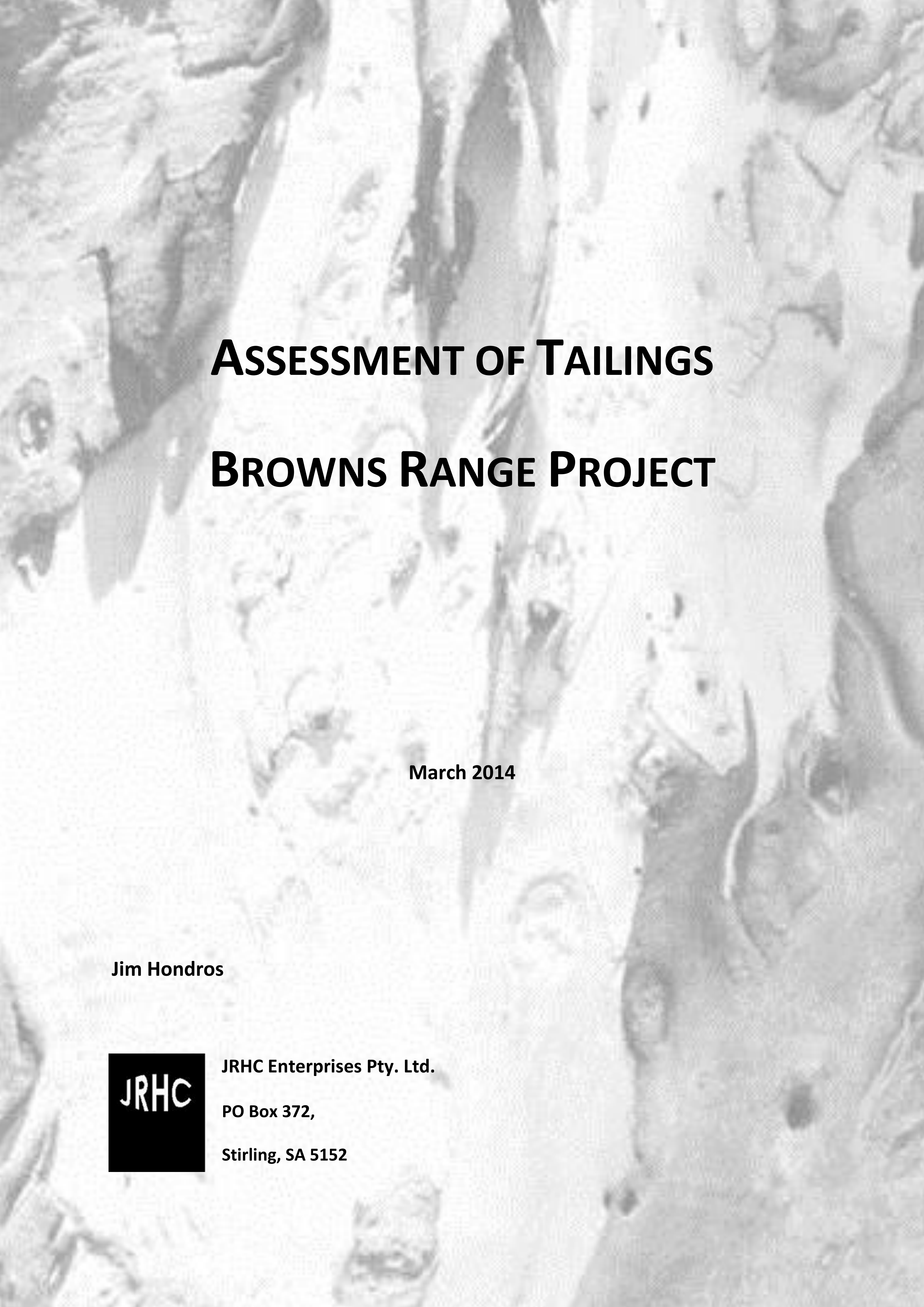

ASSESSMENT OF TAILINGS

BROWNS RANGE PROJECT

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Jim Hondros

JRHC Enterprises Pty. Ltd.

PO Box 372,

Stirling, SA 5152

INTRODUCTION

JRHC Enterprises has been requested to provide advice on the radiological classification of the tailings that would be generated from the Northern Minerals' (NML) Browns Range Rare Earths Project. This involves reviewing the results of testwork conducted by ANSTO in 2014, calculating the radionuclide concentration of the final tailings and comparing the results with recognised classification standards.

BACKGROUND

NML is intending to process ore to extract a rare earth mineral concentrate. This will involve a multistep processing facility aimed at removing impurities. This will produce two tailings (or residue) streams which will be combined for final disposal in an on-site tailings storage facility (TSF). The first stream will be from the beneficiation plant and will make up the majority of the final tailings flow (approximately 90% of the mass flow to the TSF). A second stream will be generated from the hydrometallurgical plant and make up 10% of the final combined tailings mass flow.

