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Attn: Bob Vivian

**INTERIM REPORT on
ENVIRONMENTAL RADIOACTIVITY SURVEY
FRANCES CREEK SITE
NORTHERN TERRITORY**

1 Introduction

Western Radiation Services was commissioned by Territory Iron Limited to carry out an environmental radiation survey at the above site. The survey was undertaken to check for radioactive material following the results of an airborne radiometric survey of the exploration area, namely Frances Creek in the Northern Territory. The survey was conducted between the 18th May and the 23rd May 2006.

A total of six areas were surveyed. These were Ochre Hill in the north, Thelma/Rosemary, Thelma/Rosemary (east), Jasmine, Helene 5 and Helen 6/7 in the south. The sites cover an area almost nine kilometres long and approximately two kilometres wide. The sites consisted of outcropping material, at some locations with a steep gradient, covered with tall grass and medium trees. The outcrops were in a north/south trend.

An airborne radiometric anomaly to the north of Ochre Hill could not be investigated because of boggy ground restricting access to the area.

2 Legislation

Documents used as guidelines for monitoring and sampling for radioactivity at the sites were the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2004), Radiation Protection Series-6, *National Directory for Radiation Protection edition 1.0*⁽¹⁾.

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2005) RPS 9, *Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing*⁽²⁾.

The Northern Territory of Australia (1999) *Radiation (Safety Control) Act*⁽³⁾.

The Australian Standard (AS4482.1) *Guide to the Sampling and Investigation of Potentially Contaminated Soil* (1997)⁽⁴⁾.

Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2002) RPS-1 Recommendations for Limiting Exposure to Ionising Radiation (1995) and *National Standard for Limiting Occupational Exposure to Ionising Radiation*, Annex B,.

2 Materials and Methods

Gamma Survey

A gamma survey was conducted in each area with a calibrated Health Physics 'Cypher' model 5000 survey meter coupled to a pancake Geiger Mueller (GM) detector used in the integrate mode. The integrate period was 5 minutes giving the measurement reading of nanoSieverts (nSv) per 5 minutes. This mode was used to eliminate any 'user bias' of the radiation readings observed during the survey. The System Internationale unit for equivalent radiation dose is microSieverts (μSv); hence the 5 minute integrated readings were converted to microSieverts per hour ($\mu\text{Sv/h}$) for this survey. This was converted to milliSieverts per annum (mSv/a) to give an annual dose rate.

Sampling was done in accordance with Australian Standards to avoid cross contamination. Seven samples were taken, one for each background location. Sampling holes were approximately 100mm deep. Each location was stored as a waypoint (WP) using a hand held Global Positioning System (GPS) receiver. The waypoints are in Universal Transverse Mercator (UTM) format using World Geodetic Survey (WGS 84) datum. The waypoints were downloaded to a map of the area using Map Source.

A background survey was conducted along the track leading to the Ochre Hill site. The mean of these radiation measurements plus 2 standard deviations was used to determine an arbitrary 'action level'. These measurements should account for 95% of all the background locations measured as being normally distributed. This 'action level' was used for the survey in the Ochre Hill area. Any measurement at a location in the survey area that exceeded the 'action level' was sampled for radiometric analysis. Refer to Tables 1 and 2.

The Ochre Hill site was surveyed from the north of the outcrop moving to the south. The results from gamma survey of line 1 and line 2 were reasonably homogenous; consequently the survey locations were increased to approximately 100 metres with a line spacing of 200 metres. All other sites were surveyed at roughly this interval depending on the topography and vegetation of the area. Refer to Tables 3 and 4.

A background survey was conducted along the road to the north of Helene5. The locations were approximately 10 metres apart along each side of the road and approximately 2 to 3 metres from the road side. This was done to avoid contamination of the background readings and samples with material that may have been brought in from elsewhere for the purpose of making the road. This background survey was used to establish the 'action level' for the Helene 5 and Helene 6/7 sites. Again, each location was sampled in accordance with Australian Standards observing proper sampling techniques. Seven samples were taken, one for each background location. Sampling holes were approximately 100mm deep. Refer to Tables 5 and 6.

