HASTINGS
Technology Metals Limited

APPENDIX 5-2

Radiation Waste Characterisation Report

Radiation Waste Characterisation Report

HASTINGS TECHNOLOGY METALS LIMITED

Prepared by Radiation Professionals

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Document Information

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Contents

1 Introduction

The Yangibana Rare Earths Project (the Project) is located in the upper Gascoyne Region of Western Australia, approximately 220km north-northeast of Gascoyne Junction and 450km north east of Carnarvon by road.

Rare earths oxides (REO) are found in the phosphate mineral monazite within ferrocarbonatite veins. It is generally recognised that monazite contains low levels of radionuclides, predominantly thorium, with some uranium, and their respective decay progeny in approximate secular equilibrium. While levels of these parent radionuclides are low, they are present in sufficient concentrations to require that the Project complies with legislation governing the mining and processing of naturally occurring radioactive material (NORM).

As such, to-date, activities of the Project have involved mineral exploration under Programmes of Work approvals (Department of Mines and Petroleum [DMP]), and conform with a DMP Safety Resources-approved Exploration Radiation Management Plan. Radiation monitoring commenced at the site in 2014, and has continued to-date while exploration activities are on-going. Monitoring initially focused on occupational exposures of personnel engaged in exploration activities, but expanded to include environmental and baseline monitoring in 2015. Monitoring programmes are on-going, and are expected to continue and expand through exploration, construction and operations phases.

Exploration activities at the Project have defined a resource. The Project will be developed to include open cut pits and associated waste rock landforms, beneficiation and hydrometallurgical process plants, along with storage and disposal facilities for effluent and tailings streams from both plants. Additionally, the project will host an accommodation village, airstrip and ancillary infrastructure for power generation and water supply.

The Project is expected to mine approximately 1 000 000 tpa of ore, with an average input concentration of around 0.9% rare earths oxides (REO). The processing plant is expected to produce approximately 12 880 tpa of rare earth (RE) product, which will be transported by truck to a port for export to overseas treatment facilities. Approximately 7 million tpa of waste rock will also be mined.

As the project progresses through the Definitive Feasibility Study phase and then to construction and operations phases, further considerations of radiation in the proposed Project waste streams will be required. Consideration of radionuclide levels in waste streams are a component of a broader waste strategy that also considers physical and chemical characterisation parameters.

A risk-based approach to assess radionuclides in waste will ensure management and controls are commensurate with the magnitude of the radiological risk presented by each phase and facet of the operation, including decommissioning and closure.

2 Scope

This report is one of the Project's waste characterisation studies, which specifically addresses the presence of radionuclides in the waste streams generated during operations of the Project. The objectives of this study are to:

- Describe and characterise sources of radioactive materials within the project area.
- Assess distribution of radionuclides associated with the various waste streams.
- Provide practical considerations and approaches needed to maintain radiological exposures at levels that are as low as reasonably acceptable (ALARA).

The IAEA (2007) recommends waste characterisation throughout the waste life cycle:

- Generation (i.e. mining of waste rock and ore).
- Processing (i.e. treatment, conditioning).
- Disposal (i.e. tailings storage facilities and evaporation pond).

The focus of this report is on the processing component of the waste life cycle where radionuclides become concentrated in two of the three tailings streams, although generation and disposal are also considered.

3 Legislative Context

3.1 Key legislation

The primary guidance for radioactive material is found in state regulation, as well as national standards of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). Relevant laws and regulations relating to radioactive materials in mining and mineral processing are:

- *Radiation Safety Act 1975* (WA)
- Radiation Safety (General)Regulations 1983 (WA)
- Radiation Safety (Transport of radioactive substances) Regulations 2002 (WA)
- *Mine Safety and Inspection Act 1994* (WA)
- Mine Safety and Inspection Regulations 1995 (WA), Section 16

State legislation aligns with ARPANSA's national standards relating to radioactive waste.

The Department of Mines and Petroleum (DMP) also provide guidelines for managing naturally occurring radioactive material (NORM) in mining and mineral processing. Guideline NORM-3.1 *Monitoring NORM pre-operational monitoring requirements* (DMP 2010) is relevant to the characterisation of radioactive waste. NORM-3.1 states:

> *"All development proposals (exploration, mining, concentration/separation, chemical/thermal processing, waste disposal, etc.) must be evaluated and their potential effect assessed. One of the most important items to determine may be is to establish if naturally occurring uranium and thorium are in secular equilibrium with their decay products and if the proposed operation is likely to influence this secular equilibrium and the mobility of radionuclides in the environment. It should be noted that some minerals, despite being in their `natural state', may already be depleted of certain radioisotopes from thorium and/or uranium decay chains prior to exploration/mining/processing, and it is very important to establish if this is the case prior to the commencement of operations."*

3.2 Definitions

Radioactive material is defined, according to the *Radiation Safety Act 1975* (WA), as:

> ***"…*** *any substances, whether natural or artificial, and whether in the form of a solid, a liquid, a gas, or a vapour, or any compound or mixture, including any article that has been manufactured or subjected to any artificial treatment or process, which consists of or contains more than the maximum prescribed concentration of any radioactive element, whether natural or artificial"*

Also in the Radiation Safety Regulations 1983, Regulation 5:

> *"5. Radioactive substances for purposes of Act*
> *(1) Subject to this regulation —*
> *(a) a natural radioactive substance of an equivalent specific radioactivity not exceeding 0.03 megabecquerel per kilogram;"*

In the Radiation Safety (Transport of Radioactive Substances) Regulations 2002 (WA), radioactive material is defined as:

> *"… a radioactive chemical element in a concentration that makes it "radioactive material" within the definition of that term in Section II paragraph 236 of the International Regulations[1]."*

The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) is the Australian authority on radiological protection and has developed a national directory which provides standards and guidelines on radiation related matters (National Directory for Radiation Protection (NDRP), February 2014, ARPANSA).

The directory has been developed in consultation with all state authorities and the standards and guidance are intended for adoption in all Australian state and territory regulations. Although the NDRP has yet to be fully adopted across Australia, it is generally accepted. The NDRP is consistent with IAEA definitions and notes that material containing less than 1Bq/g of each naturally occurring radionuclide are exempt from radiation related regulation.

