HASTINGS
Technology Metals Limited

APPENDIX 6-2

Tailings storage facilities closure:

Radiological design considerations

Technical Note

Tailings Storage Facility Closure

Radiological Design Considerations

For

Yangibana Rare Earths Project

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FINAL

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1. INTRODUCTION

This technical note provides radiological guidance for closure of the tailings storage facilities (TSFs) at the Hastings Technology Metals Limited Yangibana Rare Earths Project. Specifically, this note provides an indication of the thickness and general types of TSF cover material to ensure that gamma radiation levels and radon emission rates are controlled.

Details of the Yangibana project and the tailings designs are provided elsewhere (for example in ATC 2017) and are not covered in detail in this technical note. However, it is important to note that there will be three separate TSFs to be constructed, taking different tailings wastes. These are;

- TSF 1 which will take tailings from the beneficiation plant rougher and cleaner 1 flotation cells, which will comprise approximately 95% of the total generated tailings,
- TSF 2 which will take tailings from the beneficiation plant cleaner 2 to cleaner 4 flotation cells, which will comprise approximately 2-3% of the total generated tailings
- TSF 3 which will take tailings from the hydrometallurgical plant, which will comprise approximately 2-3% of the total generated tailings.

For details on the specific TSF designs see ATC 2017.

2. BACKGROUND

2.1 Radiological Design Aims

The overall closure design aim of the Yangibana project is:

> *To ensure that post closure radiation levels are consistent with the pre-operational regional radiation levels.*

It is important to note that in the Yangibana project region, naturally occurring uranium and thorium levels are variable and generally elevated compared to other regions in Australia. Therefore, the naturally occurring radiation levels in the region may be elevated compared to other regions in Australia.

For this assessment, the radiological parameters that were considered were:

- gamma radiation at 1m above the covered TSFs,
- radon exhalation rates from the covered TSFs,
- potential TSF seepage.

(Note that cover material depth does not affect potential seepage, however, broad comment is made on this parameter).

2.2 Tailings Characteristics

The radionuclide composition in the tailings of each TSF are based on an analysis of materials by ANSTO (2017). Results are summarised in table 1.

Table 1: Head of Chain Radionuclide Concentration

Facility	Activity Concentration (Bq/g)	
	Uranium (U238)	Thorium (Th232)
TSF 1	0.3	0.4
TSF 2	0.5	3.5
TSF 3	1.4	31

For this assessment, it has been assumed that long lived radionuclides in the uranium and thorium decay chains are in secular equilibrium. This is a conservative case because it is assumed that all of the mined radionuclides eventually report to tailings.

2.3 Existing Radiation Levels

The design aim refers to natural background levels of radiation, therefore a summary of the results are shown in table 2. Results are provided in more detail in RadPro 2016a and 2016b.

Table 2: Summary of Natural Background Levels of Radiation

Parameter	Average (Range)	Comments
Gamma radiation (on ore)	0.37 (0.10 – 1.26) µSv/h	
Gamma radiation (off ore)	0.23 (0.16 – 0.42) µSv/h	
Radon exhalation	N/A	Yet to be measured
Radon in air	10 Bq/m^3	
Thoron in air	(15 – 30 Bq/m^3)	Range only
Uranium in groundwater	(0.05Bq/L – 0.5Bq/L)	Range only

3. DESIGN CONSIDERATIONS

3.1 Gamma Radiation

The gamma radiation levels from tailings mainly depends upon the radionuclide content of the tailings. The density of the tailings and other constituents in the tailings may affect the gamma radiation levels, however, this is to a much lesser extent. Placing inert material above the tailings acts as a shield that attenuates the gamma radiation coming from the tailings.

The gamma radiation levels from uncovered and covered tailings for each tailings facility have been calculated using an on-line dose rate calculator (Diehl 2016). The theoretical calculated gamma dose rates from uncovered tailings and covered tailings are shown in table 3.