The Helene 5 and Helene 6/7 sites were surveyed from the north to the south. Two soil samples were taken at Helene 5 site, WP105 which exceeded the 'action level' and WP103 which was sampled because it coincided with a strong airborne anomaly. Refer to Tables 7 and 8.

At Helene 6/7 three soil samples were taken. These were at WP 110, WP 112 and WP 114. Of these one exceeded the 'action level', WP 110. The other two waypoints (WP 112 and WP114) were sampled so that there would be more than one sample from this pit area. Refer to Tables 9 and 10. Electrets were also placed at WP 110, WP 112 and WP 114. Refer to Table 12

A background survey was conducted at the Pine Creek office for comparison with the gamma radiation values at the survey site. It is assumed that workers will live in the town and commute to the mine site each day to work. For the summary of the statistics refer to Table 11.

At waypoint locations marked with an '*' soil samples were chosen by the client for radiometric analysis. These are listed in Tables 1, 3, 5, 7 and 9. At waypoint locations marked with a '^' radon analysis was conducted. These are listed in Tables 3, 7 and 9.

Radon Survey

A radon survey was conducted in parallel with the gamma survey. A passive monitoring device called an 'electret' was used to measure radon gas that may be present at anomalous locations identified by the gamma survey or at locations where radon gas may be present. For example, an electret was placed over a natural crevice in the ground near the top of the outcrop at the southern end of Ochre Hill. If radon gas was present in the earth it will emanate from this crevice. This is WP 62. Refer to Table 12. The electrets remained in the field for up to forty eight hours.

A total of four electrets were placed at Ochre Hill, one was placed at Helene 5 and three were placed at Helene 6/7. At Helene 6/7 two electrets were placed at locations on the northern side of the pit and one was placed at a location on the south west side of the pit, approximately opposite the other two locations. Access to other areas of the pit was restricted by a drill rig in the location or inaccessibility due to the steep side walls of the pit. The results are shown in Table 12.

3 Results

Gamma survey Ochre Hill

The results of the seven background measurements are in Table 1. The mean background radiation level of the 7 background locations near the site Ochre Hill site was 30.2 ± 5.24 nanoSieverts (nSv) per 5 minute counting time. This background mean equates to 0.36 $\mu\text{Sv/h}$ or 3.17 mSv per annum. Refer to Table 2. Using the upper limit (mean + 2 standard deviations) gives an 'action level' of 40.64 nSv per 5 minutes

Three background samples from WP36, WP38 and WP40 were chosen for radiometric analysis. These samples were analysed for radium-226, radium-228 and potassium-40.

Table 1

Background Gamma Values – Ochre Hill

Sample I.D	Map Location	Gamma measurement (nSv/5 min)	Gamma measurement ($\mu\text{Sv/hr}$)	Gamma measurement (mSv/a)
BKG 1	WP36*	37.9	0.455	3.98
BKG 2	WP37	26.4	0.317	2.78
BKG 3	WP38*	28.1	0.337	2.95
BKG 4	WP39	26.8	0.322	2.82
BKG 5	WP40*	23.6	0.283	2.48
BKG 6	WP41	33.9	0.407	3.56
BKG 7	WP42	34.4	0.413	3.62

* soil sample for radiometric analysis

Table 2

Background Survey Statistics – Ochre Hill

	Minimum measurement	Maximum measurement	Mean measurement	Standard Deviation
nSv/5 mins	23.6	37.9	30.2	5.24
$\mu\text{Sv/h}$	0.28	0.45	0.36	0.06
mSv/a	2.48	3.98	3.17	0.55

Three of the four locations at the Ochre Hill gamma survey site that exceeded the 'action level' were sampled for radiometric analysis. These were locations WP4, WP29 and WP58.

