HASTINGS
Technology Metals Limited

APPENDIX 5-3

Waste characterisation update

HASTINGS

TECHNOLOGY METALS LIMITED

Yangibana Rare Earths Project

Waste Characterisation Update

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Jim Hondros

JRHC Enterprises Pty. Ltd.

PO Box 372,

Stirling, SA 5152

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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 2014). The majority of the radionuclides will report through to waste streams and be disposed in the TSFs.

As part of the project approvals process, Hasting has characterised the various waste streams and conducted assessments of the radiological impacts of the proposed operations (Hastings 2017). The preliminary work was used to estimate the deportment of radionuclides to the waste streams and assist with project design.

Additional pilot test work of the processing flowsheet has since been undertaken by ANSTO (ANSTO 2017), which includes analysis of the waste streams in order to better characterise their radiological characteristics. This work involved radionuclide analysis of both solids and liquid portions of the various tailings streams. Radionuclides analysed, were from the uranium 238 (U-238), thorium 232 (Th-232) and uranium 235 (U-235) decay chains.

This technical note provides a summary of the recent ANSTO radiological testwork of the waste streams and compares the results with the levels reported in earlier works. The results are summarised in a radionuclide deportment table (see table 5), which provide an indication of where the input radionuclides report in the process. There is a focus on the radionuclide deportment to the different waste streams. The deportment table is similar to "mass balance", however, due to the very low masses of radionuclides present, it is usual to consider the activity levels of the radionuclides.

A summary of the solubility of the radionuclides in also made.

2. BACKGROUND

Processing wastes are intended to be disposed into three TSF's depending upon where the waste is generated. This is due to the variable chemical properties of the waste streams and also the radionuclide composition. TSF-1 will store beneficiaiton tailings which will not contain radionculides above the criteria for classification as radiaoctive. TSF-2 and TSF-3 will take waste streams from further in the processing with higher concentrations of radionuclides.

A summary of the original radionuclide composition of the various process and waste streams is shown in table 1 (Hastings 2017; pers. comm. L. Jefferson).

Table 1: Material Processing Summary

Material	Processing or Disposal	Approximate Quantity (tpa)	Radionuclide Concentration (Bq/g – head of chain)	
			Uranium	Thorium
Ore	Benefication plant	1,000,000	0.37	2.1
Waste Rock	Disposal	7,000,000	0.31	0.13
Beneficiation Concentrate	Hydrometallurgical plant	30,677	0.92	37.7
Beneficiation – Rougher circuit tailings	TSF 1	9,239,000 to 9,336,000 (89-91% of tailings)	0.25	0.38
Beneficiation – Cleaner circuit tailings	TSF 2	38,700 to 48,400 (3.7-4.7% of tailings)	0.59	6.20
Hydrometallurgical Plant Tails	TSF 3	63,800 (6% of tailings)	1.45	22.7
Final Product	Export	13,000-15,000	<1	0.02

3. SUMMARY OF RECENT ANSTO WORK

3.1 Background

Prior to summarising the recent ANSTO work, the caveats on the work should be presented. These are summarised below:

- Po210 results are indicative only – incomplete sample dissolution occurred.
- Th230 was difficult to detect due to interference from Th232 in sample analysis, however, it is noted that thorium should behave chemically identically).
- Beneficiation tailings (for TSF 1) samples should be considered to be in secular equilibrium despite variations. This is due to variance in analysis techniques.
- Many results are below the minimum detectable level for liquids.

3.2 Results - Overview

The results presented in the ANSTO report are summarised as follows.

- The TSF 1 solid contained 0.45 Bq/g of Th-232 and 0.30 Bq/g of U-238 and is below the reference cut off concentration of 1 Bq/g of any radionuclide.
- The TSF 2 and TSF 3 solids contained radionuclide concentration levels above the reference cut off concentration of 1 Bq/g of any radionuclide.
- The TSF 2 solid contained a concentration of approximately 3.9 Bq/g of Th-232 decay chain and 0.52 Bq/g of U-238 decay chain radionuclides
- The TSF 2 liquids contained radionuclide concentrations less than the minimum detectable levels for the respective radionuclides.
- The TSF 3 solid contained radionuclides are in approximate secular equilibrium, with maximum concentrations radionuclides form the Th232 decay being 31 Bq/g and from the U-238 decay chain being 2Bq/g
- The TSF 3 liquids contained radionuclide concentrations that are mostly less than the minimum detectable levels for the respective radionuclides.