Therefore, according to WA, ARPANSA and International Regulations, material containing naturally occurring radionuclides in secular equilibrium, with head-of-chain (HOC) (uranium or thorium) activity concentrations less than 1Bq/g would be considered exempt from regulation. See Table 1 and

[1] The IAEA Specific Safety Requirements No. SSR-6 gives the Regulations for the Safe Transport of Radioactive Material. Section II par. 236 states:" *Radioactive material* shall mean any material containing radionuclides where both the activity concentration and the total activity in the *consignment* exceed the values specified in paras 402–407." This refers to the basic values for individual radionuclides and their exempt quantities as listed in this document and referenced above in Table 1.

Table 2 for additional information.

For NORM materials, 1Bq/g is equivalent to 81 ppm uranium or 245 ppm thorium. This also applies to the total activity combined if both decay chains are present. For example, the total activity of a material is 0.9 Bq/g if it contains a mixture with 0.6 Bq/g U-238 and 0.3 Bq/g Th-232.

Table 1: Exemption levels for individual nuclides

Radionuclide	Exemption Level (Bq/g)
U_{Nat}	1
U-238	10
Th-234	1000
U-234	10
Th-230	1
Ra-226	10
Pb-210	10
U-235	10
Pa-231	1
Ac-227	10
Th-227	10
Th_{Nat}	1
Th-232	1
Ra-228	10
Th-228	1

Table 2: Summary of legislative limits for exemption of radioactive material

Legislation/Regulation	Description
Radiation Safety Regulations 1983 (WA) Regulation 5	Radioactive substances for the purposes of the act: a natural radioactive substance of an equivalent specific radioactivity not exceeding 30 Bq/g
The National Directory for Radiation Protection, Part B, Section 3.2	The criteria to **exempt** radioactive material or practices from notification, registration and licensing are: (a) the radioactive material has an activity concentration less than that prescribed in Schedule 4 Table 1
Radiation Safety (Transport of radioactive substances) Regulations 2002 (WA) (*IAEA Standard, Section 1, 107*)	natural material and ores containing naturally occurring radionuclides that are either in their natural state, or have been processed only for purposes other than for the extraction of the radionuclides, and that are not intended to be processed for use of these radionuclides, provided that the activity concentration of the material does not exceed 10 times the values specified in para. 401(b), or calculated in accordance with paras 402–406;
Mine Safety and Inspection Regulations 1995 (WA) Section 16-3	The State mining engineer may, in writing, exempt a mine from all or part of this Division where the sum of the effective doses from external radiation and intake of radioactive dust is below 1 milliSieverts (0.001 Sv) per year for each employee and the long-term average concentration of radon in the workplace is below 1 000 becquerels per cubic metre, but only if the exposure to radon is due solely to adventitious exposure to natural sources of radiation.

4 Project Description

4.1 Generation

All current mining operations are based on the simple extraction of ore from a series of open pits. Waste rock material is then transported to designated waste rock landforms near each pit and the ore is transported to the central processing plant near Bald Hill.

Mining in softer ground will simply require an excavator, dozer and truck. However, in more competent ground, standard drill-and-blast, load-and-haul techniques will be used.

Waste rock characterisation has been carried out such that more inert materials will be stored separately and used as a capping over the final dumps at mine closure. Sequential stacking and waste landform building will enable any rock with elevated radionuclide concentrations to be diluted with or encapsulated beneath these inert cappings.

The ore will be stored temporarily on run-of-mine (ROM) pads adjacent to the processing plant prior to loading into the crusher system.

4.2 Processing

The REO targets of the project are found in monazite, which also contains low levels of radionuclides – predominantly thorium and uranium and their decay progeny in approximate secular equilibrium.

An on-site beneficiation plant would treat up to 1 million tonnes per annum (tpa) of mineralised monazite-bearing ore. Approximately 30,000 tpa of mineral concentrate would be produced and then further processed via a hydrometallurgical process. Approximately 12,000 tpa of rare earths product would result from the process plant. The rare earths product will be placed in containers in preparation for transport to port.

The beneficiation process would involve crushing, grinding, and flotation of the ore. The majority of waste product will be generated during the first flotation stage (rougher), and will be sent to Tailings Storage Facility 1 (approx. 932,000 tpa). Regrinding of the rougher concentrate and further flotation (flotation cleaners) will then generate an additional waste product and a clean concentrate. The waste from flotation cleaners will be thickened before being sent to Tailings Storage Facility 2 (approx. 37,000 tpa). Following thickening and filtration, the clean concentrate will be sent to the hydrometallurgical plant.

The hydrometallurgical plant will involve a sulphation bake in a kiln, and then a water leach step will leach the rare earths into solution. The acidic solution is then neutralised with magnesium oxide to remove several impurities including thorium from the solution. The residue is then filtered and separated from the solution. The residue is further treated with lime to ensure that it maintains its alkalinity, prior to being sent to the Tailings Storage Facility 3 (approx. 56,000 tpa). The leach liquor will be purified to remove residual uranium in solution prior to precipitation of the rare earths product. The effluent (approx. 480 000 m^3/annum) from the precipitation stage will be directed to the evaporation pond.

4.3 Disposal

During the Pre-Feasibility Study (PFS), a TSF options study (ATC Williams, 2016a) was undertaken. There are two stages of the processing plant: 1) Beneficiation process and 2) hydrometallurgical process, with the majority of tailings (95%) coming from the beneficiation process. The TSF options study focused on tailings from the beneficiation process (currently TSF1 and 2 combined). The production of and disposal of tailings waste took into account the following parameters:

- Production rate of 1Mtpa x 95%
- Life of Mine = 10 years
- Storage requirements of 9.5Mt
- Physical and chemical characteristics

The outcomes of these investigations are summarised in the *Yangibana Tailings Storage Facility Options Study* report (112391.03 R01; ATC Williams 2016). The report considered the following tailings disposal options:

- Conventional paddock system
- Integrated waste landform (IWL) incorporating tailings and mine waste
- Stacked, thickened discharge of tailings into a valley type impoundment
- Dry stacking of thickened and filtered tailings

Backfilling of the pits with tailings was not considered as a viable option because, "*…mineralisation in the proposed pits are expected to be open with depth, in-pit disposal has not been considered at this stage*" (ATC Williams (2016a))

Six different locations for the facilities were also considered in the study.

The study determined that the optimal disposal option was valley fill of either thickened or unthickened tailings in a location to the east of the process plant (ATC Williams, 2016).