Table 3

Site Survey Gamma Values – Ochre Hill

Line Number	Map Location	Gamma measurement (nSv/5 min)	Gamma measurement (µSv/hr)	Gamma measurement (mSv/a)
	WP1	OHRC 143		
Line 1	WP2	38.8	0.466	4.07
Line 1	WP3	35.1	0.421	3.69
Line 1	WP4*^	41.2	0.494	4.33
Line 1	WP5	35.7	0.428	3.75
Line 1	WP6	35.9	0.431	3.77
Line 1	WP7	28.2	0.338	2.96
Line 1	WP8	24.3	0.292	2.55
Line 1	WP9	29.9	0.359	3.14
Line 1	WP10	33.8	0.406	3.55
Line 1	WP11	34.4	0.413	3.62
Line 1	WP12	32.2	0.386	3.38
Line 2	WP13	35.3	0.424	3.71
Line 2	WP14	31.9	0.383	3.35
Line 2	WP15	31.7	0.380	3.33
Line 2	WP16	40.2	0.482	4.23
Line 2	WP17	31.0	0.372	3.26
Line 2	WP18	29.0	0.348	3.05
Line 2	WP19	33.6	0.403	3.53
Line 2	WP20	37.6	0.451	3.95
Line 2	WP21	35.3	0.424	3.71
Line 2	WP22	34.6	0.415	3.64
Line 2	WP23	37.6	0.451	3.95
Line 2	WP24	37.4	0.449	3.93
Line 2	WP25	37.2	0.446	3.91

* soil sample for radiometric analysis

^ radon analysis was conducted at this location

Table 3 (cond't)**Site Survey Gamma Values – Ochre Hill**

Line Number	Map Location	Gamma measurement (nSv/5 min)	Gamma measurement (μSv/hr)	Gamma measurement (mSv/a)
Line 3	WP26	28.7	0.344	3.02
Line 3	WP27	34.4	0.413	3.62
Line 3	WP28	41.9	0.503	4.40
Line 3	WP29*^	42.7	0.512	4.49
Line 3	WP30	35.4	0.425	3.72
Line 3	WP31	36.9	0.443	3.88
Line 3	WP32	29.6	0.355	3.11
Line 3	WP33	27.8	0.334	2.92
Line 3	WP34	30.5	0.366	3.21
Line 3	WP35	30.2	0.362	3.17
Line 4	WP50	40.1	0.481	4.21
Line 3	WP51	30.4	0.365	3.20
Line 3	WP52	39.0	0.468	4.10
Line 3	WP53	32.8	0.394	3.48
Line 3	WP54	37.5	0.450	3.942
Line 5	WP55	37.9	0.455	3.98
Line 5	WP56	30.9	0.371	3.25
Line 5	WP57	32.8	0.394	3.45
Line 5	WP58*^	54.2	0.650	5.70
Line 5	WP59	39.5	0.474	4.15
Line 5	WP60	23.0	0.276	2.42
Line 5	WP61	22.7	0.2724	2.39
Line 5	WP62^	27.1	0.325	2.85
Line 5	WP63	27.7	0.332	2.92

Table 4**Site Survey Statistics – Ochre Hill**

	Minimum measurement	Maximum measurement	Mean measurement	Standard Deviation
nSv/5 mins	22.7	54.2	34.1	5.7
μSv/h	0.27	0.65	0.41	0.07
mSv/a	2.39	5.70	3.53	0.60

Gamma survey Helene

The mean background radiation level of the 7 locations along the roadside to the north of the Helene 5 site was 33.3 ± 3.3 nanoSieverts (nSv) per 5 minute counting time. This mean equates to 0.4 $\mu\text{Sv/h}$ or 3.5 mSv per annum. Refer to Table 6. Using the upper limit (mean + 2 standard deviations) gives an 'action level' of 39.9 nSv per 5 minutes.

