APPENDIX 5-6

Radiation Impact Assessment

HASTINGS

TECHNOLOGY METALS LIMITED

Yangibana Rare Earths Project

Radiation Impact Assessment

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1. INTRODUCTION

Hastings Technology Metals Limited (Hastings) is proposing to develop the Yangibana Rare Earths Project (the Project) in the Gascoyne region of Western Australia to produce a rare earth concentrate for export and treatment at an overseas processing facility. The project will consist of a series of open cut mines, associated with discrete deposits, a common beneficiation facility and a hydrometallurgical processing facility. Tailings from the various processes will be directed to dedicated Tailings Storage Facilities (TSF's).

The ore contains elevated naturally occurring uranium and thorium at reported average concentrations of 27ppm and 450ppm respectively. When combined, the total activity concentration of the ore is approximately 2Bq/g (heads of chain). The thorium concentration and the combined activity concentration of the ore meets the definition of a radioactive material (ARPANSA 2014a). In addition, during processing of the ore, elevated concentrations of radionuclides occur in various process and residue streams as impurities are removed from the final products.

Accordingly, the radiological impacts of the project have been considered and assessed.

This document provides an overview of the radiological characteristics of the project and an assessment of the potential radiation doses to the public, workers and the environment. A description of the proposed management measures for radiation is also included.

2. RADIATION AND RADIATION PROTECTION

2.1 Overview of Radiation

The assessment in this document assumes a basic understanding of radiation protection and a summary of key aspects relevant to the assessment is provided in this section. For a more detailed discussion on radiation and radiation safety, refer to the *Radiation Workers' Handbook* (AUA 2011) and to the website of the Australian national authority on radiation protection, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA).

2.2 Describing 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'. Together with cosmic 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 detriment, reported as ‘Sieverts’ (Sv), which takes into account the different types of radiation and the way that the particular exposure occurs.

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

Naturally occurring background radiation produces doses ranging from 1 to 10 mSv/y in different parts of the world. In Australia, the average dose from background radiation is about 2 mSv/y (ARPANSA, 2012).

2.3 Framework for Radiation Protection

2.3.1 International Approach

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

- The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which provides a consolidated overview of the effects of radiation by regularly reviewing research and publishing the summaries. UNSCEAR provides the scientific basis for radiation protection.
- The International Commission on Radiological Protection (ICRP) is recognised as the pre-eminent authority on radiation protection and has developed the philosophy for radiation protection and publishes recommendations on radiation protection. ICRP provides the philosophical basis for radiation protection.
- The International Atomic Energy Agency (IAEA) develops and publishes industry standards and guides, and provides advice on basic safety precautions when dealing with radiation for both operators and regulators. The IAEA develops operating standards.

In Publication 26 (ICRP 1977), the ICRP first recommended the ‘system of dose limitation’, which has become the internationally accepted approach to radiation protection and is universally adopted as the basis of legislative systems for the control of radiation. 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 the radiation doses and potential costs should be balanced so that doses are 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, 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.

While the ALARA principle is the foundation for radiation protection, prescribed radiation dose limits have been established to provide an absolute level of protection. The limits apply only to the radiation dose received as a result of a 'practice', and excludes natural background radiation. The limits are:

- 20 mSv/y for a worker (whilst at work), and
- 1 mSv/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 50 mSv in any one year for workers (ICRP 2007).

The protection of the natural environment from emissions from nearby operations has historically been based solely on the protection of humans. This approach was outlined by the ICRP, which stated that "*if man is protected then it can be assumed that the environment is protected*" (ICRP 1991).

It is now generally accepted, however, that there is a need to demonstrate that flora and fauna are protected from emissions from operations.

This has been addressed by the ICRP in more recent publications (ICRP 2014), in which it is recommended that assessments be made of the impact of radiation on non-human biota (i.e., plants and animals). An important aspect is that protection of plants and animals is at the species levels rather than the individual levels, as is the case for humans.

2.3.2 Australian Radiation Standards

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) develops guidance, standards and Codes of Practice based on the IAEA publications.

The primary national guidance documents related to radiation protection in the mining or processing of radioactive materials are:

- Fundamentals for Protection Against Ionising Radiation (ARPANSA, 2014a)
- The Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing 2005; known as the Mining Code (ARPANSA, 2005)
- Safety Guide for the Management of Naturally Occurring Radioactive Material (ARPANSA, 2008)
- The Code of Practice for the Safe Transport of Radioactive Material 2014 (ARPANSA, 2014 b).

2.3.3 Western Australian Requirements

In Western Australia, the primary regulations for radiation control in mining of radioactive materials are:

- Mines Safety and Inspection Regulations 1995,
- *Radiation Safety Act 1975*
- Radiation Safety (General) Regulations 1983
- Radiation Safety (Qualifications) Regulations 1980
- Radiation Safety (Transport of Radioactive Substances) Regulations 2002

3. RADIOLOGICAL CHARACTERISTICS OF THE PROJECT

3.1 Summary of Project

A detailed description of the proposed project is provided elsewhere and the key aspects relevant to radiation protection are outlined in this section.

Ore will be mined from the deposits at a rate of approximately 1mtpa and will contain an average of approximately 1.15% total rare earth oxides (TREO). Overburden and waste rock would be removed and stockpiled at a rate of approximately 6-7mtpa.

The ore will be trucked from the mines to the processing facility and an optimised blend would feed the beneficiation process, which will include crushing, grinding and flotation circuits. Approximately 95% of the initial mass input will be rejected as tailings with the TREO concentrate making up 5% of the flow. The beneficiation tailings (approx. 930,000 tpa) will not contain radionuclide concentrations above 1Bq/g, and will therefore not be defined as radioactive. These tailings will disposed in a dedicated on-site tailings storage facility (known as TSF1).

The TREO concentrate will then undergo regrinding and secondary flotation in the beneficiation process to produce approximately 30,000tpa of TREO concentrate consisting of approximately 20% of TREO. Tailings from the re-flotation (approx. 37,000 tpa) will contain elevated radionuclide concentrations, and be thickened and sent to a second tailings disposal facility (known as TSF2).

The TREO concentrate stream will be thickened and filtered, and then treated in an on-site hydrometallurgy plant to remove impurities including remnant radionuclides. The TREO concentrate will undergo a series of cleaning steps, including sulphuric acid bake, water leach and neutralisation to produce a final rare earth product (approx. 13,000tpa) for export. The residue from the hydrometallurgical processing (approx. 56,000tpa) will be disposed in a separate dedicated disposal facility (TSF3). An effluent evaporation pond will process approximately 500,000 m^3/a of liquid wastes from the hydrometallurgical process.