The project design will include three separate tailings storage facilities as follows;

- A 6.6 mt capacity central discharge thickened facility for the concentrate tailings with compacted base.
- A 0.3 mt capacity lined surface facility for the rougher tailings.
- A 0.4 mt capacity lined surface facility for hydrometallurigcal waste.

In addition, a lined evaporation pond of ~36 ha capacity (conservative estimate based on the discharge of 480,000m3/annum of effluent) will also be constructed.

Design of the tailings facilities, evaporation pond and water storage pond take into account DMP and ANCOLD guidelines. A preliminary water balance conceptually assessed the likely contribution of return water from the TSF water storage pond to the process plant. The inputs of the water balance included rainfall run-off, tailings discharge water, and excess pit water discharge. Outputs of the water balance included evaporation, decant return water and seepage.

During DFS stage this design will be further refined based on outcomes of various studies including this report.

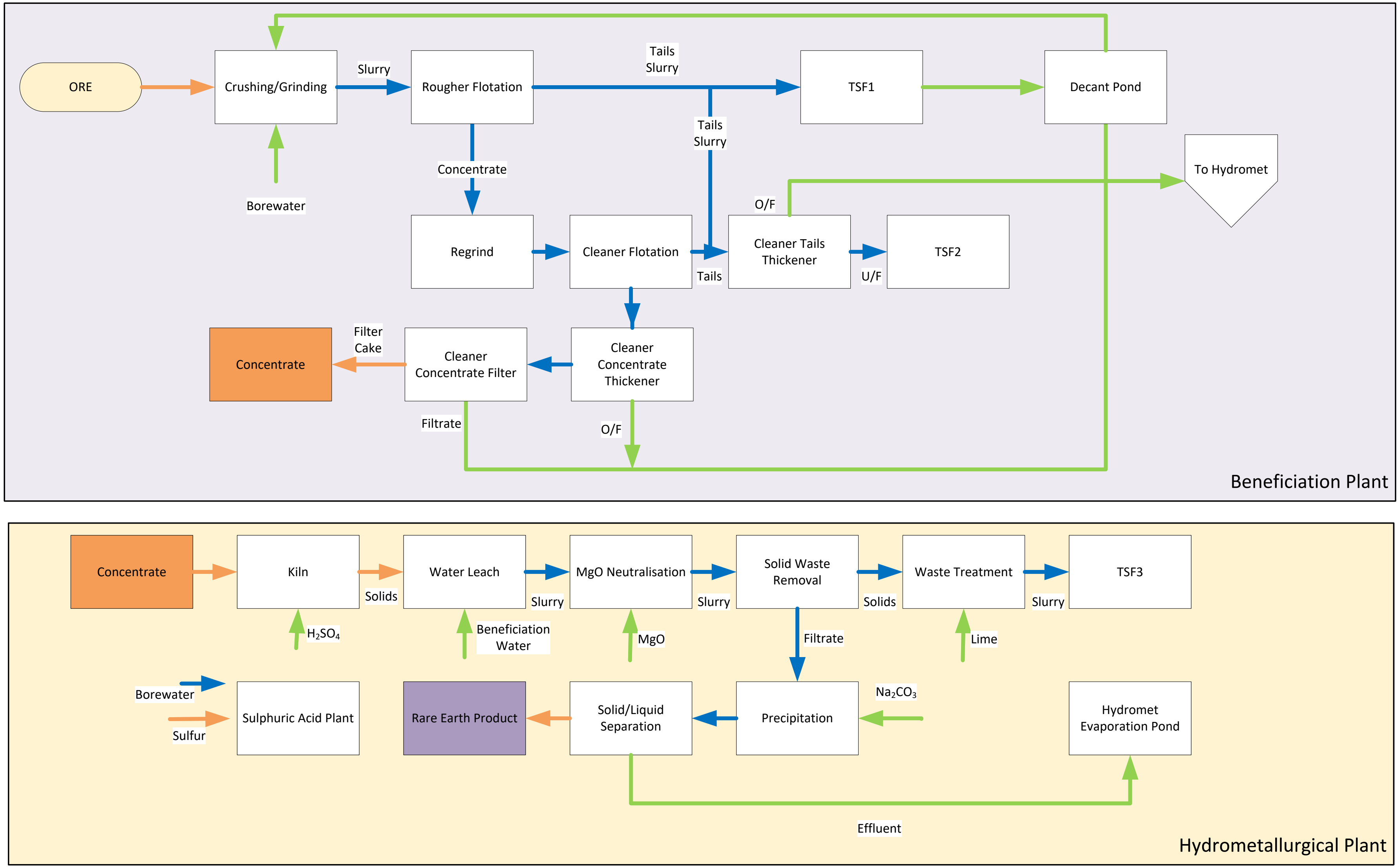

Figure 1- Overview of the Process Flow

5 Waste Characterisation

5.1 Mined Materials

Figure 2 shows the current known, and named deposits and prospects within the Yangibana Project (Border, 2016). The well explored targets with JORC Indicated Resources are at Bald Hill South, Fraser's and Yangibana West within tenements in which Hastings holds 100% interest, and Yangibana North in which it holds a 70% interest.