<u>Table 3:</u> Calculated Gamma Dose Rates

	Gamma Dose Rate (µSv/h)	
Facility	**Uncovered**	**Covered with either 1m compacted soil or 1m rock**
TSF1	0.3	0.01
TSF2	3.0	0.01
TSF3	10.6	0.01

For the assessment, it was assumed that the covering material has very low levels of uranium and thorium. The results show that cover material is very effective in attenuating gamma radiation from the uranium and thorium radionuclides in the tailings. The calculations also show that the residual gamma dose rate is primarily due to uranium and thorium in the cover material.

The results indicate that 1m of compacted soil or rock is more than sufficient to reduce gamma radiation levels to negligible levels.

3.2 Radon

For radon emission, the aim of a cover material above the tailings is to sufficiently constrain the rate of migration of radon gas so that the radon decays to solid decay products within the cover material and is therefore unable to be released into the atmosphere. The rate of constraint is dictated by the permeability of the cover material to inert gases.

The tailings contain uranium and thorium, therefore two isotopes of radon require consideration, being Rn222 (commonly referred to as radon) and Rn220 (commonly referred to as thoron). However, the half-life of radon is approximately 5 orders of magnitude higher than for thoron. Therefore, unless there are extremely high levels of thoron compared to radon being generated, the controls for radon will always be suitable for control of thoron.

An estimate of the radon and thoron emission rates from tailings is provided in the radiological assessment (JRHC 2016) and these were based on emission rates from a separate similar sized project. The estimated thoron emission rates are approximately 100 times higher than the radon emission rates, and therefore have not been further assessed. (Note and as mentioned above, the thoron emissions rates need to be hundreds of thousands of times higher than radon emission rates to be a factor for consideration).

In this assessment, a conservative approach has been used to estimate the emission rates of radon from the different tailings streams. The US EPA assumes a radon emission rate of 1Bq(Rn222)/m^2/s per Bq(Ra226)/g of tailings (USEPA 1986). Based on this factor, the emission rates are shown in table 4.

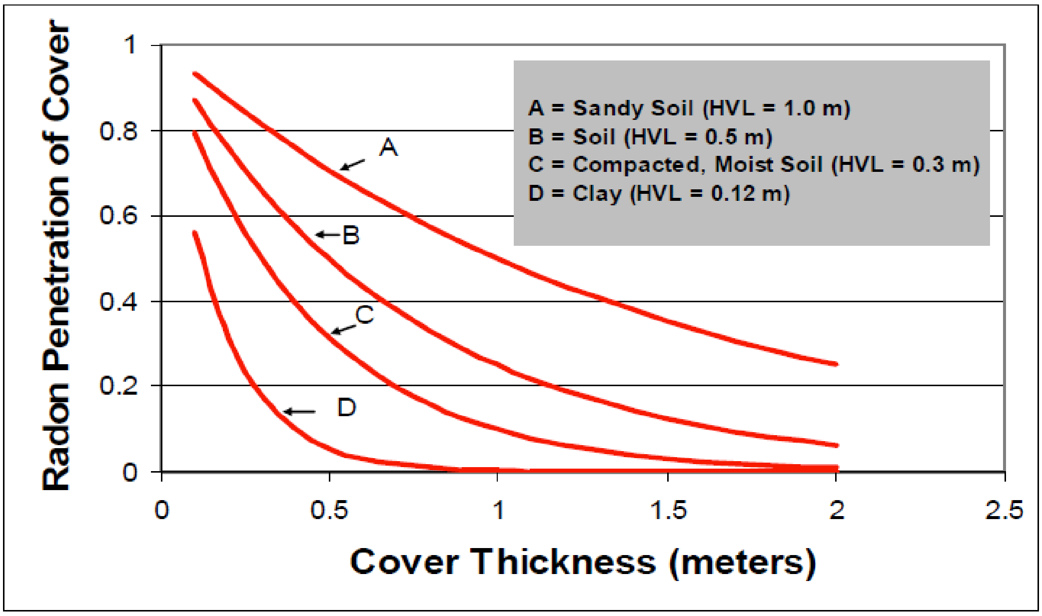
Table 4: Estimated Radon Emission Rate

Sources	**Ra226 Content (Bq/g)** **(Based on analysis)**	**Calculated Radon Emission Rate (Bq/m^2/s)**
TSF1	0.3	0.3
TSF2	0.5	0.5
TSF3	1.4	1.4

