CAMECO

YEELIRRIE DEVELOPMENT

RADIATION TECHNICAL REPORT

June 2015

Jim Hondros

JRHC

JRHC Enterprises Pty. Ltd.

PO Box 372,

Stirling, SA 5152

INDEX

1. INTRODUCTION

The aim of this technical report is to provide the detail for the assessment of the radiation related risks to human health and non-human biota. This report provides the data, methods and assumptions used to estimate the human health and non-human impacts for the Public Environmental Review (PER) for the Yeelirrie Uranium Project.

This report consists of the following:

- summary of background radiation monitoring including;
    - data from the WMC 1978 Environmental Impact Statement (EIS)
    - data from BHP Billiton (2009 – 2011)
    - recent work by Cameco (since 2012)
- summary of the radiological characteristics of the project
- details for the occupational and public dose assessment
- assessment of potential doses from bush tucker
- radiological impact assessment for non-human biota
- overview of radiation control measures.

2. SUMMARY OF BACKGROUND RADIATION MONITORING

This section provides a summary of the background radiation monitoring information that has been collected since investigative work commenced at Yeelirrie in the 1970's.

2.1 AVAILABLE INFORMATION

Information was obtained from three main sources, the WMC EIS, background survey work completed by BHP Billiton and monitoring conducted by Cameco. A summary of the information is provided below.

WMC EIS

In 1978, WMC submitted an environmental impact statement (EIS) for the Yeelirrie project which contained a section on the radiation impact of the project. The radiation assessment was conducted by the Australia Atomic Energy Commission (AAEC), and results were provided in the following document;

AAEC 1978 Report [Australian Atomic Energy Commission, Three baseline studies in the environment of the uranium deposit at Yeelirrie, Western Australia, May 1978].

A key finding of the AAEC work is summarised in the executive summary of the 1978 EIS and is reproduced here as follows:

> *Measured radioactivity levels in all environmental media (water, soils, air and biota) in the Yeelirrie valley are higher than normal. The undisturbed ore body affects the quality of air in its immediate neighbourhood. Radon daughter concentrations over the ore body can peak 'pre-dawn' almost to the Code of Practice maximum permissible concentration for continuous occupation by members of the public. Radon daughter concentrations elsewhere are much less. The radium concentrations in groundwater are high except to the north and east of the Homestead.*
>
> *Radioactivity in soils and vegetation along the central drainage channel is locally high but generally much less elsewhere.*

The finding notes and acknowledges that the Yeelirrie deposit is in an area of naturally occurring elevated radiation levels.

The 1978 AAEC report provides information in the following areas:

- Background radon and radon decay product concentrations
- Background radionuclide concentrations in soils, flora and fauna

Both the 1978 EIS and 1978 AAEC reports use units of radioactivity which are no longer in use. For activity, the documents reported in units of Curies, while the current standard unit is Becquerels. Also, radiation dose is reported in the unit of Rem, while the current unit is the Sievert. When figures from these earlier reports are used in this technical report, they have been converted to the current standard units.

- The 1978 documents did not present results for any background gamma monitoring or values for radionuclides in airborne dusts.

BHP Billiton Background Surveys

BHP Billiton conducted extensive background monitoring between 2009 and 2011 and results have been summarised for this report. This data is currently unpublished and has been extracted from consultant reports and internal BHP Billiton documents related to Yeelirrie.

