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A Survey of Naturally Occurring Radioactive Material Associated with Mining

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3.4 Radon in Underground Mines

The results from the initial survey are shown in figure 15. The measured radon concentrations are indicated by the height of the individual bars, while the error bars indicate the 95% confidence limits for each measurement. The bars are shaded to more easily differentiate data from different mines. The dark grey horizontal line shows the action level for occupational exposure (1000 Bq/m^3; ARPANSA, 2002).

For most of the minesites, the averages of the measured radon concentrations were below the action level for occupational exposure.

For operator o, the average of the measured concentrations exceeded the action level. The two measurements were carried out at mine extraction exhaust locations, and so it is possible that concentrations in other parts of the mine are lower than at these locations.

A further set of monitors were sent to operators o and y to be placed in the working areas of the mine as a follow-up survey. Monitors were in place in the period February-April 2012 (Figure 16). In the case of operator o, there were two underground mines being worked in the same region, and sufficient monitors were supplied to make measurements in both mines on this occasion. The repeat results for the first mine are designated o31-o36 and those from the second (new) mine are designated o21-o26. The repeat results for the other operator are designated y21-y26. For all three minesites, the averages of the radon concentrations measured were below the action level.

Overall, variability in radon concentrations between minesites was quite large with averages at each mine ranging from less than 100 Bq/m^3 to above 800 Bq/m^3. There was also high variability between samples at each individual mine. This was to be expected considering the different types of location for detectors chosen at each of the mines. A number of detectors were placed in mine exhausts, but some detectors were also placed in well ventilated areas where radon concentrations could be expected to be low. The results are presented in Table 3.

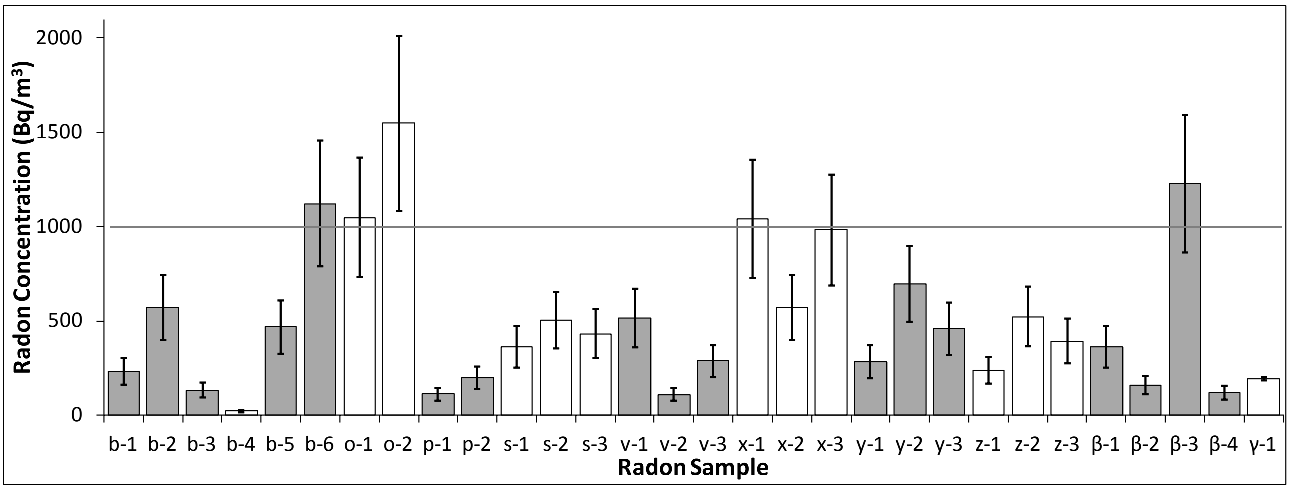

Figure 15: Measured radon concentration in underground mines, March-May 2011.
The error bars indicate the 95% confidence interval of the measurements.
The horizontal line indicates the action level for occupational exposure to radon.