3.2 Sensitive Receptors

Doses to members of the public occur when emissions from inside the operation impact upon people outside the operation. This is quantified by identifying a representative person at locations of interest and then determining the potential radiation dose to that person from the project emissions. For impacts to non-human biota, it is common to use the same locations.

In this assessment, the locations of interest are:

- Accommodation Village (approximately 5km from the main project area)
- Gifford Creek homestead (approximately 10km to the south of the main project area)
- Edmund Station homestead (approximately 20km north of the main project area)

For the accommodation village, it is assumed that camp workers, such as cleaners and chefs, are members of the public with reduced exposure hours. This means that they are subject to the member of public dose limit of 1mSv/y.

3.3 Assessment Factors

The following factors have been used in this radiological impact assessment. Note that the figures presented in the project description may vary slightly from the figures used in this assessment, however, any changes are small and therefore any changes to the final assessed impacts are expected to be minor.

Production Factors

- Average total mining rate – 7.1Mtpa (mineralised material and waste rock)
- Average ore (mineralised material) mining rate – 1Mtpa
- Average thorium content of ore – 450ppm
- Average uranium content of ore –27ppm
- Mine operating life is 7 years

Public Exposure Factors

- Member of the public exposure hours – 8,670h/y
- Member of the public breathing rate – 1.0m^3/h
- Camp worker exposure hours (working year) – 4,000h/y (assumes 2,000h/y working and 2,000h/y not working)

Physical Property Factors:

- Relationship between uranium and thorium content and radionuclide activities are:
    - 1ppm U = 12.3mBq(U^{238})/g, and
    - 1ppm Th = 4.06mBy(Th^{232})/g.
- Uranium and thorium in ore is in approximate secular equilibrium when mined
- Deposited dust will mix in the top 10mm of soil (Kaste 2007)
- Bulk density of soil in the environment is 1m^3 = 2 tonne

Radon and Dust Factors:

The radon isotope Rn^{222} is a natural decay product from the uranium decay chain. Rn^{220} is the radon isotope form the thorium decay chain and is generally known as thoron. The decay products of these radon isotopes are primarily responsible for the doses and impacts and are known as radon decay products (RnDP) and thoron decay products (TnDP).

Dose conversion factors are used to calculate the dose from inhalation of radionuclides in dusts. The figures are published in ARPANSA 2005. It is also conservatively assumed that all dust emitted from the project is mineralised ore.

3.4 Radiological Characteristics of the Materials

Hastings has determined the uranium and thorium content of the ore and various processing streams and a summary can be seen in Table 1 (RadPro 2016a).

Table 1: Uranium and Thorium Content of Materials

Material	Unit	Uranium	Thorium	Comment
Ore	ppm	27	450	Estimated to be in secular equilibrium
Waste Rock	ppm	10	71	Estimated to be in secular equilibrium
Beneficiation Tailings (TSF1)	ppm	23	147	Estimated to be in secular equilibrium
Re-flotation Tailings (TSF2)	ppm	45	1,922	Estimated to be in secular equilibrium
TREO Concentrate	ppm	171	9,298	Estimated to be in secular equilibrium
Hydromet Residue (TSF3)	ppm	94	5,092	Considered to be out of equilibrium
Liquid Residue from Hydromet	mg/L	0.19	0.003	Considered to be out of equilibrium
Rare Earth Product	ppm	<80	6	Considered to be out of equilibrium

For this radiological assessment, the concentration in Table 1 have been used.

3.5 Radon and Thoron Emission Rates

To determine the impact of the operation, the radon and thoron emissions rates were estimated. The estimations of radon and thoron emissions from the project are based on published figures from a similar sized operation, which have been scaled (Arafura 2015). It is recognised that the emissions are dependent upon local factors however, there are similarities in the projects and generally impacts are low, therefore the indicative emission rates are considered suitable. Hastings plan to undertake experimental radon and thoron emission test work at a later date to verify the estimations.

A summary of the radon emission rates is shown in Table 2. (Note that the relatively higher figure for thoron is due to its very short half-life. Once thoron is produced, it almost immediately decays, therefore, the activity is high. Whereas, for radon, the longer half-life means that there is a lower activity for a similar number of atoms of radon).

Table 2: Estimated Radon Releases

Source	Radon (MBq/s)	Thoron (MBq/s)
Mine	0.8	40
Beneficiation Plant	0.1	0.1
Beneficiation Tailing	0.1	25
Processing Plant	0.1	175
Process Residues	Minor	Minor
Stockpiles	0.9	60
Total	2	300

3.6 Dust Emissions

The dust sources for the air quality assessment are provided in the air quality report (PEL 2016).

As noted previously it has been assumed that all of emissions are mineralised dust, which has an average uranium concentration of 27ppm and average thorium concentration of 450ppm. In practice, a significant proportion of the emitted dust will be non mineralised.

At these concentrations, there will be approximately 0.3Bq/g of each radionuclide from the uranium decay chain (U238) and 2Bq/g of each long lived radionuclide in the thorium decay chain.

3.7 Air Quality Modelling Outputs

Air quality modelling (PEL 2016) was conducted to determine the potential increments in airborne concentrations as a result of airborne emissions from the project. The modelling utilised the radon and thoron emission rates outlined in Sections 3.5 and dust emission factors referred to in section 3.6.

This section summarises the modelling results.

3.7.1 Radon

The modelled annual average ground level concentrations during operations at each of the locations of interest can be seen in Table 3. It should be noted that the baseline monitoring (RadPro 2016 b) gives an average naturally occurring radon and thoron concentration of approximately 10/m^3 and 20Bq/m^3 respectively (using long term passive detectors).

Table 3: Annual Average Modelled Radon Ground Level Concentrations

Location	Incremental Ground Level Radon Concentrations Annual Average (Bq/m^3)	Incremental Ground Level Thoron Concentrations Annual Average (Bq/m^3)
Accommodation Village	0.003	<0.001
Gifford Creek Station	0.001	<0.001
Edmund Station	0.002	<0.001

3.7.2 Airborne Dust Concentrations

Table 4 shows the modelled total suspended solids (TSP) dust concentrations during operations.

The dust concentration is multiplied by the specific activity of the dust (see section 3.6) to give an activity concentration and these are also shown in Table 4.