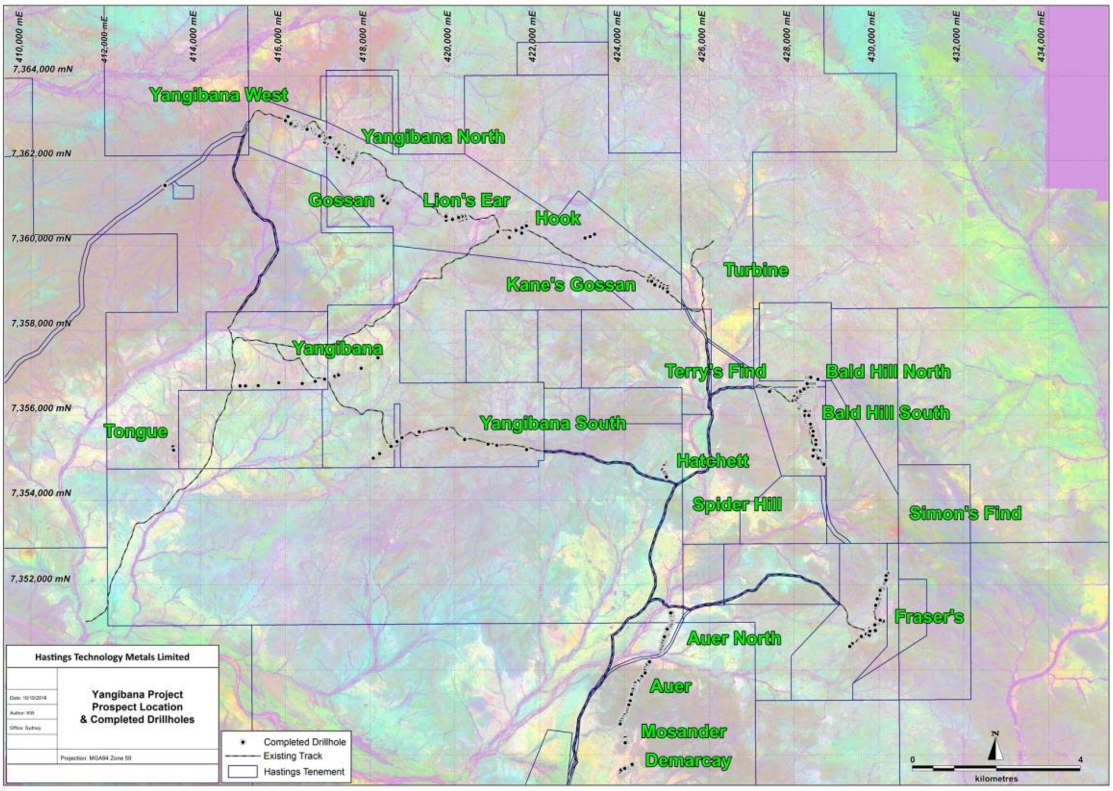

Figure 2 - Yangibana Project, location of defined rare earths targets

Figure 3 provides an image of thorium radiometric data from the 2016 aeromagnetic and radiometric survey, commissioned by Hastings and interpreted by Southern Geoscience Consultants Pty Limited (SGC). This survey identified a number of new targets that will be assessed over the coming years.

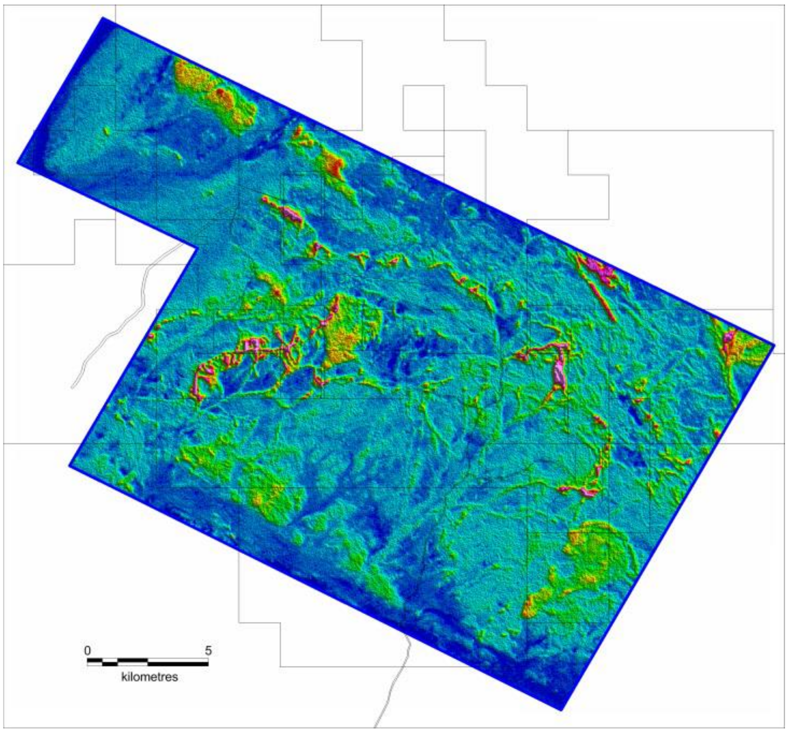

Figure 3– Yangibana Project, thorium radiometric image

The rare-earths bearing ironstone units are well defined by the thorium data due to the host mineral being monazite (Border, 2016). In particular, the semi-continuous belt of ironstone between Yangibana North and Kane's Gossan; the ironstone at Bald Hill South and its continuing trend south to Fraser's ironstone; and the ironstone belt that extends from east of Yangibana prospect to Tongue prospect, show extremely well in this data. The broad zones around particularly Bald Hill South and Yangibana-Tongue relate to the large quantities of ironstone scree at these sites and the concentration of finer ironstone scree in the small creeks flowing from them (Border, 2016).

5.1.1 Waste rock

The Project occurs within a range of structures that affect the basement of granitic and metamorphic rocks. The waste rocks to be derived from the mining operations are predominantly granite, with lesser schists and gneiss occurring locally (Figure 1). The hosts are both locally strongly weathered to clays and saprolite but only in regionally limited areas with large portions of the mineralised bodies hosted by massive, unaltered granite at surface. There is no expectation of any change in host rock lithology at the depths likely for mining.

Hastings has sampled the unmineralised material within a few metres of the mineralisation in all holes at all targets tested. All these intersections have been assayed for thorium and uranium as well as the target rare earths and other selected elements (Border, 2016). A total of 677 samples have been assayed from 28 drill holes (Yangibana North: 7 drill holes; Yangibana West: 3 drill holes, Frasers: 3 drill holes and

Bald Hill: 15 drill holes) and of these, 453 samples were considered waste rock. Forty two of the waste rock samples were considered to have NORM concentrations above 1 Bq/g.

In early 2015, Hastings undertook a limited programme of random sampling of material from the 2014 drilling programmes at Yangibana North and Bald Hill South. These samples provide analyses of material in the hanging wall well away from the mineralised zones (Border, 2016).

Table 3 shows the number of samples taken from each area and the mean ThO_2 and U_3O_8 values[2] derived from those analyses. For assessment purposes, samples from drilling have been split into those that are immediately adjacent to the mineralisation (usually up to 1m from mineralisation) and those slightly further from the mineralisation and carrying less than total rare earths oxides. The closer samples have been further split to show the association of Th and U with the higher REO grades.