The final mass of final tailings will be higher than the mass of the original treated ore due to the addition of reagents during processing.

DEFINITION OF A RADIOACTIVE MATERIAL

The primary guidance for radioactive materials is provided in National standards by the Australian Radiation Protection and Nuclear Safety Agency (ARAPNSA). ARPANSA 2005 and ARPANSA 2014 note that material containing naturally occurring radionuclides in secular equilibrium, with head-of-chain uranium or thorium activity concentrations less than 1Bq/g would generally be considered inherently safe and therefore exempt from regulation. 1Bq/g is equivalent to 81ppm uranium or 245ppm thorium and also applies to the combined activity if both decay chains are present.

For example, if a material contains 0.5Bq/g of uranium (as U^{238}) and 0.2Bq/g of thorium (as Th^{232}), then the activity of the material is considered to be 0.7Bq/g.

Table 1 provides a comparison of the radionuclide concentrations of material currently associated with the project.

Table 1: Uranium and Thorium Content of NML Related Materials

	Uranium		Thorium	
Material	**(ppm)**	**(Bq/g)**	**(ppm)**	**(Bq/g)**
Soils (above ore body)	1.2	0.02	11	0.05
Ore Bodies (average)	40	0.50	30	0.12
World Crustal Average	3	0.04	6	0.02
Radioactivity Classification Threshold Level	81	1.0	245	1.0

ARPANSA (ARPANSA 2014) provides guidance for materials that contain radionuclides that are not in secular equilibrium.

The concentrations of individual radionuclides in the material are divided by exemption levels (provided in ARPANSA 2014) as shown in Table 2 and the fractions are added together. If the total exceeds 1, then the material is defined as radioactive.

Table 2: Exemption Levels (Mixture Method)

Radionuclide	Exemption Level (Bq/g)
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^{232}	1
Ra^{228}	10
Th^{228}	1

INFORMATION AND DATA USED

Two main sources of data were used in this assessment.

1. Email from Chris Griffith (ANSTO) to Enej Catovic (NML) dated 28 March 2014 entitled: Browns Range Project - Preliminary Tailings Geochemical Assessment (ANSTO 2014a)
2. Technical Note AM_TM_2014_06_04, Browns Range Project – Stage 2 – Optimisation of Increased Impurity Rejection Flowsheet – Radioactivity Deportment. (ANSTO 2014b)

Generally, only the longer lived radionuclides are analysed. This is because the shorter lived radionuclides grow into equilibrium with the longer lived “parent” radionuclide in a relatively short amount of time and are usually accounted for when considering the radiological effects of the parent.

RESULTS

Beneficiation Plant Tailings

Radionuclide concentration analysis of beneficiation plant materials can be seen in Table 3, with data for the ore, non-magnetic tails and flotation tails from ANSTO 2014a. The percentage mass flows from NML metallurgists have been used to calculate the radionuclide concentrations for a weighted average beneficiation plant tailings material.

(Note that the 4% discrepancy in mass flow is attributed to the beneficiation mineral concentrate which goes forward to the hydrometallurgical plant for impurity removal).

Table 3: Summary of Radionuclides in Beneficiation (Bene) Plant Materials

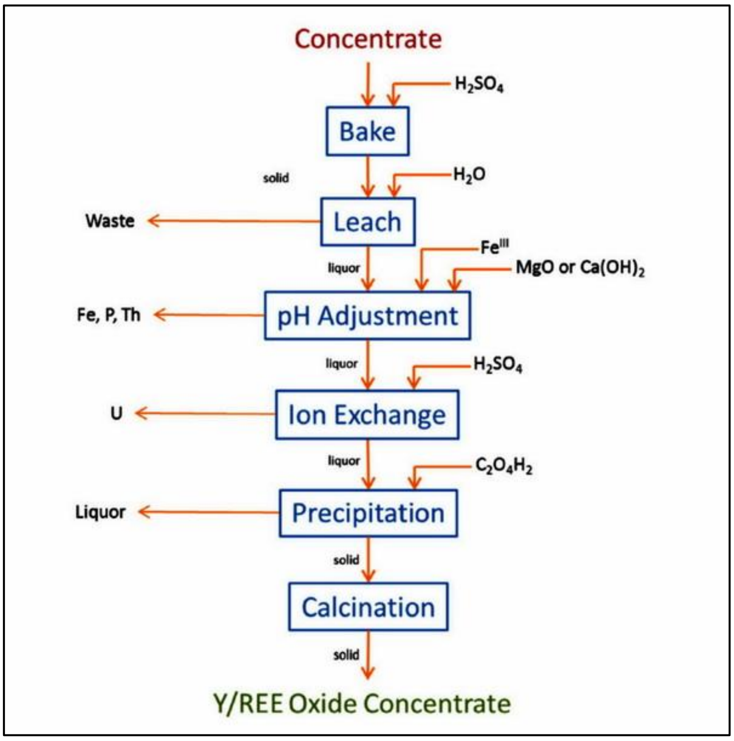
	Radionuclide Concentration (Bq/g)			
	Ore Feed	**Non Magnetics**	**Flotation Tailings**	**Combined Bene Plant Tailings**
Mass Flow (%)	*100*	*80*	*16*	*96*
U^{238}	0.6	0.25	0.41	0.27
Th^{230}	0.5	0.25	0.48	0.28
Ra^{226}	0.6	0.25	0.42	0.27
Pb^{210}	0.6	0.25	0.44	0.27
Th^{232}	0.13	0.08	0.17	0.09
Ra^{228}	0.13	0.08	0.16	0.09
Th^{228}	0.12	0.08	0.17	0.09
U^{235}	0.028	no result available	0.019	0.015