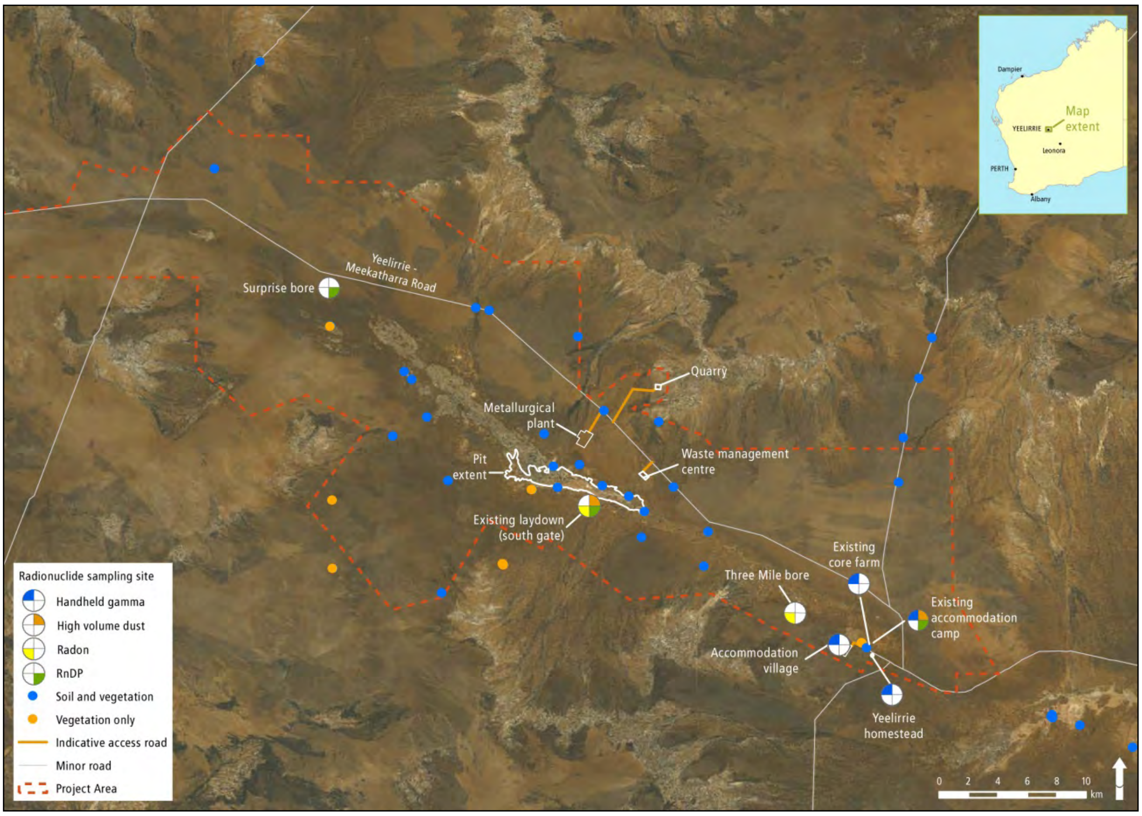
The main data includes the results from:

- Real time radon and radon decay product concentration monitoring in the location of the orebody and at the Yeelirrie homestead.
- Passive radon monitoring conducted over an extended area.
- High volume dust sampling, which provide concentrations of radionuclides in airborne dust.
- Analysis of soils, flora and fauna for long lived radionuclides.
- Sampling and analysis of surface water and groundwater for long lived radionuclides.
- Gamma radiation surveys including an aerial radiometric survey and on ground monitoring.

During the second half of 2011, BHP Billiton placed the Yeelirrie project into care and maintenance and data collection was significantly reduced. In particular, the real time radon and radon decay product monitoring was reduced and a program for sampling and analysis of radionuclides in kangaroos was cut short. However, a number of kangaroo samples had been taken and these were subsequently analysed for radionuclides by BHP Billiton.

Figure 1 shows the locations of all the BHP Billiton background monitoring and sampling locations.

Figure 1: Location of sampling sites



Cameco Monitoring

When Cameco acquired Yeelirrie in 2012, some radon and radon decay product monitoring programs were continued. This monitoring was conducted at the same locations as before and therefore provides a comparison of results over time.

Cameco has also undertaken some additional investigative radiation related work to determine more accurate and representative measures of the radon emanation rate from tailings and broken ore.

2.2 RADON AND RADON DECAY PRODUCTS

The 1978 documents present results from an extensive survey of atmospheric radon and radon decay products (RnDP) and also included estimates of radon emanation. The main sampling was conducted during an on-site field trip during 1978. A summary of the monitoring results is presented in Table 1.

Table 1: Summary of 1978 EIS results

Location	Parameter Measured	Value	Comments
Directly over ore body	Radon emanation	3.7Bq/m^2.s	Measured at sunrise
	RnDP concentration	<0.125µJ/m^3	Average of two-weekly sampling runs
	RnDP concentration (average of spot samples in evening)	0.125µJ/m^3	Average of samples taken at sunrise and sunset
	Equilibrium factor	0.07	Average of side by side radon and RnDP measurements
Well away from ore body (and downwind)	Radon emanation	0.37Bq/m^2.s	Measured at sunrise
	RnDP concentration	<0.06µJ/m^3	Average of two-weekly sampling runs
	RnDP concentration (Integrated sampling)	0.021µJ/m^3	Average of samples taken at sunrise and sunset
	Equilibrium factor	0.24	Average of side by side radon and RnDP measurements
Trial mining slot	RnDP concentration	0.104µJ/m^3	Work conducted in 1972 and is average of spot samples before sunrise
Trail mining slot	RnDP concentration	0.03µJ/m^3	Work conducted in 1972 and is average of spot samples during day time
Averages over stockpile	RnDP concentration	0.052µJ/m^3	Work conducted in 1972 and is average of spot samples during daytime