Table 4: Annual Ground Level Concentrations

Location	Ground Level Concentrations Dust (µg/m^3)	Equivalent Uranium Chain Radionuclide Concentration (µBq/m^3)	Equivalent Thorium Chain Radionuclide Concentration (µBq/m^3)
Accommodation Village	0.30	0.09	0.60
Gifford Station	0.16	0.05	0.32
Edmund Station	0.40	0.12	0.80

3.7.3 Dust Deposition

The deposition rate of dust into the environment was modelled and the total dust and radionuclide deposition into the environment at the sensitive receptors has been calculated for the life of the project (7 years).

The results are used to provide an estimate of human doses from ingestion of food that has taken up radionuclides. The results are also used for determining project originated soil radionuclide concentration estimates of impacts to non-human biota. Results from the modelling are shown in Table 5.

Table 5: Dust Deposition

Location	**Cumulative Dust Deposition (7 years) (g/m^2)**	**Uranium Chain Radionuclide (Bq/m^2)**	**Thorium Chain Radionuclide (Bq/m^2)**
Accommodation Village	1.18	0.40	2.21
Gifford Station	0.17	0.06	0.32
Edmund Station	0.59	0.20	1.10

4. OCCUPATIONAL DOSE ASSESSMENT

4.1 Approach

This section provides an assessment of occupational doses to the following workgroups:

- Mine workers,
- Beneficiation plant workers,
- Hydrometallurgical plant workers, and
- Administration workers.

In dose assessment, the main exposure pathways are:

- Gamma irradiation,
- Inhalation of radon decay products (RnDP) and thoron decay products (TnDP), and
- Inhalation of radionuclides in dust.

The exposures and potential doses for workers are predicted to be similar to or less than doses experienced in other similar rare earth operations and other operations where elevated concentrations of naturally occurring radioactive materials are handled. For example, it is relevant to note that miner doses at the Ranger uranium open cut uranium mine and processing facility are less than 5mSv/y.

Another comparison that is relevant is the Olympic Dam hydrometallurgical processing facility, which is used to concentrate uranium. Doses to workers in the facility are low, of the order of 2 to 3 mSv/y. The processing is wet, therefore inhalation doses are able to be managed effectively.

An assessment of the potential doses follows.

4.2 Dose Parameters

For calculating the potential doses to workers, the following factors are used:

- Worker exposure hours (working year) – 2,000h/y
- Worker breathing rate – 1.2m^3/h
- RnDP conversion factor 1.2mSv /mJ (workers) [ARPANSA 2005]
- TnDP conversion factor 0.39mSv /mJ (workers) [ARPANSA 2005]
- Radionuclide in dust inhalation for uranium in ore 7.2µSv/αdps (ARPANSA 2005)
- Radionuclide in dust inhalation for thorium in ore 11µSv/αdps (ARPANSA 2005)
- Radon/RnDP equilibrium factor is 0.4 (UNSCEAR 2000)
- Thoron/TnDP equilibrium factor is 0.01 (Arafura 2016)

4.3 Gamma Radiation Exposure Rates

Gamma radiation exposure estimates are based on the work of Thompson and Wilson (1980) who derived a gamma dose rate factor for natural *in situ* uranium of 65µSv/h per %U for a 2π exposure situation (which is equivalent to standing on an infinite plane source, that is, being exposure from one side only). For thorium in ore, the IAEA provide a factor of 16µSv/h per %Th for 2π exposure (IAEA 2006).

Based on these factors, dose rates for the various materials can be calculated (see Table 6). Note that the dose rate assumes that the materials are in secular equilibrium.

Table 6: Gamma Dose Rate for Various Materials

Material	Concentrations (ppm)		Total Dose Rate (µSv/h)
	Uranium	Thorium	
Ore	27	450	0.9
Waste Rock	10	71	0.2
Beneficiation Tailings (TSF1)	23	147	0.4
Refloat Tailings (TSF2)	45	1,922	3.4
TREO Concentrate	171	9,298	16
Hydromet Residue (TSF3)	94	5,092	8.8
Final Product	<80	6	0.5

4.4 Mine Worker Doses

Miner dose estimates are based on assessing doses to worker in the largest mine pit (Frasers), which has a mined size of 39Mt, with an assumed volume of $13Mm^3$ (based on a rock density of $3t/m^3$). A simplified representation of the pit is used and it is assumed that the pit is a round conical flat bottomed pit, with a depth of 150m, giving a diameter of approximately 600m.

4.4.1 Gamma Radiation

In practice, heavy mining equipment tends to absorb and attenuate the exposure to equipment operators. Testwork in an underground mine has shown that totally enclosed work cabins on mining equipment can provide up to 67% attenuation of gamma radiation and partially enclosed cabins can provide 40% attenuation (ERA 2014). Therefore, in this assessment, it has been assumed that large mining equipment offers, on average, a 50% reduction in gamma radiation exposure. In practice, for a 2π exposure geometry, the actual attenuation is higher due to the equipment shielding most of the gamma radiation from below.

Based on exposure to ore for 2,000 hours per year, the predicted miner gamma doses are:

- Annual Dose = 0.9µSv/h x 2,000h/y x 0.5 = 0.9mSv/y

4.4.2 Radon and Thoron Decay Products

A modified box model has been used to estimate doses to mine workers.

The model considers:

- The amount of radon (Rn^{222}) and thoron (Rn^{220}) entering the mine void,
- The ventilation rate of the mine void, (which is the time it takes for air to turn over in the mine) and is based on the average natural wind speed,
- The calculation of a steady state (equilibrium) concentration of radon and thoron in the mine,
- Determination of the decay product concentrations from the radon and thoron gas concentrations using established equilibrium factors,
- Calculation of worker doses based on exposure time and decay product concentrations.

Emission estimates used for the air quality modelling (and shown in Table 2) indicate that approximately 0.13MBq/s of radon and 8MBq/s of thoron will be emitted from the operating mine pits.

For the assessment, the following assumptions have been made:

- Since Frasers is the largest pit, with almost 50% of the material mined, it is assumed that half the estimated release of radon and thoron is emitted from this one mine pit,
- The dimensions of the modelled pit are; length is 600m, width is 600m and depth is 150m,
- The pit volume is $13Mm^3$, and
- The average wind speed in the region is approximately 4m/s (PEL 2016).

The ventilation rate of the one mine pit is calculated using the following formula (Thompson 1994);

- $T = 33.8 \times (V/U_rLW) \times (0.7\cos(\theta) + 0.3)$, where:
    - T is the residence time of air in the pit,
    - U_r is the wind velocity in metres per hour,
    - L is the length of the pit, and
    - W is the width of the pit.