Published information on the attenuation rate of materials for radon varies and the key sources of information used in this technical note are as follows:

- Sonter 2002 suggests a post closure radon emission target of the order of 0.1Bq/m^2/s and notes that “any thick cover” provides good attenuation of radon.
- Chambers 2009 provides the attenuation graph shown in figure 1. (Note that the figure is sourced from “Environmental Radon, C. Richard Cothern, James E Smith, Environmental Science Research, Vol 35, 1987, Plenum Press”.)

Figure 1: Radon Attenuation for Various Materials



(Note that "HVL" means the half value layer, which is the depth of material required to reduce radon emission by one half.)

The factors required to achieve the Sonter 2002 target of approximately 0.1Bq/m^2/s, combined with the chart from Chambers 2009 provides an indication of the potential cover requirements as shown in table 5.

Table 5: Radon Reduction Requirements

Source	Calculated Uncovered Radon Emission Rate (Bq/m^2/s)	Reduction Factor to Achieve 0.1Bq/m^2/s	Penetration of Cover (inverse of reduction factor)
TSF1	0.3	3.0	0.33
TSF2	0.5	5.0	0.20
TSF3	1.4	14	0.07

The cover options can be optimised, depending upon availability of cover material and can be a combination of the various materials. See the following examples:

- For TSF1, 0.5m of soil reduces the emissions to 0.15Bq/m^2/s and another 0.5m of soil reduces the emission to 0.075Bq/m^2/s.
- For TSF2, 0.5m of soil reduces the emissions to 0.25Bq/m^2/s and 0.24m of clay (which is 2 HVLs) reduces the emission to 0.06Bq/m^2/s.
- For TSF3, 0.5m of clay (which is approximately 4 HVLs) reduces the emissions to 1.4 x 0.5 x 0.5 x 0.5 x 0.5 = 0.09Bq/m^2/s.

Note that it is prudent to build in a level of additional protection, rather than designing exactly to the requirement.

3.3 Seepage

ATC 2017 notes that, the likelihood of seepage from the TSFs pond coming into contact with groundwater or surface water external to the facilities is very low. This is because the testwork has shown that the radionuclides in the tailings are fixed in the solids portion of the tailings solids and are immobile under both acidic and alkaline conditions.

In addition, the physical design requirements for the TSF include compacted clay bases for TSF1 and TSF 2 and a synthetic liner and clay base for TSF3.

Therefore, the seepage of radionuclides from the facilities is considered unlikely and very low risk.

4. SUMMARY

Using theoretical methods and experiences elsewhere, it is possible to provide an indication of the optimal depth of cover materials for the proposed TSFs to ensure that radiological emissions post closure result in radiation levels are that consistent with the regional levels.

Approximately 1m of compacted soils and crushed rock provides good attenuation for both gamma radiation and radon emission. The exact composition depends upon the quantities of uranium and thorium in the tailings and can be optimised dependent upon availability of cover materials.

5. REFERENCES

ATC 2017	Hastings Technology Metals Limited Yangibana Project Western Australia, Feasibility Study Design Tailings Storage Facilities, September 2017
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Diehl 2016	World Information Service on Energy (WISE) Uranium Project. www.wise-uranium.org Last accessed May 2017
JRHC 2016	Hastings Technology Metals Limited, Yangibana Rare Earths Project, Radiation Impact Assessment, December, 2016, JRHC Enterprises Pty. Ltd.
Radpro 2016a	Yangibana Rare Earths Project Baseline Radiation Report. A report prepared by Radiation Professionals for Hastings Technology Metals Ltd
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USEPA 1986	Final Rule for Radon-222 Emissions from Licensed Uranium Mill Tailings. Background Information Document, U.S. Environmental Protection Agency, Office of Radiation Programs, Washington, DC, August 1986, 226 p., Report No. EPA/520/1-86/009