Table 5

Background Gamma Values – Helene

Line Number	Map Location	Gamma measurement (nSv/5 min)	Gamma measurement ($\mu\text{Sv/hr}$)	Gamma measurement (mSv/a)
BKG 15	WP117	29.0	0.348	3.05
BKG 16	WP118	33.2	0.398	3.49
BKG 17	WP119	36.9	0.443	3.88
BKG 18*	WP120	31.3	0.376	3.29
BKG 19*	WP121	37.0	0.444	3.89
BKG 20	WP122	30.1	0.361	3.16
BKG 21	WP123	35.4	0.425	3.72

Table 6

Background Survey Statistics – Helene

	Minimum measurement	Maximum measurement	Mean measurement	Standard Deviation
nSv/5 mins	29.0	37.0	33.3	3.30
$\mu\text{Sv/h}$	0.35	0.44	0.40	0.04
mSv/a	3.05	3.89	3.50	0.34

The results in Table 7 are for measurements taken at the Helene 5 site. These waypoints are not sequential order as it was easier to conduct the survey on one side of the road way and then move to the other side and work up the side of the outcrop. Soil samples were taken at WP 103 and WP105. An electret was also placed at WP105. Refer to Table 12.

Table 7

Site Survey Gamma Values – Helene 5

Line Number	Map Location	Gamma measurement (nSv/5 min)	Gamma measurement (µSv/hr)	Gamma measurement (mSv/a)
Line 1	WP96	36.9	0.443	3.88
Line 1	WP97	30.2	0.362	3.17
Line 1	WP98	29.1	0.349	3.06
Line 2	WP99	34.7	0.416	3.65
Line 2	WP100	29.9	0.359	3.14
Line 2	WP106	31.4	0.377	3.30
Line 2	WP108	33.3	0.400	3.50
Line 3	WP104	28.6	0.343	3.00
Line 3	WP103*	28.3	0.340	2.97
Line 3	WP102	30.1	0.361	3.16
Line 3	WP101	36.6	0.439	3.85
Line 3	WP105*^	41.3	0.496	4.34
Line 3	WP107	28.7	0.344	3.02

Table 8

Site Survey Statistics – Helene 5

	Minimum measurement	Maximum measurement	Mean measurement	Standard Deviation
nSv/5 mins	29.0	37.0	33.3	3.26
µSv/h	0.34	0.50	0.39	0.05
mSv/a	3.05	3.89	3.50	0.34

The results in Table 9 are for measurements taken round the pit at Helene 6/7. These results are not in regular lines but are at convenient locations around the pit depending on the location of the drill rigs in the area, hence line numbers are not listed. Soil samples were taken at WP110, WP112 and WP114 for radiometric analysis. Refer to Table 9. Electrets were also placed at these waypoints. Refer to Table 12.

Table 9

Site Survey Gamma Values – Helene 6/7

Map Location	Gamma measurement (nSv/5min)	Gamma measurement (µSv/hr)	Gamma measurement (mSv/a)
WP109	39.5	0.474	4.15
WP110*^	48.4	0.581	5.09
WP111	29.1	0.349	3.06
WP112*^	40.2	0.482	4.22
WP113	37.3	0.448	3.92
WP114*^	37.1	0.445	3.90
WP115	24.9	0.299	2.62
WP116	34.9	0.419	3.67

Table 10

Site Survey Statistics – Helene 6/7

	Minimum measurement	Maximum measurement	Mean measurement	Standard Deviation
nSv/5 mins	24.9	48.4	36.4	7.14
µSv/h	0.30	0.58	0.44	0.09
mSv/a	5.09	2.62	3.83	0.75

Table 11

Background Survey Statistics – Pine Creek

	Minimum measurement	Maximum measurement	Mean measurement	Standard Deviation
nSv/5 mins	23.0	29.1	25.03	2.19
µSv/h	0.28	0.35	0.30	0.03
mSv/a	2.42	3.06	2.63	0.23

Radon survey

The recommended limit for radon activity is 1000 Becquerels per cubic meter (Bq/m^3)⁽⁵⁾. The highest value measured (300 Bq/m^3) was at Ochre Hill away from the outcrop at WP4. This measurement was well below the limit for radon activity. Interestingly the lowest radon measurement was over the natural crevice in the Ochre Hill outcrop.

The radon activity measured at Helen 6/7 was below the minimum detection limit for the devices indicating that radon activity in the pit is low.