The term '$(0.7\cos(\theta) + 0.3)$' is used to take into account the shape of the pit, however, for simplicity, the pit has been approximated to a square, therefore the term equates to 1.

The average wind speed for the region is 4m/s, which is equivalent to 14,400m/h. Using the formula and the assumptions, the calculated air residence time is 0.08h. This is the same as saying that at the average wind speed, the air in the pit would turn over approximately 12 times per hour.

The radon equilibrium concentration is calculated using the following equation:

- Radon concentration (Bq/m^3) = ER/(PV x VR) (derived from box model in Cember 2009) where,
    - ER is the radon (or thoron) generation rate in the pit (in Bq/h),
    - PV is the pit volume, and
    - VR is the number of air changes per hours.

Using the figures above, the equilibrium concentrations are as follows:

- Radon (Rn^{222}) is $2Bq/m^3$, and
- Thoron (Rn^{220}) is $46Bq/m^3$.

These figures are above the naturally occurring levels that exist in the region, and are a result of the proposed operations. The concentrations are low because the emission rate is relatively low and the ventilation rate is high.

The equivalent decay product concentrations can be calculated using the following relationships (ARPANSA 2008):

- RnDP (mJ/m^3) = $5.56 \times 10^{-6} \times E_{Rn} \times$ Radon conc. (Bq/m^3)
- TnDP (mJ/m^3) = $7.57 \times 10^{-5} \times E_{Tn} \times$ Thoron conc. (Bq/m^3)

- where:
  - RnDP and TnDP are the potential alpha energy exposures to radon progeny and thoron decay products,
  - E_{Rn} is the equilibrium factor for radon progeny (0.4),
  - E_{Tn} is the equilibrium factor for thoron progeny (0.01),
  - C_{Rn} is the radon gas concentration (Bq/m^3), and
  - C_{Tn} is the thoron gas concentration (Bq/m^3).

The calculated concentrations are:

- RnDP – 0.004uJ/m^3, and
- TnDP – 0.035uJ/m^3.

The doses are calculated as follows:

- Dose (mSv/y) = RnDP Conc. (mJ/m^3) x Working hours (h/y) x dose factor (mSv.m^3/mJ.h)

This gives estimated doses from inhalation of RnDP and TnDP of 0.013 and 0.033mSv/y, respectively, giving a total inhalation dose from decay products of radon and thoron of 0.046mSv/y.

4.4.3 Radionuclides in Airborne Dust

Airborne dust exposures can be determined by combining the activity concentration of the airborne dust with the exposure time. The activity concentration can be calculated from the dust mass concentration combined with the known radionuclide composition of the dust.

For this assessment, an average mine dust mass concentration of 3mg/m^3 has been used. (Note that there is a lack of published data available on dust concentrations in open pit mines. HSE 2006 reports that 1% of respirable dust samples in UK quarries exceeded 3mg/m^3.) The figure is also a level at which the average long term dust levels would be likely to become intolerable requiring remedial action (such as watering of roads and dust suppression). It is unlikely that the long term average dust concentrations would exceed this level.

The mineralised ore contains on average 27ppm of uranium and 450ppm of thorium and the average activity concentrations are therefore 0.3 and 1.8 Bq/g, respectively (The activities are based on specific activities of U238 and Th232 of 12,400 Bq/g and 4,060 Bq/g, respectively.)

Dust Dose (U) = 3mg/m^3 x 0.3mBq/mg x 1.2m^3/h x 2,000h/y x 7.2uSv/αdps x 5αdps/Bq

= 0.081mSv/y

Dust Dose (Th) = 3mg/m^3 x 0.3mBq/mg x 1.2m^3/h x 2,000h/y x 11uSv/αdps x 4αdps/Bq

= 0.119mSv/y

4.4.4 Summary of Miner Doses

The estimated doses for miner are shown in Table 7.

Table 7: Occupational Dose Estimates for Miners

Work Group	Dose (mSv/y)					
	Gamma	**RnDP**	**TnDP**	**Dust (U)**	**Dust (Th)**	**Total**
Miners	0.9	0.01	0.03	0.08	0.12	1.3

4.5 Processing Plant Worker Doses

Gamma doses in the beneficiation plant and the hydrometallurgical plant are expected to be low and this is due to a number of key factors. These include:

- Once crushed and ground, the ore will be in a slurry form, therefore opportunities for dust generation will be absent,
- The slurries will be in process vessels and tanks in a diluted form (due to the slurry nature)
- Defacto shielding will be provided by the processing vessels and tanks,
- Processing facilities do not have permanent work locations, apart from control rooms. It is usual for plant operators to move all around the plant to undertake their duties, and
- Identification of areas where radiation levels are elevated and implementation of appropriate operating procedures.

Experience at uranium production operations, for example Ranger and Olympic Dam, shows that metallurgical plant workers generally receive gamma doses of approximately 1 mSv/y. The material in the Yangibana processing facilities will provide similar gamma radiation levels to those experienced at these other operations.

The main area where it is likely that there will be elevated gamma radiation is in the handling of the TREO concentrate. The concentration of thorium decay chain radionuclides and the subsequent estimated gamma dose rates can be seen in Table 6. The material will contain elevated concentrations of thorium chain radionuclides, prior to their removal in the hydrometallurgical process and the surface dose rates in this area will depend on the total mass of material and the contained activity. The residence time will also be a factor, because decay products may grow into equilibrium with parent radionuclides.

An assessment of doses via the exposure pathways is difficult due to the uncertain exposure geometries. Therefore, for this assessment, it is assumed that the doses received by workers will be similar to doses received at an operation with similar processing methods and radioactivity levels.

For this assessment, the actual doses from the Olympic Dam concentrator and hydrometallurgical plant have been used.

Table 8 shows the assumptions used for the assessment. The Olympic Dam doses are the average doses from 2001 to 2007 (BHP Billiton, 2009).

Table 8: Assumptions Used in Processing Plant Workers Dose Estimates

Processing Plant Area	Assumptions
Beneficiation Plant	Use doses received by Olympic Dam concentrator plant workers and scaled
Hydrometallurgical Plant	Use doses received by Olympic Dam hydrometallurgical plant workers

Based on the assumptions, 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	RnDP	Total
Beneficiation Plant	0.3	0.3	0.1	**0.7**
Hydrometallurgical Plant	0.8	0.7	0.3	**1.8**

4.6 Doses to Other Workers

Administration workers would mainly work in offices located adjacent to the processing plant. The work area would be outside of the main processing plant area and workers would not be required to undertake any special requirements for radiation exposure control.