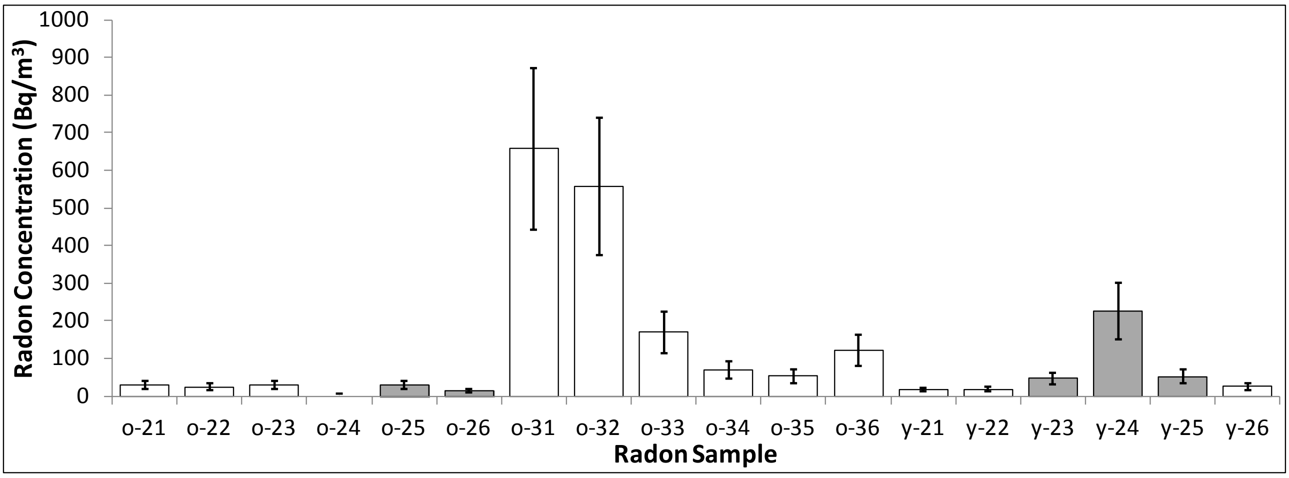

Figure 16: Measured radon concentration at work areas in mines, February-April 2012. The error bars indicate the 95% confidence interval of the measurements.

Table 3: Placement of radon monitors at mines, and average and range of measured radon concentrations

Mine	Number of Monitors	Date Placed	Days in Place	Average Rn (Bq/m^3)	Range (Bq/m^3)
b-1-6	6	March 2011	54	420	20-1120
o-1,2 o-31-36	2 6	April 2011 February 2012	14 31	1300 270	1050-1550 50-660
p-1,2	2	April 2011	83	160	110-200
s-1,2,3	3	April 2011	21	430	360-500
v-1,2,3	3	April 2011	34	300	110-520
x-1,2,3	3	May 2011	14	860	570-1040
y-1,2,3 y-21-26	3 6	May 2011 February 2012	15 30	480 70	280-700 20-230
z-1,2,3	3	May 2011	36	380	240-520
β-1,2/3,4	2	May-June 2011	37,48	470	120-1230
o-21-26	6	February 2012	41	20	0-30

4. Conclusion

In most cases, the activity concentrations of the U-238 and Th-232 decay series radionuclides in the ore, tailings and solid waste from all of the mine types were found to be consistent with the range expected from soils (20 – 70 Bq/kg). Furthermore, in most cases, the radionuclides in each series were found to be in secular equilibrium, indicating that the processing of the ores does not significantly alter the elemental composition of the materials.

Almost all of the waters from the mines exhibited significant enhancement of U-234. They also exhibit significant variations in the activity concentrations of the other radionuclides in the series relative to U-238. Nonetheless, the actual activity concentrations in most of the water samples were low and most would meet the Australian Drinking Water Guidelines (NHMRC 2004) in terms of radioactivity.

These results indicate that most mining operations do not have issues relating to elevated levels of naturally occurring radioactive materials.