TSF 1 tailings is not defined as radioactive, because the sum of the radionuclides from the U-238 and Th-232 decays chains total less than 1Bq/g for heads of chain. The tailings is therefore characterised as a material containing a total of 0.75Bq/g.

3.3 Results – Further Details

Table 2 provides a summary of the ANSTO metal analysis of uranium and thorium. The results show that uranium and thorium do not report to liquids in any of the tailings streams.

Table 2: Analyses of Thorium and Uranium Elements in Various Materials

Material	Thorium (ppm)	Uranium (ppm)
Concentrate	7,950	154
Final Product	12	6
TSF 1 Solids	110	24
TSF 1 Liquors	< 0.01	< 0.01
TSF 2 Solids	860	42
TSF 2 Liquors	< 0.01	< 0.01
TSF 3 Solids	7540	110
TSF 3 Liquors	< 0.01	< 0.01

Table 3 and 4 provide a summary of the measured radionuclide concentrations in the tailings and process streams. It is important to note that the units for solids are Becquerels per gram (Bq/g) and the units for liquids are Becquerels per litre (Bq/L). There is a 1,000 fold difference in volume when comparing grams and litres.

Table 3*:* Radionuclide Concentrations in Various Waste Streams

	TSF1 Solid	TSF 1 Water	TSF2 Solid	TSF2 Water	TSF3 Solid	TSF3 Liquid	Barren Liquor
	Bq/g	Bq/l	Bq/g	Bq/l	Bq/g	Bq/l	Bq/l
Natural Thorium Decay Chain Radionuclides							
Th232	0.45	<0.04	3.5	<0.04	31	<0.04	<0.4
Ra228	0.33	<0.12	3.9	<0.15	30	<0.11	<0.1
Th228	0.34	<0.04	3.7	<0.1	30	0.25	<0.04
Ra224	0.32	<0.47	3.7	<0.58	30	<0.45	<0.45
Natural Uranium (U238) Decay Chain Radionuclides							
U238	0.3	<0.12	0.52	<0.12	1.36	<0.12	<1.2
Th230	0.22	<2.5	0.98	<4.7	n.d.	4.2	<3.9
Ra226	0.27	<0.09	0.5	<0.11	2	<0.08	<0.08
Pb210	0.31	<0.72	0.54	<0.93	1.9	<1.1	<0.77
Po210	0.23	<0.02	0.46	<0.02	1.2	0.03	<0.02
Natural Uranium (U235) Decay Chain Radionuclides							
U235	0.014	<0.21	0.024	<0.28	0.063	<0.23	<0.24
Pa231	0.049	<0.9	0.14	<0.72	<0.4	<0.25	<0.68
Ac227	0.0093	<0.12	0.046	<0.15	<0.26	<0.12	<0.09
Th227	0.0093	<0.12	0.046	<0.15	<0.26	<0.12	<0.09

Note that "n.d." refers to not detected

Table 4: Radionuclide Concentrations in Various Process Streams

	Ore	Concentrate	Final Product
	Bq/g	Bq/g	Bq/g
Natural Thorium Decay Chain Radionuclides			
Th232	2.1	32	0.05
Ra228	2.1	32	<0.0063
Th228	2.1	32	0.009
Ra224	2.1	32	<0.02
Natural Uranium (U238) Decay Chain Radionuclides			
U238	0.37	1.91	<0.074
Th230	0.37	n.d.	<0.26
Ra226	0.37	2.1	<0.004
Pb210	0.37	2.5	<0.13
Po210	0.37	0.9	0.05
Natural Uranium (U235) Decay Chain Radionuclides			
U235	0.01	0.088	<0.015
Pa231	0.01	<0.23	<0.035
Ac227	0.01	<0.36	0.165
Th227	0.01	<0.36	0.165

Table 5 provides a summary of the percentage deportment of radionuclides to the various outputs (final product and waste streams). Note that the percentage deportment is indicative due to a number of measured results being less than the minimum detectable level.