Table 3 Yangibana Project, mean ppm ThO_2 and U_3O_8 values for waste rock samples

	Waste (Adjacent to ore and containing <0.1% REO)			**Waste (Adjacent to ore and containing <0.2% REO)**			**Non Mineralised Samples**		
	No.	**ThO_2**	**U_3O_8**	**No.**	**ThO_2**	**U_3O_8**	**No.**	**ThO_2**	**U_3O_8**
Bald Hill South	375	36	7	1645	81	10	10	33	11
Fraser's	234	30	8	480	57	10			
Yangibana North	185	25	6	497	78	9	54	24	6
Yangibana West	293	30	5	317	91	8			

These results indicate an elevated level of thorium in samples containing higher REO concentrations (Border, 2016).

Uranium levels are consistent and relatively low (Border, 2016).

In 2016, Landloch undertook additional rock chip sampling, which was analysed for thorium. Landloch (2016) reported the following levels (ppm) of thorium: Ironstone contained 188 ppm, surface granite contained 25.4 ppm and weathered granite contained 23.7 ppm of thorium.

[2] The samples were analysed for U and Th and converted to oxides.

provides a summary of the expected levels of mineralisation in the various types of materials as estimated for waste rock samples from existing exploration assays and lithology data.

Table 4 Estimated mineralisation of waste rock from exploration assay and lithology data.

Waste Rock Type	% of Total Waste Material**	Number of Samples	Elemental (ppm)				Total Activity*** (Bq/g)	
			U (Avg)	U (Max)	Th (Avg)	Th (Max)	Avg	Max
Aplite	0.5	22	6.1	13.2	65.9	508.1	0.34	2.18
Breccia	0.5	3	14.3	21.8	96.4	181.4	0.57	1.01
Diorite	0.5	3	4.3	6.1	46.4	79.5	0.24	0.39
Granite	70.0	268	6.3	57.8	71.4	1015.6	0.37	4.32
Granodiorite	0.5	1	2.8	-	55.5	-	0.26	-
Ironstone	0*	72	28.2	149.5	130	767.7	0.88	3.61
Pegmatite	2.0	7	6.9	48.5	56.4	194.2	0.31	0.81
Quartz Vein	5.0	15	6.5	24.9	67.5	251.2	0.36	1.15
Saprock	21.0	62	10.2	32.4	47.5	177.1	0.32	1.07

*The REE are found within the ironstone and thus only minor amounts are found in waste materials.

**Varies between locations

***Nuclide activities (U-238 & Th-232 derived from elemental ppm values)

The comprehensive assay programme conducted by Hastings to-date, shows that the majority of waste rock does not have NORM above 1 Bq/g. However the small proportion of the waste rock with NORM above 1 Bq/g, will be subject to a monitoring and management programme to guide the disposal methodology.

5.1.2 Ore

The Yangibana rare earths mineralisation is associated with rocks of the Gifford Creek Ferrocarbonatite Complex (GCFC). The GCFC is a high-level, carbonatite-associated igneous intrusive suite that includes localities such as the Yangibana ironstones (shown as Targets 1-10 in Figure 4) and ferrocarbonatites, the Spider Hill ring intrusion (Target 11 in Figure 4), and the Bald Hill intrusions. It is characterised by ferrocarbonatite dykes, veins and sills and surrounded by fenitised (due to wallrock metasomatism) country rocks, which are generally southeast to east-southeast trending. They consist of dolomite, ankerite and siderite with accessory minerals that include magnetite, and the REE-bearing mineral phosphate monazite [usually $(Ce,La,Nd)PO_4$].

Sinuous ironstone veins and pods (mainly magnetite, hematite and goethite) are spatially associated with (but likely post-date) the ferrocarbonatite intrusions. They are north-northeast to east-southeast trending, surrounded by narrow haloes of fenitic alteration and are locally anomalously radioactive. Based on resource estimations the overall average values for the mineralisation within the Yangibana Project is 25ppm U_3O_8 and 450ppm ThO_2[3].