The significant exceptions were three metalliferous mines which were found to have activity concentrations of U-238 and Th-232 decay series radionuclides in the ore, products, tailings and solid wastes approaching the regulatory reference level of 1000 Bq/kg. However, all three of these mines extract heavy metal products from the ores and are already covered by a specific code of practice (ARPANSA 2005).

While the mine waters from the coal mines were consistent with the activity concentrations found in normal waters, the activity levels of U-234 were found to be relatively high in most of the process waters. It was noted that these process waters were highly recycled, enabling this radionuclide to accumulate over time. It was also noted that the highly recycled process waters were relatively depleted in Ra-226. The large disequilibrium between uranium and radium in the process water and whether the radium precipitates out in the system should be further investigated.

The measurements of radon from the underground mines gave average radon concentrations which were below the action level for occupational exposure (1000 Bq/m^3), for the period and locations measured. However, variability in concentrations was quite high, both within and between minesites. The high variability between sampling locations within some minesites is most probably due to the effects of varying ventilation rates in different areas and accumulation of radon in the air stream as it passes through the mine workings. Average mine concentrations ranged from less than 100 Bq/m^3 to above 800 Bq/m^3. Given the high variability observed, and the limited number of mines sampled, this study indicates that it is likely some underground mines may be above the action level.

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Appendix A: Tabulated Results for Quarries

In the following tables:

The quoted uncertainties indicate the 95% confidence interval.
The term 'Not Available' means that sample could not be chemically treated in order to extract these radionuclides.
The term 'MDC' refers to estimate of the smallest activity concentration of the radionuclide that can be quantified with 95% confidence.
The term '<MDC' means that the activity concentration of the radionuclide could not be quantified in the sample.

Table A1: Activity Concentration (Bq/kg) of Radionuclides in Ore

Sample	Polonium-210	Lead-210	Radium-226	Thorium-230	Uranium-234	Uranium-238	Thorium-228	Radium-228	Thorium-232
a117	27.3 ± 4.4	17 ± 16	25.1 ± 3.5	Not Available	28.6 ± 4.4	30.6 ± 4.6	20.8 ± 3.1	20.1 ± 4.8	Not Available
a118	26.3 ± 4.6	42 ± 18	26.7 ± 4.1	Not Available	28.3 ± 4.6	28.7 ± 4.6	22.2 ± 3.3	17.5 ± 5.8	Not Available
e137	14.1 ± 3.4	13 ± 9	13.6 ± 2.1	13.5 ± 5.3	14.8 ± 2.8	14.3 ± 2.7	17.6 ± 2.5	22.0 ± 4.0	14.9 ± 5.5
i170	15.2 ± 3.1	25 ± 11	18.6 ± 2.8	Not Available	10.9 ± 2.4	10.7 ± 2.4	19.0 ± 2.8	21.6 ± 4.5	Not Available
j171	30.7 ± 5.7	32 ± 17	32.0 ± 4.2	Not Available	32.9 ± 6.2	29.3 ± 5.8	43.9 ± 6.0	43.0 ± 6.3	Not Available
j172	27.4 ± 4.6	19 ± 16	28.6 ± 3.7	Not Available	28.7 ± 5.1	33.9 ± 5.8	43.2 ± 5.9	42.9 ± 6.5	Not Available
q223	<MDC	<MDC	<MDC	Not Available	<MDC	<MDC	<MDC	<MDC	Not Available
r226	5.0 ± 2.5		4.3 ± 1.2	Not Available	7.2 ± 2.5	6.0 ± 2.1	4.0 ± 1.1	<MDC	Not Available
MDC	*4.0*	*20*	*10*	*4.0*	*4.0*	*4.0*	*10*	*10*	*4.0*