Exposures for administration workers would be as follows:

- Gamma radiation – no close sources of gamma ore, therefore gamma dose expected to be negligible.
- Dust exposure – assume that a dust concentration of 0.5 mg/m^3 of ore dust is present in the workplace (note that this would be considered a relatively high concentration and require mitigation), the inhalation dose would be approximately dose 0.033 mSv/y.
- RnDP exposure – assumed to be negligible (based on miner doses).

Therefore the estimated total dose is less than 1 mSv/y and monitoring would be conducted to confirm this.

Final product concentrate is to be transported by road to port. Since the final product is below the specification for a radioactive material, it is expected that doses to the truck drivers would be less than 1 mSv/y. Monitoring would be conducted to confirm this once operations commence.

4.7 Consideration of Changes in Dose Factors

The ICRP has published a revised dose factor for radon decay products (ICRP 2015). The new factor has yet to be adopted in national laws, although it is likely that this would occur in the near future.

The new dose factor is 2.4 times higher than the current dose factor. As shown in Table 7, the doses from inhalation of the decay products of radon and thoron are very low, therefore the impact of the revised dose factor is minor.

4.8 Summary of Occupational Radiological Impacts

The assessment has shown that the radiological impacts from the proposed project to workers would be low. Conservative estimates show that doses to all workers would be less than 5 mSv/y, compared to the annual limit of 20 mSv/y.

5. PUBLIC DOSE ASSESSMENT

5.1 Background

The potential exposure pathways for members of the public are:

- Irradiation by gamma radiation,
- Inhalation of the decay products of radon and thoron,
- Inhalation of radionuclides in dust, and
- Ingestion of animals or plants that have come in contact with emissions.

The assessment assumes that a member of the public resides at the locations of interest for a full year at the Edmund and Gifford Creek Station homestead locations and 4,000 hours per year for the accommodation village location.

Table 10 provides a summary of the dose assessment methods for the different exposure pathways.

Table 10: Exposure Estimation Methods

Exposure Pathway	Assessment Method
Gamma Radiation	Considered to be negligible
Inhalation of radionuclides in dust	Estimation based on air quality modelling results
Inhalation of radon and thoron decay products	Estimation based on air quality modelling results
Ingestion of radionuclides	Estimation based on modelled dust deposition and transfer factors to the plants and animals

5.2 Gamma Radiation

Gamma radiation exposure to members of the public from sources within the project area is considered to be negligible due to the distance between the sources and the public. The sources of gamma radiation (for example ore stockpiles) are well within the project boundary and inaccessible by the public.

Gamma radiation intensity reduces significantly with distance (as one divided by the distance squared when the source is at a distance to be considered to be a point source). The gamma levels at the closest accessible area would be barely detectable, of the order of nSv/h.

5.3 Airborne Dose Estimates

Doses from inhalation of radionuclides in dust and the decay products of radon (RnDP) and thoron (TnDP) are based on the modelled annual average concentrations at each location of interest.

5.3.1 Dust

The dust dose is based on the modelled average radionuclide concentrations in air (see section 3.7) and the individual radionuclide inhalation dust factors as outlined in ICRP Publication 119 (ICRP 2012). The formula is:

- Inhalation dose (mSv/y) =

  Dust activity concentration (Bq/m^3) x

  Breathing rate (1.0m^3/h) ×

  Hours per year (8,760h/y and 4,000h/y as appropriate) ×

  Dose Conversion Factor for each uranium and thorium radionuclide (mSv/Bq)

5.3.2 Radon Decay Products

For RnDP the first step is to convert the modelled radon concentration to a RnDP concentration using the following equation (IAEA 2003):

- RnDP Concentration (μJ/m^3) = Equilibrium factor x 0.00556 x Rn concentration Bq/m^3

Note that due to the very low modelled thoron concentration, the potential doses have been assumed to be zero.

For this assessment, an equilibrium factor of 0.4 has been used.

The RnDP dose is then calculated using the following formula:

- Dose (mSv/y) = RnDP Conc (mJ/m^3) x

  Exposure hours (8,760h/y for public and 4,000h/y for accom. camp) x

  Breathing rate (1.0m^3/h) ×

  Dose Conversion Factor (1.2mSv/mJ)

5.3.3 Inhalation Dose Summary

A summary of the inhalation dose estimates can be seen in Table 11.

Table 11: Public Inhalation Dose Estimates

Location	TSP Dust Dose (mSv/y)	RnDP Dose (mSv/y)*	ThDP Dose (mSv/y)
Accommodation Village	0.001	0.001 (0.002)	0.000
Gifford Station	<0.001	<0.001 (0.001)	0.000
Edmund Station	0.001	0.001 (0.002)	0.000

* As noted is section 4.7, the ICRP has recently recommended an increase in the dose conversion factor for radon decay products (ICRP 2015), although this has yet to be adopted in Australia. The increase is a factor of 2.4 and the doses using the new dose conversion factor can be seen in parentheses and for this assessment the increase is applied to both isotopes of Rn.

5.3.4 Ingestion Dose Estimates

The ingestion doses have been calculated for people living at each location of interest based on the conservative assumption that all food consumed is sourced from the location. In practice, the Yangibana region is sparsely populated with plants and animals. Therefore, consuming food solely generated in the region is highly unlikely, although this provides a conservative estimate of the ingestion doses.

The assessment method assumes that dust emissions from the operation deposit in the surrounding environment and are taken up by plants and animals. Exposure to people occurs when the plants and animals are consumed. The assessment only considers the project originated radionuclides.

There are three main factors to consider when making an ingestion dose assessment as follows:

- Food consumption rates and characteristics,
- Concentration factors into foods,
- Incremental concentrations of radionuclides from the project.

For this assessment, the most conservative ingestion rate is provided, which assumes that all meat consumed in 1 year is local kangaroo meat.

<u>Consumption Rates</u>

The assessment is based on the following consumption rates from http://www.goodfood.com.au/;

- Vegetation
    - 40kg/y of non leafy vegetables
    - 10kg/y of leafy vegetables
    - 70kg/y of root vegetables
- 110kg/y of meat (assumed to be kangaroo from the local area).