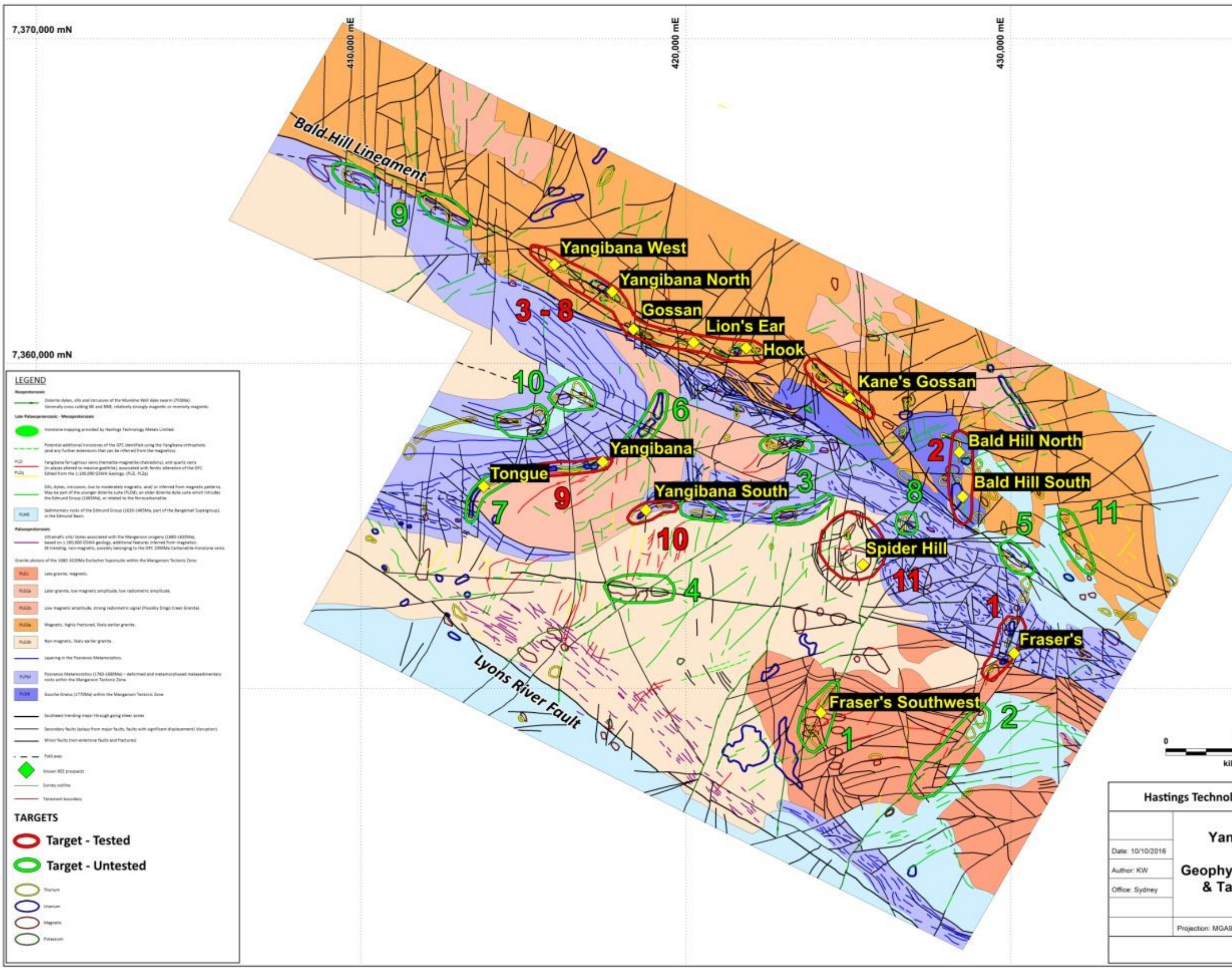

Figure 4 Geophysical interpretation and resource targets within the Yangibana Rare Earths Project area

[3] The samples were analysed for U and Th and converted to oxides.

5.2 Processing and Disposal Materials

5.2.1 Modelled Concentrations

In order to understand material flow into, within and out of the processing plant a METSIM model was constructed. The model incorporates mining rates, ore grades and information generated during the metallurgical testwork programmes to produce a simulation of the operations. The model enables the quantity and composition of the streams within the processing plant and the various outputs (TSF 1, 2, 3, rare earth carbonate product and evaporation pond) to be determined. The model will be continuously updated as new information becomes available.

Table 5 shows the estimated concentrations for material currently associated with the planned process involved in this project.

Table 5 Estimated elemental uranium and thorium content of materials for various stages of the process

	Ore	TSF1	TSF2	TSF3	Conc	Rare Earth Product
tpa Solids	1,000,000	932,133	37200	56000	30667	12880
% w/w Solids	92	28	20	30	85	65
ThO_2 ppm	450	147	1922	5092	9298	6
U_3O_8 ppm	27	23	45	94	171	267

5.2.2 Radionuclide Analysis

Batch laboratory test work of the process are now underway and representative samples of waste streams have been collected to undertake mass flow analysis. Further radionuclide analysis of these samples will be undertaken to determine the radionuclide balance and to verify the results from the modelling described in section 5.2.1.

At the time of producing this report, radionuclide analysis had been completed on five solid and two liquid samples. The solid samples included:

1) Ore entering the process circuit.
2) Tailings from first stage beneficiation (going to TSF 1).
3) Tailings from second stage beneficiation (going to TSF 2).
4) Tailings from hydrometallurgical processing (going to TSF 3).
5) Concentrate from first and second stage beneficiation, input to the hydrometallurgical processing.

The liquid samples included:

1) Decanted water from the first stage tailings stream (TSF1 decant).
2) Decanted water from the first stage tailings stream (TSF2 decant).

Additional samples, which are yet to be analysed, include:

- TSF3 solution.
- Evaporation pond solution.
- Rare earth carbonate product.

The above samples will be generated in future testwork, and submitted for radionuclide analysis.

The analysis of the samples was performed by Queensland Health laboratory and the resulting report (LSL_HAS150225_L601_3) is provided in Appendix A. The method used to determine levels of radionuclides in the process streams were high resolution gamma spectrometry for solid samples and the sequential determination of Pb-210 and Po-210 in water. High resolution gamma ray spectroscopy is considered best practice for the quantification of radionuclides in environmental media, water and soils.

Radionuclide concentration analysis show that the ore, TSF1 and TSF2 material are in approximate secular equilibrium (Table 6). Furthermore, the tailings generated from the first stage beneficiation process, which comprise over 90% of the tailings generated, does not exceed 1Bq/g for U-238 or Th-232 as heads of chain. Therefore, tailings material in TSF1 is classified as non-radioactive.

All other material streams (i.e. TSF 2 and TSF 3 tailings materials, and concentrate) indicate either Th-232 or both U-238 and Th-232 concentrations exceed 1Bq/g (Table 4). Therefore, the rare earths flotation concentrate and tailings waste streams (specifically for TSF 2 and 3) are classified as radioactive.

Table 6 Summary of radionuclide analysis

Radionuclide (Bq/g)	Ore	TSF1	TSF2	TSF3	Conc
Th-234	0.33 ± 0.05	0.21 ± 0.02	0.52 ± 0.05	0.77 ± 0.09	0.92 ± 0.08
Ra-226	0.37 ± 0.02	0.25 ± 0.02	0.59 ± 0.03	1.45 ± 0.09	2.21 ± 0.13
Pb-210	0.16 ± 0.02	0.16 ± 0.02	0.31 ± 0.05	0.43 ± 0.08	0.30 ± 0.05
U-235	<0.04	<0.01	<0.01	<0.03	<0.03
Pa-231	<0.03	<0.02	<0.06	<0.14	<0.1
Th-227	<0.02	<0.008	<0.03	<0.07	<0.3
Ac-228	2.0 ± 0.1	0.36 ± 0.02	5.7 ± 0.3	21.7 ± 1.3	37.7 ± 2.3
Ra-224	2.1 ± 0.12	0.38 ± 0.02	6.2 ± 0.36	22.7 ± 1.3	37.1 ± 2.2
K-40	0.78 ± 0.05	0.67 ± 0.4	0.50 ± 0.03	0.20 ± 0.04	2.7 ± 0.25

The hydrometallurgical process is a chemical process involving leaching and chemical separation. This results in variations in radionuclide concentrations in the materials as shown in Table 7.

No sampling of the product or water that flows to the hydrometallurgical evaporation pond has been performed yet. These will be analysed and results included in future revisions of this report.