Table 5: Percentage Radionuclide Deportment to Waste Streams

	Percentage Deportment (%)			
	Final Product	TSF-1	TSF-2	TSF-3
Natural Thorium Decay Chain Radionuclides				
Th232	0	18	6	76
Ra228	0	14	7	79
Th228	0	15	6	79
Ra224	0	14	7	79
Natural Uranium (U238) Decay Chain Radionuclides				
U238	0	74	5	20
Th230	1	64	11	24
Ra226	0	66	5	29
Pb210	0	69	5	26
Po210	0	71	6	23
Natural Uranium (U235) Decay Chain Radionuclides				
U235	1	74	5	20
Pa231	1	62	7	30
Ac227	8	32	6	54
Th227	8	32	6	54

3.4 Solubility of Radionuclides

The solubility of radionuclides in the various tailings streams can be determined by comparing the radionuclide concentrations in the solids streams and the liquid streams for each type of tailings. The solubility will primarily be a function of the element rather than the radionuclide (or radioisotope), therefore average elemental solubility assessments are shown in Table 6. Caution should be exercised when considering the results because in the majority of cases, radionuclide concentrations in liquids were recorded as less than the minimum detectable level and this has been noted in the comments column.

To provide a qualitative measure of the relative solubility of radionuclides in tailings, a "solubility ratio" has been determined by dividing the activity concentration in solids (in Bq/g) by the activity concentration in liquids (in Bq/l) divided by 1,000. (Note that the division by 1,000 ensures that the volumes of the solids and liquids are comparable). The solubility ratio is intended to only provide an indication of the relative quantities of radionuclides that dissolve from solids phase of tailings into the liquid phase.

Table 6: Solubility of Elements in Tailings Streams

	Solubility Ratio (Bq/g per Bq/mL)			**Comments**
	TSF-1	**TSF-2**	**TSF-3**	
Thorium	10,000	50,000	400,000	Th232 and Th228 only. Th230 masked by Th232 and Th227 all results (solids and liquors less than MDL*)
Uranium	2,500	4,000	10,000	U238 only
Radium	3,000	15,000	100,000	Ra226, Ra228 only
Polonium	10,000	20,000	40,000	Po210 only
Lead	400	600	1,700	Pb210 only
Actinium	100	300	2,000	Ac227 only
Protactinium	50	200	2,000	Pa231 only

*MDL – Minimum Detectable Limit

The definition of solubility (from Solubility 2017) are summarised as follows:

- A material will be defined as "sparingly soluble" if the amount that can be dissolved in 100ml of solute ranges between 1g and 3g.
- A material will be defined as "slightly soluble" if the amount that can be dissolved in 100ml of solute ranges between 0.1g and 1.0g (equivalent to a "solubility ratio" of between 100 and 1,000).
- A material will be defined as "very lightly soluble" if the amount that can be dissolved in 100ml of solute ranges between 0.01g and 1g (equivalent to a "solubility ratio" of between 1,000 and 10,000).
- A material will be defined as "Insoluble or practically insoluble" if the amount that can be dissolved in 100ml of solute is less than 0.01g (equivalent to a "solubility ratio" greater than 10,000).

Table 6 shows that generally radionuclides have a low level of solubility as follows:

- All radionuclides are very lightly soluble to insoluble in TSF-3 tailings.
- Uranium, radium and polonium are very lightly soluble to insoluble in all tailings.
- Lead actinium and protactinium are slightly soluble in TSF-1 and TSF-2 tailings (however, care should be made with this assumption given that all liquid results were less than the minimum detectable levels).

In general, it can be concluded that the vast majority of radionuclide remain in the solids phase rather than the liquids phase of the tailings.

4. CONCLUSION

The key observations of the ANSTO radionuclide characterisation work are as follows:

- The majority of radionuclides in ore report through to tailings.
- The majority of the liquid streams (also known as tailings liquor) gave results that were less than the minimum detectable level.
    - This would indicate that radionuclides have low solubility and remain in the solids phase of the tailings.

REFERENCES

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