<u>Concentration Ratios</u>

The concentration ratio is a factor that relates the concentration of an element in the media (such as soil and foods) and the concentration of the element in the plant or animal. For plants, it is the ratio between the soils and the plant. For animals, it is the ratio between the food and the animals.

Published factors are available in IAEA (2010) and the Compendium of Transfer Factors (DoE, 2003). For this assessment, the uptake factors used can be seen in Table 12.

Table 12: Uptake Factors

	Vegetation[1] Bq/kg (dry weight)/Bq/kg (dry soil weight)			Kangaroo[2] Bq/kg (whole body) per Bq/d (ingested)
	Non Leafy	**Leafy**	**Root**	**Whole Body**
Uranium	0.053	0.020	0.028	0.007
Thorium	0.0022	0.0012	0.0087	0.00016
Radium	0.061	0.091	0.071	0.41
Polonium	0.00019	0.0074	0.077	0.55
Lead	0.015	0.080	0.063	0.022

Note 1: The concentration ratio figures are quoted as 'dry weight'. To apply the ratios to live plant matter, a factor needs to be applied which converts the dry weight to a wet weight. For this assessment it has been conservatively assumed that the wet weight is twice the dry weigh. In reality the wet weight may be 4 or 5 times higher and depends upon the plant species, so the figure used is conservative.

Note 2: Concentration ratios are from ARPANSA 2014c and are provided for assessment of dose from intake of kangaroo meat.

Incremental Radionuclide Concentrations

The calculated change in soil radionuclide concentrations at each location of interest is based on the air quality deposition modelling. Table 13 shows the calculated change in soil concentration based on soil density of $2t/m^3$ and a mixing depth of 10mm. It is assumed that the uranium and thorium decay chain is in secular equilibrium, therefore the radionuclide concentration applies to each of the radionuclides in the uranium decay chain.

Table 13: Change in Soil Radionuclide Concentration (after 7 years of operations)

Location	Radionuclide Deposition (Bq/m^2)^{*1}		Change in Soil Concentration (Bq/kg)^{*2}	
	Uranium Series	Thorium Series	Uranium Series	Thorium Series
Accommodation Village	0.40	2.21	0.020	0.110
Gifford Creek Station	0.06	0.32	0.003	0.016
Edmund Station	0.20	1.10	0.010	0.055

Note 1: From table 6.

Note 2: Calculated as follows

Soil concentration (Bq/kg) = Deposition (Bq/m^2) / (Mixing Depth (m) x Soil Density (kg/m^3))

Assessment of Intakes

The intake of radionuclides is a function of the quantity of radionuclides in the soil, the quantity of radionuclides that transfer to food and the food intake rate.

For example, to calculate the dose from project originated U^{238} from ingestion of leafy vegetables at the closest eastern boundary, the calculations are as follows:

- Data:
  - Assumed ingestion of leafy vegetables is 10kg/y
  - The projects originated soil uranium 238 concentration is 0.020Bq/kg
  - The concentration ratio for uranium for leafy vegetables is 0.02Bq/kg (dry eight) per Bq/kg (soil) (converting to wet weight gives 0.01Bq/kg(wet weight) per Bq/kg (soil))
- Calculation of plant uptake:
  - Plant uranium concentration is 0.01 x 0.020, giving 0.002 Bq/kg
- Calculation of intake:
  - Assume consumption of 10kg per year, giving an intake of uranium 238 of 0.02Bq

This calculation method is then applied to each radionuclide for the different food types and consumption rates and added together to give the total intake for each radionuclide.

Convert Intake to Dose

Standard ICRP ingestion dose conversion factors convert an intake (in Bq) into a dose (mSv) for different radionuclides (ICRP 2012). The total dose can be calculated at the locations of interest locations and the results shown in Table 14.

Table 14: Data for Ingestion Dose Assessment

	Dose (mSv/y)			
Location	**Vegetation Ingestion**	**Kangaroo Ingestion**	**Total Ingestion**	**Meat[1] Ingestion**
Accommodation Village	0.0004	0.005	0.005	<0.0001
Gifford Station	0.0001	0.001	0.001	<0.0001
Edmund Station	0.0002	0.003	0.003	<0.0001

Note 1: Standard meat (beef) consumption doses provided for comparison purposes.

5.4 Total Dose Estimates

The total dose estimates at the sensitive receptors can be seen in Table 15. Note that the doses are based on 100% occupancy (that is 8,760 hours per year) for the station homestead locations and 4,000 hours per year for the accommodation village. The figures in parenthesis represent the calculated dose based on the new ICRP dose factor for radon decay products.

Table 15: Public Total Dose Estimates

Location	**Exposure Pathway Dose (mSv/y)**					
	Gamma	**Dust**	**ThDP**	**RnDP**	**Ingestion**	**Total Dose**
Accommodation Village	0.000	0.000	0.000	0.001 (0.002)	0.005	0.006 (0.007)
Gifford Station	0.000	0.000	0.000	<0.001 (0.001)	0.001	0.002 (0.002)
Edmund Station	0.000	0.000	0.000	0.001 (0.002)	0.003	0.004 (0.006)

6. FLORA AND FAUNA IMPACT

6.1 Background

This section discusses the potential radiological effects on non-human biota (NHB) of the operation. The assessment has been conducted based on the potential airborne emissions from the project, which leads to the deposition of radioactive dusts on surrounding soils.

As noted in section 2.3.1, the protection of the natural environment from emissions from nearby operations has historically been based solely on the protection of humans. This approach has changed and there is now an expectation that an assessment of the radiological impacts to flora and fauna will occur.

6.2 The ERICA Tool

ARPANSA notes that the ERICA Software Tool (where ERICA is short for Environmental Risk from Ionising Contaminants: Assessment and Management) is applicable for use in Australia (ARPANSA 2010) for assessing radiological impacts to plants and animals. The software uses the change in media radionuclide concentrations and concentration ratios in species, derived from studies, to provide a measure of radiological impact to a number of reference species.

An ERICA assessment is a tiered assessment. This means that the level of assessment depends upon the level of impact (i.e., the higher the potential impacts, the higher the level of scrutiny) (ARPANSA 2010). Tier one is the simplest assessment level, requiring the minimum input data. Where more data is available, or the potential impacts are higher, then a tier 2 assessment can be conducted. The final level is tier 3, which is used when the likely impacts need to be better defined. The aim of the tiered approach is to ensure that the level of assessment is commensurate with the actual risk.

The assessment method produces a dose rate, which is compared to a 'screening level'. This is the level below which no effects would be observed. The default ERICA level is set at 10 µGy/h (ARPANSA 2010).