Table C2: Activity Concentration (Bq/kg) of Radionuclides in Product

Sample	Polonium-210	Lead-210	Radium-226	Thorium-230	Uranium-234	Uranium-238	Thorium-228	Radium-228	Thorium-232
b125	12.4 ± 5.5	<MDC	14.3 ± 2.2	12.0 ± 3.5	10.6 ± 3.5	10.3 ± 3.2	13.4 ± 2.5	15.7 ± 4.0	9.3 ± 3.0
b126	20.6 ± 6.2	30 ± 16	25.7 ± 3.3	16.9 ± 3.8	16.6 ± 3.9	12.9 ± 3.2	23.5 ± 3.4	24.9 ± 3.8	19.0 ± 4.0
h163	10.6 ± 4.7	<MDC	12.8 ± 2.8	7.0 ± 3.5	10.8 ± 4.0	10.9 ± 4.0	10.4 ± 2.7	7.3 ± 5.0	10.1 ± 3.0
h164	17.1 ± 8.0	29 ± 22	12.4 ± 3.0	13.1 ± 4.2	18.3 ± 6.4	15.5 ± 5.5	19.1 ± 3.9	19.2 ± 6.3	19.1 ± 4.3
h165	17.9 ± 7.3	26 ± 16	15.3 ± 2.7	9.8 ± 3.7	9.6 ± 3.9	12.8 ± 4.1	18.2 ± 3.3	19.6 ± 5.4	11.8 ± 3.2
k174	5.7 ± 2.3	<MDC	7.0 ± 2.2	5.3 ± 2.2	5.1 ± 2.7	4.4 ± 2.3	6.5 ± 2.1	<MDC	4.0 ± 1.6
l184	6.4 ± 3.0	<MDC	9.1 ± 2.0	7.3 ± 2.7	5.9 ± 2.7	5.5 ± 2.4	11.2 ± 1.9	10.4 ± 2.8	8.3 ± 2.4
m189	6.5 ± 3.6	<MDC	9.4 ± 3.2	5.4 ± 3.1	7.3 ± 3.2	3.8 ± 2.2	12.3 ± 2.8	15.1 ± 5.7	7.4 ± 2.7
n192	8.7 ± 3.0	<MDC	8.8 ± 3.8	4.4 ± 3.7	6.7 ± 2.8	7.5 ± 2.7	9.7 ± 3.4	8.7 ± 7.6	6.8 ± 2.9
n193	10.0 ± 4.0	<MDC	6.2 ± 3.2	5.1 ± 3.2	6.0 ± 2.8	3.9 ± 2.1	4.6 ± 3.2	<MDC	4.1 ± 1.9
s243	25.3 ± 5.8	<MDC	24.6 ± 3.6	20.6 ± 4.3	21.9 ± 4.8	18.9 ± 4.3	24.4 ± 3.8	24.8 ± 6.5	21.2 ± 4.3
MDC	*4.0*	*30*	*10*	*4.0*	*4.0*	*4.0*	*10*	*10*	*4.0*

Table C3: Activity Concentration (Bq/kg) of Radionuclides in Solid Waste

Sample	Polonium-210	Lead-210	Radium-226	Thorium-230	Uranium-234	Uranium-238	Thorium-228	Radium-228	Thorium-232
b124	37.4 ± 7.0	53 ± 14	46.5 ± 5.4	26.7 ± 4.7	26.9 ± 4.6	16.0 ± 3.2	56.5 ± 7.2	55.3 ± 6.9	35.7 ± 5.5
h166	21.2 ± 5.1	47 ± 16	20.8 ± 3.1	23.1 ± 4.9	22.2 ± 5.3	22.4 ± 5.1	38.7 ± 5.4	36.4 ± 6.8	29.4 ± 5.2
k175	18.4 ± 4.2	26 ± 17	28.4 ± 3.7	14.1 ± 3.3	15.1 ± 3.6	9.8 ± 2.7	43.8 ± 5.9	38.7 ± 5.7	20.1 ± 3.7
l185	17.0 ± 4.5	30 ± 11	18.7 ± 2.5	12.0 ± 4.3	10.8 ± 3.6	9.2 ± 3.1	21.9 ± 3.1	18.8 ± 3.3	11.3 ± 3.8
l186	20.4 ± 4.7	23 ± 12	26.1 ± 3.2	16.4 ± 3.8	14.5 ± 3.5	10.3 ± 2.8	31.4 ± 4.2	25.9 ± 3.9	9.8 ± 2.8
n194	20.7 ± 4.8	28 ± 15	22.2 ± 3.3	14.4 ± 3.6	17.3 ± 3.8	13.2 ± 3.2	32.0 ± 4.6	31.2 ± 5.9	22.5 ± 4.2
s244	35.6 ± 6.8	103 ± 24	76.2 ± 9.0	27.7 ± 5.1	30.6 ± 7.1	29.4 ± 6.8	54.8 ± 7.4	48.6 ± 7.3	38.0 ± 6.0
MDC	*4.0*	*20*	*10*	*4.0*	*4.0*	*4.0*	*10*	*10*	*4.0*