Table 12

Site Survey Radon Values

Site	Map Location	Radon Activity (Bq/m^3)
Ochre Hill	WP4	300 ± 18
Ochre Hill	WP29	<MDL
Ochre Hill	WP58	<MDL
Ochre Hill	WP62	20 ± 5
Helen 5	WP105	73 ± 7
Helene 6/7	WP110	<MDL
Helene 6/7	WP112	<MDL
Helene 6/7	WP114	<MDL

4 Discussion

Data collected by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA)⁽¹⁾ specify the mean natural background radiation within Australia is 2.3 mSv per annum. This equates to $0.26 \mu\text{Sv/h}$. The world average for natural background radiation is about 3.5 mSv/a, equating to $0.4 \mu\text{Sv/h}$. The calculated background gamma exposure rate for the Ochre Hill site ($0.36 \mu\text{Sv/h}$ and 3.17 mSv per annum) is above Australian average levels, but below world levels.

The sites Thelma/Rosemary and Jasmine East were surveyed using the same methodology. The assumption is the geology is similar in this area to that at Ochre Hill and so the 'action level' used at the Ochre Hill site was applied to the data collected from Thelma/Rosemary and Jasmine East sites.

The calculated background gamma exposure rate for the Helene 5 site ($0.40 \mu\text{Sv/h}$ and 3.50 mSv per annum) is above Australian average levels and the same as world levels.

The calculated background gamma exposure rate for the Pine Creek township ($0.30 \mu\text{Sv/h}$ and 2.63 mSv per annum) is above the Australian average but less than the world levels.

The results of the radon-222 gas survey at the mine site were below the recommended limit of 1000 Bq/m³ in the work place⁽⁵⁾.

Positional gamma monitors will be placed in the field once the local bush fires have passed through the survey area. These monitors will be placed approximately one metre above the ground at suitable locations for a period of 3 to 4 months to determine the average background gamma radiation and radon gas concentration in air at the survey sites.

5 Conclusions

The gamma radiation measurements across the surveyed area are consistent with the normal background measurements for the world and above the natural background for Australia. In order to estimate the annual gamma exposure to workers at the proposed mine, the measured background gamma at Pine Creek was subtracted from the mean of the measured mine site data at Frances Creek. The difference value (μSv/hr) was multiplied by 2000 hours (standard working year) to obtain an estimate of the occupational gamma exposure of the mine workers. From the site survey statistics, the Ochre Hill area (Table 4) mean exposure was 0.41 μSv/h. This was the highest mean gamma reading for the site. The estimated increased gamma exposure using this value was 0.22 mSv/annum which is below the 1mSv/annum recommended exposure limit.

The above exposure estimate may change when the quarterly estimate of radon gas exposure is measured from the passive monitors on site. From grab samples taken during the gamma survey, it is considered unlikely that radon gas exposures will be sufficient to exceed the recommended limits.

6. Recommendations

It is recommended that radiation exposures be recalculated when measured radon in air concentrations are available from passive monitors currently placed on site and at Pine Creek. This is expected to confirm the estimated values as being below the recommended limits.

It is recommended that a gamma survey at the perimeter of the ore storage pad at the port be carried out before and after the ore for export is stockpiled.

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Western Radiation Services

References

1. Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2004) *RPS-6 National Directory for Radiation Protection, Edition 1.0*
2. Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2005) *RPS-9 Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing*.
- 3 Northern Territory of Australia (1999) *Radiation (Safety Control) Act*.
- 4 Australian Standard (AS4482.1 1997) *Guide to Sampling and Investigation of Potentially Contaminated Soil Part 1*.
5. Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) (2002) *RPS-1 Recommendations for Limiting Exposure to Ionising Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionising Radiation, Annex B*,.

Appendix 1

Equipment used at Frances Creek

Gamma survey

Health Physics Instruments

“CYPHER” model 5000 serial number 501142

coupled with GM pancake detector serial number 551427

Calibrated on 11th May 2006

Location

Garmin GPS

Model 76S

serial number 93805386

Minimum Detection Limits (MDL)

For radiometric analysis

Radium-226 15 Bq/kg

Potassium-40 20 Bq/kg

Radium-228 15 Bq/kg