The combined beneficiation plant tailings are in approximate secular equilibrium and do not exceed 1Bq/g for U^{238} and Th^{232} (as heads of chain). Therefore the beneficiation plant tailings are not classified as radioactive.

Hydrometallurgical (Hydromet) Plant Tailings

The hydromet process can be seen in Figure 1. A number of residue streams are combined to form a final hydromet tailings stream. The residue streams are shown on the left side of the figure.

Figure 1: Hydromet Process Flow Diagram



The hydromet process involves the addition of significant quantities of reagents which are used for impurity removal. This alters the mass flow and acts to dilute impurities (including radionuclides).

ANSTO (in ANSTO 2014b) conducted radionuclide analysis of the majority of the streams in the hydromet plant and the results can be seen in Table 4. The calculated total weighted average (by mass flow) hydromet tailings solid and liquid radionuclide concentrations are also provided in Table 4.

Table 4: Summary of Radionuclides in Hydromet Plant Materials

	Radionuclide Concentration (Bq/g solids, Bq/L liquids)					
	Leach Solid)	**pH Adjustment Solids**	**Ion Exchange (IX) Liquids**	**Precipitation (Precip) Liquids**	**Total Hydromet Tailings**	
					Solids	**Liquids**
Mass Flow (tph)	1.56	1.45	1.98	34.1	See note *	36
U^{238}	1.85	1.07	7320.0	12.0	0.55	413.4
Th^{230}	6.63	3.30	61.0	1.2	1.86	4.5
Ra^{226}	15.94	0.04	8.1	1.8	3.06	2.1
Pb^{210}	15.87	0.06	40.7	2.6	3.05	4.7
Th^{232}	1.19	0.53	10.9	0.2	0.32	0.8
Ra^{228}	2.86	0.01	5.7	0.6	0.55	0.9
Th^{228}	1.19	0.53	10.9	0.2	0.32	0.8
U^{235}	0.08	0.05	332.7	1.4	0.02	19.6
Pa^{231}	0.37	0.12	40.7	3.3	0.09	5.4

** Includes 5.13 tph of inert precip and IX residues*

The total hydromet tailings is not in secular equilibrium and using the mixture method outlined earlier, would be considered to be radioactive. This is primarily due to the Th^{230} concentration (see exemption levels in Table 2).

However, it is noted that it is an intermediate process stream.

Combined Tailings Residue

NML reports that the tailings mass flows would be approximately 90% from the beneficiation plant and 10% from the hydrometallurgical plant. The calculated combined tailings radionuclide concentrations are provided in table 5.

Table 5: Combined Tailings Radionuclide Concentrations

	Radionuclide Concentration (Bq/g solids, Bq/L liquids)				
	Bene Plant Solids	**Hydromet Plant**		**Combined Tailings**	
		Solids	**Liquids**	**Solids**	**Liquids**
U^{238}	0.3	0.6	410	0.3	41
Th^{230}	0.3	1.9	5	0.4	0.5
Ra^{226}	0.3	3.1	2	0.6	0.2
Pb^{210}	0.3	3.1	5	0.6	0.5
Th^{232}	0.1	0.3	1	0.1	0.1
Ra^{228}	0.1	0.6	1	0.1	0.1
Th^{228}	0.1	0.3	1	0.1	0.1
U^{235}	0.02	0.02	20.0	0.02	2.0

The combined processing plant tailings is in secular equilibrium for Th^{232}.

When using the mixture method, the final tailings is also not classified as radioactive.

As noted in Table 1, the ore itself is not defined as radioactive. Since most of the mass of the processed ore reports to tailings, it is logical that the final tailings should also not be defined as radioactive. The analytical results confirm this.

CONCLUSION

The analysis of the samples indicates the following:

- The beneficiation tailings stream **does not exceed** the criteria for being defined as a radioactive material.
- The hydromet tailings stream **exceeds** the criteria for being defined as a radioactive material (however, this is an intermediate process material).
- The combined tailings stream **does not exceed** the criteria for being defined as a radioactive material.

It is noted that this is consistent with the NML report that the feed ore is defined as non-radioactive.

REFERENCES

ARPANSA 2014 - National Directory for Radiation Protection (NDRP) February 2014

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