Table 7 Radioactive element mass balance

		Material	Uranium		Thorium		U+Th
		tpa	Bq/g	ppm	Bq/g	ppm	Bq/g
INPUT	Beneficiation						
	Ore	1,000,000	0.37	29.97	2.10	516.60	2.47
OUTPUT	TSF1	932,133	0.25	20.25	0.38	93.48	0.63
	TSF2	37,200	0.59	47.79	6.20	1525.20	6.79
	Concentrate	30,667	0.92	73.8	37.7	9274.2	38.62
	Waste Rock	7,000,000	0.31	73.8	0.13	10.4	0.44
INPUT	Hydrometallurgical						
	Concentrate	30,667	2.20	178.20	37.10	9126.60	39.30
OUTP	TSF3	56,000	1.45	117.45	22.70	5584.20	24.15
	Product*	12,880	3.3	267**	0.02	6	3.32

**Results for the Waste Rock and Product was based on estimations as per information given. No radionuclide analysis results were available for product material, only elemental assay results.*
U-238 & Th-232 values derived from ppm values
***One of the objectives of the current metallurgy program is to reduce U to less than 10ppm.*

5.2.3 Comparison of modelled concentrations and analysis data

A comparison of the estimated radionuclide concentrations (described in Section 5.2.1) with the results from the radionuclide analysis (described in Section 5.2.2) verifies the model outcomes. Overall, the results are very closely aligned (Table 6). The model overestimated the concentrations of radionuclides in TSF1 and TSF2 tailings waste streams.

Table 6: Comparison of Estimated Radionuclide Concentrations (Estim) with those of the Analysis (Anal) of samples from batch laboratory tests for the Ore, Tailings Storage Facility (TSF) 1, 2 and 3 tailings, and the concentrate (Conc).

	EBM Ore		TSF1		TSF2		TSF3		EBM Conc	
	Anal	Estim	Anal	Estim	Anal	Estim	Anal	Estim	Anal	Estim
Th ppm	480	450	86.4	147	1368	1922	5208	5092	9048	9298
U ppm	26.73	27	17.01	23	42.12	45	62.37	94	74.52	171
U+Th Bq/g	2	~2	0.36	~0.9	5.7	~9	21.7	22	37.7	~40

6 Discussion

6.1 Practical considerations

A risk based approach to assess radionuclides in waste will ensure management and controls are commensurate with the magnitude of the radiological risk presented by each phase and facet of the operation, including decommissioning and closure. The following sections highlight aspects of the Project that have the potential to carry high risk associated with radioactive waste. Management considerations are also listed.

The outcomes of the waste characterisation highlight specific phases that will present risk, namely:

- Processing
- Disposal

6.1.1 Generation

6.1.1.1 Potential Risks

Mining of waste rock containing low-level radionuclides triggers an exemption as referenced in *The National Directory for Radiation Protection* (Part B, Section 3.2), which provides exemptions from regulatory control where the concentration of each radionuclide in raw materials is less than 1Bq/g. A small portion of the waste rock will contain NORM with levels greater than 1Bq/g. Where regulatory control is determined necessary by the authority, the level of control should be commensurate with the risk. Characterisation of the target ore shows NORM levels do exceed 1Bq/g. Therefore no exemptions apply under *The National Directory for Radiation Protection* (Part B, Section 3.2).

6.1.1.2 Mitigation

A Baseline Radiation Report accompanies this report, which provides pre-operational monitoring results, taking into account *NORM Guideline 3.1 Pre-operational Monitoring* (DMP, 2010), and in accordance with the requirements of Regulation 16.6 of the Mine Safety and Inspection Regulations 1995 (WA).

A Construction Radiation Management Plan (RMP) and an Operations RMP will be prepared in accordance with the requirements of Regulation 16.7 of the Mine Safety and Inspection Regulations 1995 (WA; MSIR). The RMPs will identify risks and mitigation to ensure risks are reduced to ALARA, and include monitoring, training and reporting. In addition, the RMPs will also designate controlled or supervised areas and outline the waste management system. A separate Radioactive Waste Management Plan (RWMP) will be prepared for the project and will include specific information on:

- restricted release zones;
- facilities and procedures involved in the handling, treatment, storage and disposal of radioactive waste; and
- an outline of the proposal for the eventual decommissioning and rehabilitation of the mine (MSIR, R16.31).

6.1.2 Processing

6.1.2.1 Potential Risks

The concentration of radionuclides within the processing plant (beneficiation and hydrometallurgical processes) will present potential risks of:

- Exposure to the workforce.
- Release of radioactive materials to the surrounding environment.

6.1.2.2 Mitigation

A Construction Radiation Management Plan and an Operations Radiation Management Plan will need to be prepared, approved by the State Mine Engineer and implemented (MSIR, R16.7) as described in Section 6.1.1.2.

The processing plant, or components of it, will be 'controlled' areas, and as such:

- access will be limited to certain persons who are qualified or trained to work in this area;
- the boundaries of the area will be clearly delineated and made known to employees at the mine; and
- any person entering the area will receive appropriate instructions about the nature of the radiation hazards in the area (MSIR, R16.12)

Design of the processing plant will need to consider the management of radioactive waste and concentrate streams using best practicable technology having regard to:

- achievable levels of effluent control and the extent to which pollution and degradation of the environment is minimized or prevented in comparable mining operations elsewhere;
- the cost of the application or adoption of that technology relative to the degree of radiological and environmental protection expected to be achieved by its application or adoption;

- evidence of detriment or lack of detriment to the environment after the commencement of mining operations;
- the location of the mine;
- the age of the equipment and facilities in use for mining purposes and their relative effectiveness in achieving radiological and environmental protection; and
- potential long term hazards from the wastes (MSIR, R16.1).

6.1.3 Disposal

6.1.3.1 Potential risks

The lower than background levels and less than 1 Bq/g of each radionuclide in tailings generated from the first stage of the beneficiation process indicate that TSF 1 will be exempt from regulatory control in relation to radionuclides. Over 90% of tailings waste will be disposed in this facility.

The human health and environmental risks associated with the source (TSF 1), practice or type of person using TSF 1 are sufficiently low as to be of no regulatory concern in relation to radiation.

However, TSF 2 and 3 contain radioactive waste as per the definitions within the State regulation, as well as national standards of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (Section 3).

