plant workers are based on the modelled radon concentrations from the air quality modelling. This shows an annual average radon concentration of 100 Bq/m^3 at the processing plant location.

For a working year of 2,000 hours, the dose to processing plant workers is calculated to be 0.6 mSv/y using the dose conversion factor from ARPANSA (2005). Using the proposed new ICRP dose conversion factor (ICRP 2015), the estimate dose is 1.5 mSv/year.

Total Dose

The estimated average annual dose to the process plant workers is 1.24 mSv from gamma, 0.25 mSv from inhalation of potentially radioactive dust (alpha), and 1.5 mSv/year from radon; resulting in a conservative total dose estimate of 3 mSv/year.

The assumptions used in this assessment are very conservative. The derived external gamma doses to the process plant workers do not take account of the shielding effects of the processing equipment, any dust suppressions systems put in place, and the workers wearing appropriate PPE. In practice, it is expected that the total dose to the process plant workers will be less than 3 mSv/year. Monitoring will confirm the actual exposure levels.

1.1.2.3 Public Radiation Exposure

The nearest point of general public access is the Great Northern Highway, located 32 km away from the mine site. Visitors may be present on site on occasions, however this is expected to be over a short timeframe.

Gamma radiation and dust inhalation exposure to members of the public from the product is considered to be negligible due to short exposure timeframes (for visitors) and the significant distances between the product and the public.

1.1.3 Management Measures

All activities at the Mine Site will be undertaken in accordance with the RSA and Radiation Safety (Transport of Radioactive Substances) Regulations 2012.

The Proponent will be responsible for the health, safety and welfare of its employees and will have a duty of care to the public and the environment for all activities associated with the Thunderbird Mineral Sands Project. The activities at the Mine Site will be registered under the RSA with the Radiological Council and DMP, and the Proponent will be required to engage the services of a RSO to implement a RMP and RWMP on behalf of the Proponent. The RMP and RWMP must be endorsed by the Radiological Council and DMP as it will define the requirements of periodic monitoring for both personal and environmental radiation levels, the findings of which will be formally reported to Radiological Council and DMP for consideration.

1.1.3.1 Radiation Monitoring Regime

Radiation monitoring will be conducted periodically at the Mine Site. The first step to any periodic radiation monitoring is to undertake a background survey to establish an environmental baseline of radiation levels for the proposed Mine Site activities; e.g. the areas destined to become the mining voids, prior to any operations associated with the Project taking place.

The principal purpose of undertaking environmental monitoring is to understand natural background variation in radiation levels and through periodic monitoring during Mine Site operations, evaluate what impacts the Project operations have upon these ambient levels. It is also necessary to establish the rehabilitation targets when waste is returned to the mine voids and when Project operations have ceased. Background radiation monitoring will include (though not exclusively):

- Activity concentration of long-lived, alpha-emitting radionuclides in the dust;
- Concentration of radon in air;
- Concentration of radon decay products in air;
- Gamma dose rate in air 1 m above the ground surface;
- Gamma dose rate in air (derived from aerial gamma surveys);
- Concentration of radionuclides in soil;
- Concentration of radionuclides in groundwater; and
- Concentration of radionuclides in surface waters.

During operations at the Mine Site, periodic occupational and environmental monitoring should be initiated and agreement sought from the Radiological Council and DMP as to the schedule of the surveillance period. Monitoring may include (though not exclusively):

- Environmental gamma radiation levels for around the Mine Site using personal and hand-held monitors;
- Airborne dust levels for the presence of alpha radiation for the Mine Site operations using static and/or mobile dust monitors;
- Radon/thoron levels for the presence of alpha radiation for the Mine Site operations using static monitors;
- Personal gamma external dose monitoring for workers involved in Mine Site operations and within the Processing Plants using personal and hand-held monitors; and
- Personal alpha internal dose monitoring for workers involved in Mine Site operations and within the Processing Plants using personal monitors, where there is a potential for dust generation.

1.1.4 Predicted Outcome

The predicted dose to mine workers and process plant workers was conservatively estimated to be 2.15 mSv/year and 3 mSv/year respectively which is below the dose rate limit for radiation workers of 20 mSv/year. The predicted dose to a member of the public was considered to be negligible and certainly well below the public limit of 1 mSv/year.

The Mine Site will be registered under the RSA and the Proponent will engage a RSO on the implementation of a RMP and a RWMP, to implement periodic personal and environmental monitoring of radiation levels for formal reporting to the Radiological Council and the DMP.

Implementation of these arrangements will ensure that any potential radiation doses to workers, the public and the environment will be monitored, controlled and minimised to ensure that all legal requirements are met, that radiation doses are below limits and that doses are managed to be As Low As Reasonably Achievable (ALARA).

Based on the information provided above, activities at the Project Mine Site are not expected to result in impacts to human health. The EPA Objective for this factor can therefore be met.