Table C4: Activity Concentration (Bq/kg) of Radionuclides in Tailings

Sample	Polonium-210	Lead-210	Radium-226	Thorium-230	Uranium-234	Uranium-238	Thorium-228	Radium-228	Thorium-232
b127	34.1 ± 6.8	45.0 ± 21.0	42.4 ± 5.4	30.1 ± 5.7	27.7 ± 5.5	21.4 ± 4.6	53.1 ± 7.2	59.8 ± 9.6	39.5 ± 6.5
h167	24.8 ± 5.7	34.0 ± 22.0	31.7 ± 4.5	29.3 ± 5.3	28.4 ± 5.9	24.6 ± 5.2	30.2 ± 4.5	41.6 ± 7.0	32.5 ± 5.4
k181	16.4 ± 5.4	24.0 ± 25.0	18.3 ± 4.4	12.0 ± 3.5	10.0 ± 3.2	8.3 ± 2.7	32.0 ± 5.0	25.0 ± 6.2	9.7 ± 3.0
l187	39.9 ± 8.2	43.0 ± 19.0	34.3 ± 4.7	21.7 ± 4.6	14.2 ± 3.8	15.9 ± 3.8	43.2 ± 6.0	48.8 ± 8.7	23.4 ± 4.8
n195	Not Available	Not Available	20.3 ± 4.8	Not Available	Not Available	Not Available	Not Available	31.9 ± 8.9	Not Available
MDC	*4.0*	*30*	*10*	*4.0*	*4.0*	*4.0*	*10*	*10*	*4.0*

Table C5: Activity Concentration (mBq/litre) of Radionuclides in Mine and Process Water

	Sample	Polonium-210	Lead-210	Radium-226	Thorium-230	Uranium-234	Uranium-238
Mine	b121	<MDC	<MDC	13.3 ± 3.0	<MDC	274.0 ± 75.0	74.0 ± 16.0
	h169	<MDC	<MDC	<MDC	<MDC	88.0 ± 13.0	26.2 ± 5.5
	k178	<MDC	<MDC	21.7 ± 8.7	4.6 ± 3.9	223.0 ± 28.0	46.8 ± 8.0
	s246	41.4 ± 7.4	46.0 ± 29.0	<MDC	<MDC	5.3 ± 2.8	3.0 ± 2.1
Process	b120	<MDC	52.0 ± 27.0	7.9 ± 7.8	<MDC	433.0 ± 63.0	185.0 ± 29.0
	h168	4.8 ± 3.0	21.0 ± 26.0	12.0 ± 7.9	<MDC	89.0 ± 13.0	30.6 ± 6.0
	k179	<MDC	<MDC	10.7 ± 8.2	<MDC	751.0 ± 94.0	221.0 ± 31.0
	k180	<MDC	<MDC	35.3 ± 9.7	1.8 ± 1.2	1240.0 ± 140.0	305.0 ± 38.0
	l188	<MDC	<MDC	14.3 ± 9.5	<MDC	359.0 ± 44.0	78.0 ± 12.0
	n196	<MDC	<MDC	60.0 ± 12.0	<MDC	188.0 ± 25.0	128.0 ± 18.0
	s245	31.2 ± 6.0	54.0 ± 31.0	43.0 ± 11.0	<MDC	12.3 ± 3.8	3.8 ± 2.2
	MDC	*4.0*	*40*	*10*	*4.0*	*4.0*	*4.0*