The following potential risks associated with the disposal of high levels of radionuclides in TSF 2 and 3 include:

- Seepage to the surrounding environment;
- Dust generation;
- Contaminated surface water; and
- Long-term TSF integrity following decommissioning and closure.

6.1.3.2 Mitigation

A Radiation Waste Management Plan (RWMP) will describe a waste management system (MSIR, R16.7) that identifies specific risks and mitigation to reduce potential risks to ALARA, monitoring, review and auditing, and reporting. The waste management system will also include details of:

- restricted release zones; and
- facilities and procedures involved in the handling, treatment, storage and disposal of radioactive waste; and

- an outline of the proposal for the eventual decommissioning and rehabilitation of the mine (MSIR, R16.7).

Design of TSF 2 and TSF 3 will need to use best practicable technology (as described for the processing plant in Section 6.1.2.2) and minimize the release of radioactivity (MSIR, R16.33).

7 Conclusion

Waste characterisation has been undertaken for three phases of mining operations, namely:

- Generation
- Processing
- Disposal

Radionuclide levels in all but the TSF1 waste stream have triggered exceedances identified in relevant legislation (as summarised in Table 8). Taking into account that the Uranium decay chain has 13 daughters and the thorium decay chain has 9 daughters with equal activities as the parent when in secular equilibrium. Three out of the four waste streams have shown elevated radionuclide concentrations. As a result a greater level of consideration of risk associated with radiation is required in the handling of the ore during the generation phase, the concentrate during the processing phase, two of the tailings streams (TSF 2 and 3) during the disposal.

Additional samples, which are yet to be analysed, will need to be assayed, and include:

- TSF3 solution
- Evaporation pond solution
- Rare earth carbonate product

Engineering design considerations, of the processing and TSF 2 and 3 facilities, and the evaporation pond, will need to use 'best practicable technology'.

In addition, the following management plans will also need to be developed, approved and implemented:

- Construction RMP
- Operations RMP
- Radiation Waste Management Plan

The radionuclide levels in the product will also need verification, with levels estimated in the model, and a Radiation Transport Management Plan will need to be developed.

Table 8 Summary of radionuclide concentrations of various process materials and waste streams

	Applicable Regulations	Exceed	Not Exceed	U-238 (Bq/g)	Th-232 (Bq/g)	U +Th (Bq/g)
Ore	Radiation Safety Regulations, 1983 WA Regulation 5		x	0.37	2.1	2.47
	The National Directory for Radiation Protection, Part B, Section 3.2	x				
	Radiation Safety (Transport) Regulations WA *(IAEA Standard, Section 1, 107)*	x				
Waste rock	Radiation Safety Regulations, 1983 WA Regulation 5		x	0.31	0.13	0.44
	The National Directory for Radiation Protection, Part B, Section 3.2		x			
	Radiation Safety (Transport) Regulations WA *(IAEA Standard, Section 1, 107)*		x			
TSF1	Radiation Safety Regulations, 1983 WA Regulation 5		x	0.25	0.38	0.63
	The National Directory for Radiation Protection, Part B, Section 3.2		x			
	Radiation Safety (Transport) Regulations WA *(IAEA Standard, Section 1, 107)*		x			
TSF2	Radiation Safety Regulations, 1983 WA Regulation 5	x		0.59	6.2	6.79
	The National Directory for Radiation Protection, Part B, Section 3.2	x				
	Radiation Safety (Transport) Regulations WA *(IAEA Standard, Section 1, 107)*	x				
TSF3	Radiation Safety Regulations, 1983 WA Regulation 5	x		1.45	22.7	24.15
	The National Directory for Radiation Protection, Part B, Section 3.2	x				
	Radiation Safety (Transport) Regulations WA *(IAEA Standard, Section 1, 107)*	x				
Concentrate	Radiation Safety Regulations, 1983 WA Regulation 5	x		2.2	37.1	39.3
	The National Directory for Radiation Protection, Part B, Section 3.2	x				
	Radiation Safety (Transport) Regulations WA *(IAEA Standard, Section 1, 107)*	x				

8 References

ATC Williams. 2016a. *Yangibana Project Tailings Storage Facility Options Study*. A report prepared by ATC Williams for Hastings Technology Metals Limited. April 2016.

ATC Williams. 2016b. *Yangibana Project Pre-Feasibility Study of Tailings Storage Facility*. A report prepared by ATC Williams for Hastings Technology Metals Limited. April 2016.

Border, Andrew. 2016. *Yangibana Geological Profile and Radionuclide Analysis*. Technical Note. Hastings Technology Metals. 27 October 2016.

Department of Mines and Petroleum, 2010. Managing naturally occurring radioactive material (NORM) in mining and mineral processing guideline. NORM-3.1. Monitoring NORM pre-operational monitoring requirements guideline: Resources Safety, Department of Mines and Petroleum, Western Australia, 19pp

Radiation Safety Act, 1975 (WA)

Radiation Safety (Transport of Radioactive Substances) Regulations, 2002 (WA)

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), National Directory for Radiation Protection (NDRP), 2014

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing, 2005

Appendix A

LABORATORY REPORT

Report Number: LSL_HAS150225_L601-3
Report Date: Tuesday, 18 October 2016

A. CLIENT:

Company Name:	Hastings Technology Metals
Address:	Suite 2508, Level 25 St Martins Tower 31 Market Street Sydney, WA 6000

B. SAMPLE DESCRIPTION:

Sample Matrix:	5x Solid, 2x Liquid
Quantity:	7
Analysis Required:	Gamma Spectrometry – Th^{234}, Ra^{226*}, Pb^{210}, U^{235}, Pa^{231}, Ac^{228}, Th^{227}, Ra^{224*}, K^{40} Alpha Spec – Po^{210} Liquid Scintillation – Pb^{210}

C. RECEIVAL

Date:	8 August 2016
Packaging:	Sample Jars

D. METHOD REFERENCES

QIS 25279 QHFSS in-house method, based on ISO18589-2&3:2015 (soil) and ISO10703:2007 (water)
QIS 32270 QHFSS in-house method Lead 210
QIS 32270 QHFSS in-house method Polonium 210

E. UNCERTAINTY

Activity concentrations stated as x ± U (k=2, 95%CI) or as <MDL (minimum detectable level).

Analysed by: Mr. Ross Kleinschmidt
Position: Principle Health Physicist
Radiation and Nuclear Sciences
Date: October 18, 2016