The two important inputs for an ERICA assessment are:

- Operationally derived changes in media concentration, which is the additional radionuclide concentration in either soils or waters attributable to the operation and is in units of Bq/kg or Bq/l,
- Radionuclide concentration ratios, which are the ratios of radionuclide concentrations in the media and concentrations in flora and fauna.

The latest version of the ERICA software was released in February 2016 (version 1.2.1).

6.3 Assessment Approach

A Tier 2 ERICA assessment was conducted because some additional concentration ratio data on kangaroos is available (ARPANSA 2014c).

The assessment was conducted for the full set of default ERICA terrestrial flora and fauna.

The user defined parameters for a kangaroo assessment are as follows:

- The ‘Kangaroo’ with dimensions of; mass 50kg, height 1.5m, width 0.75m and depth 0.75m (based on best estimate).

6.4 ERICA Concentration Ratios

The key factors in an ERICA assessment are concentrations ratios (CR). These are the ratio of the whole body average radionuclide concentrations in the specific species to the concentration of the radionuclides in the media (e.g., soil and water). ERICA provides a series of default CR values and additional CR data for kangaroos can be found in ARPANSA 2014c as shown in Table 16.

Table 16: Published Concentration Ratios (note that ERICA CR values are provided for comparison)

Species	Elemental Concentration Ratio (Bq/kg (species))/(Bq/kg (soil))					Source
	Uranium	**Thorium**	**Radium**	**Lead**	**Polonium**	
Red Kangaroo[1]	0.007	No data[2]	0.41	0.022	0.55	ARPANSA 2014c
Large Mammal	*0.0044*	*0.000136*	*0.044*	*0.037*	*0.089*	*ERICA Default*

Note 1: ARPANSA 2014c figures are reported as concentration ratios – average of two sample sets used

Note 2: Default ‘large mammal’ value for thorium has been used in assessment.

6.5 ERICA Assessment Outputs

The media concentrations are seen in Table 5. For this ERICA assessment, the maximum media concentration has been used (from accommodation village).

The output of the assessment can be seen in Table 17, which shows that a 10 µGy/h screening level is not exceeded at a Tier 2 level, using the default values.

The species with the highest level of exposure is lichen and bryophytes, however the exposure level remains well below the trigger level for further assessment.

Table 17: Output of ERICA Assessment

Species (all ERICA Default Species Unless Noted)	Total Dose Rate (µGy/h)
Amphibian	<0.001
Annelid	<0.001
Arthropod - detritivorous	<0.001
Bird	<0.001
Flying insects	<0.001
Grasses & Herbs	0.005
Lichen & Bryophytes	0.014
Mammal - large	<0.001
Mammal - small-burrowing	<0.001
Mollusc - gastropod	<0.001
Reptile	<0.001
Tree	<0.001
Kangaroo (user defined)	<0.001

The ERICA assessment indicates that there is no radiological risk to reference plants and animals or kangaroos from emissions from the proposed project.

7. MANAGEMENT OF RADIATION

7.1 Overall Approach

Hastings will comply with the relevant state regulations on radiation protection and the radiological impacts of the proposed project would be managed and controlled through good design and ongoing operational management systems.

The operational controls will be outlined in the Radiation Management Plan and Radioactive Waste Management Plan, which will be submitted to the competent authority in the permitting stage of the project.

This section provides an overview of the main radiation management systems and controls.

7.2 General Site Controls

7.2.1 Classification of Work Areas and 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.

Hastings has defined the whole of the project area within the proposed lease boundary as a 'supervised area'. Within this area, the mines and hydrometallurgical plant would be defined as a 'controlled area'.

Employees working in the controlled areas would be defined as 'designated' radiation workers. Other workers would be defined as 'non-designated' radiation workers. These classifications would be reviewed when sufficient radiation monitoring data has been obtained.

7.2.2 Site Access Control

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

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

7.2.3 Change-rooms

Designated workers would 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 would be a general health and hygiene requirement and not just a radiation requirement.

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

7.2.4 Other General Controls

Hastings would 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 include radiation safety aspects,
- procedures to segregate, isolate and clean 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.

7.3 Radiation Control in the Mine

Hastings would implement management controls to ensure that doses remain well controlled. 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,
- using standard dust suppression techniques,
- providing mining equipment with air conditioned cabins, and
- installing a separate wash-down pad within the site area for vehicles that have come from the mine area.

7.4 Radiation Control in the Processing Facility

Both wet and dry process material would be handled in the processing facility requiring specific design considerations for dust control and spillage containment. This includes:

- crushers and conveyor systems fitted with appropriate dust control measures such as dust covers,
- 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, and
- washdown water points and hoses supplied for spillage clean-up.

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

7.5 Radiation Control in the Hydrometallurgical Plant

Specific radiation controls will need to be included in the design of the hydrometallurgical plant to ensure that doses to workers are optimised. As part of the design process, Hastings would identify those areas requiring additional controls using hazard and risk assessments.
Once identified, controls could include:

- Shielding, such as through thicker tank structures, to reduce the ambient workplace gamma radiation level.
- Restricting access to ensure that only trained workers work in the area.
- Maintenance work or non routine tasks conducted under a radiation work permit, where the specific radiation hazards are identified and adequate controls implemented before work commences.
- Spillage rigorously managed to ensure that the spills do not dry and become dust sources.
- Tanks would have concrete sloped flooring and sump for spillage control.

It should be noted that the controls are not new. Similar controls exist in practice in other processing facilities where radioactive materials are handled and the company would ensure that good practices and good designs are implemented.

7.6 Operational and Administrative Controls

In addition to the design controls, administrative controls would be implemented.

7.6.1 Radiation Safety Expertise

Hastings would ensure that suitably qualified and experienced radiation safety professionals are available to assist during the design and construction phases of the proposed project.

During operations, Hastings would employ a suitable qualified and resourced Radiation Safety Officer (RSO) who would influence the day to day workings of the project, ensure that appropriate radiation safety advice is available to implement the RMP and RWMP, and provide ongoing advice to the General Manager.

7.6.2 Induction and Training

All employees and contractors would 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 would be provided to personnel involved in the handling of process materials containing elevated levels of radionuclides.

Managers and supervisors would receive additional training in the recognition and management of situations that have the potential to increase a person's exposure to radiation.

7.6.3 Record Keeping

A computer based data management system would be used to store and manage all information relating to radiation management, monitoring and worker doses.

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

7.7 Radiation Monitoring Program

As part of the ongoing management of radiation, an occupational monitoring program would be developed and implemented.

The Radiation Monitoring Program would include:

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

An outline of the proposed occupational radiation monitoring is shown in Table 18.

Table 18: Radiation Monitoring Program

Radiation Exposure Pathway and Monitoring Method	Mine	Processing Plant	Administration Area
Gamma radiation Survey with handheld monitor	Monthly areas survey	Monthly area survey	Annual area survey
Gamma radiation Personal TLD badges	Quarterly TLD badges on selected designated workers	Quarterly TLD badges on selected workers	
Airborne dust Sampling pumps with radiometric and gravimetric analysis of filters	Monthly personal dust sampling for: • equipment operators • maintenance personnel	Weekly personal and workplace samples in selected work areas	Annual area samples
Radon and Thoron Decay Products Grab sample using the appropriate method	Monthly 'grab' sample in: • Each mine	Monthly grab samples in concentrator area and hydrometallurgical area	
Surface Contamination	Monthly survey of: • workshop • lunchroom	Monthly survey of: • plant • workshop • lunchroom	Annual survey

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

For routine management control of radiation, Hastings 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 19 provides an overview of the proposed action levels and actions.

Table 19: Exposure Action Levels and Actions

Radiation Measurement Type	Action Level	Actions
Gamma radiation Handheld Instrument	10 µSv/h	Investigate and identify source. Consider redesign of workplace or tasks to reduce exposure.
Gamma radiation TLD (quarterly result)	1 mSv	Investigate and identify source. Redesign workplace or tasks to reduce exposure. Shield if necessary.
Radon Decay Products	2 µJ/m^3	Investigate
Surface contamination (in workshops, control rooms and lunchrooms)	4,000 Bq/m^2	Immediate cleanup
Airborne Dust	5 mg/m^3 1 mg/m^3 in the processing plant area	Identify source and suppress (e.g. water suppression, housekeeping and ventilation)

Table 20 provides a list of the typical radiation monitoring equipment that would be used to conduct the radiation monitoring.

Table 20: List of Equipment required for Occupational Monitoring

Radiation Measurement Type	Equipment
Gamma radiation	Hand held gamma radiation monitor
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
Airborne Dust	2 L/min personal dust pumps fitted with suitable 'inhalable' filter holders Microbalance for weighing of filters Alpha slide drawer assembly and rate-meter
Radon and Thoron Decay Products	2 L/min personal dust pumps fitted with suitable 'inhalable' filter holders Portable alpha slide drawer assembly and rate-meter

7.8 Environmental Monitoring Program

An environmental radiation monitoring program will be conducted during operations. The aims of the program are to provide data for the assessment of radiation doses to the public, to provide data for the assessment of radioactive impacts to the environment and to ensure that the onsite radiation controls are effective.

A detailed environmental monitoring plan will be prepared as part of project permitting prior to construction commencing and an outline of the elements of such a plan are shown in Table 21.

Table 21: Proposed Environmental Radiation Monitoring Programme

Environmental Pathway	Measurement Method	Typical Location and Frequency
Direct (external) gamma	Handheld environmental gamma monitor, TLDs	Annual survey and passive detectors at environmental monitoring locations.
Radon and Thoron Concentrations	Long term passive monitors	Placed at the environmental monitoring locations and changed quarterly
Dispersion of dust containing long-lived, alpha-emitting radionuclides	High volume sampling	Sampler rotates between suitable off-site locations (requires mains power).
Dispersion of dust containing long-lived, alpha-emitting radionuclides	Dust deposition gauges	Sampling at off-site environmental monitoring locations. Samples composited for one year then analysed for radionuclides.
Seepage of contaminated water	Groundwater sampling from monitoring bores	Sampling from monitoring bores and analyses for radionuclides.
Run off contaminated water	Surface water sampling	Opportunistic surface water sampling will occur following significant rainfall events.
Radionuclides in potable water supplies	Sampling and radiometric analysis	Annually

8. RADIOACTIVE WASTE DISPOSAL

There are three main categories of radioactive waste generated by the proposed project:

- tailings from the beneficiation plant and hydrometallurgical plants,
- water that may have come into contact with radioactive materials including surface runoff, from areas which contain process material
- miscellaneous wastes that may have become contaminated through contact with ores and process residues (referred to as contaminated waste).

Waste rock from mine overburden is not considered to be radioactive and is to be used for construction purposes or disposed of on a waste rock landform with no radiation control measures necessary. Where waste rock contains nominally more that 1Bq/g (equivalent to 80ppm of uranium), it will not be used for construction and instead encapsulated in more benign waste rock.

8.1.1 Tailings

There are three main metallurgical processing waste streams that are produced, and these will be disposed in separate TSF's as follows:

- a slurry residue stream from the beneficiation process, which will be defined as non-radioactive,
- residues from re-flotation in the beneficiation plant,
- residues from the hydrometallurgical plant.

The TSF structures will all be specifically designed to ensure that tailings are properly contained and managed. The design aims to ensure that tailings are effectively contained in the long-term and that radiation doses from tailings to the proposed workforce are minimised.

8.1.2 Contaminated Water

Water that has come in contact with mineralised material, such as stormwater runoff from the ore stockpile or processing plant may contain entrained radioactive dusts and sediments. The site will be designed so that all surface water is collected and contained and does not flow from the site to surface water landforms or into groundwater. The method of control involves the construction of sedimentation dams, from which water can be reclaimed, and appropriate collection bunds and channels.

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

8.1.3 Contaminated Waste Control

This material includes contaminated equipment and wastes from operational areas, including equipment, steel, discarded conveyor belts, rubber lining material, pipes, filter media and used protective equipment. Hastings would implement a contaminated waste program, which aims to minimise waste to be disposed of. 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:

- Incorporation into the waste rock stockpiles,
- Disposal into the mine at the end of operations, and
- Disposal in an approved on-site landfill.

A system that retains records of the disposal, including type of material, quantities and locations would be maintained.

9. POST CLOSURE RADIATION IMPACTS

Hastings has a closure and rehabilitation strategy focussed on enclosing contaminated facilities and contaminated materials with inert waste rock. The overall aim is to ensure the long-term stability of any post closure landforms.

From a radiological perspective, the post closure levels are planned to be consistent with the pre-mining levels.

10. SUMMARY

The radiation assessment shows that the impacts would be manageable, with potential doses well below the recognised limits.

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