A summary of the key conclusions of the 1978 radon and RnDP work are as follows:

- There was no change in atmospheric RnDP concentrations with increasing height from 1m to 7m over the ore body.
- The RnDP concentrations varied with time-of-day by two orders of magnitude over the ore body and one order of magnitude off the ore body.
- The ore body has a significant radon emanation signature when compared to surrounding areas.
- The low equilibrium ratio confirms the ore body as the primary source of radon in the environment.
- The concentration of RnDP increases in the hours before dawn and this is due to stable atmospheric conditions.

During 2010 and 2011, concentrations of radon and RnDP were monitored continuously using real time monitors at Yeelirrie for extended periods (see Figure 1 for sampling locations).

The monitoring was conducted using the Durridge Rad 7 for radon and an environmental radon decay monitor (ERDM) from Radiation Detection Systems for RnDP.

Radon sampling was conducted at two main locations:

- South gate – on the ore body
- Three Mile bore – 5km north-west of the homestead.

RnDP monitoring was conducted at three main locations:

- South gate – on the ore body
- the existing accommodation camp – adjacent to the homestead
- Surprise bore – 15km north-west of the ore body.

A summary of the radon results can be seen in Table 2 and Table 3.

Table 2: Summary statistics of real-time radon concentration (Bq/m^3) – South gate

Month	Rn (Bq/m^3)		
	Av	Max	Median
July-10	127	1720	23
Aug-10	69	995	18
Sept-10	36	1115	9
Oct-10	18	411	7
Nov-10	33	783	8

Table 3: Summary statistics of real-time radon concentration (Bq/m^3) – 3 Mile Bore

Month	Rn (Bq/m^3)		
	Av	Max	Median
July-10	46	320	18
Aug-10	43	435	15
Sept-10	18	231	8
Oct-10	46	435	15
Nov-10	30	304	11

The data shows;

- average radon concentrations are higher closer to the ore body, with average levels being higher at South gate compared to Three Mile Bore, and
- that there is monthly variation in the indicative statistics.

Figure 2 is a plot of the real time radon concentrations for one month showing the variation that occurs. Note that the radon concentrations peak on almost every day and this is usually associated with the times that very stable atmospheric conditions occur (early morning).

Figure 2: Radon concentrations for South gate and Three Mile bore

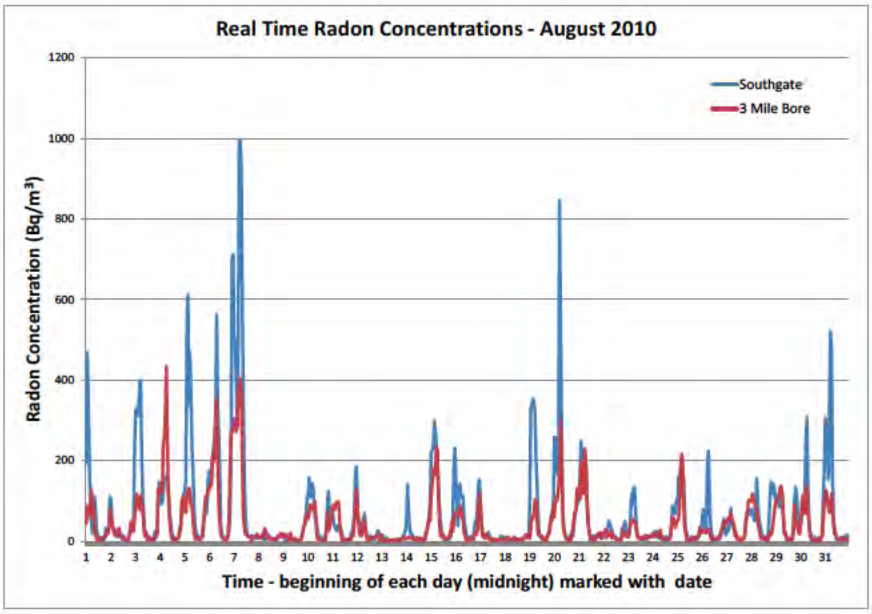
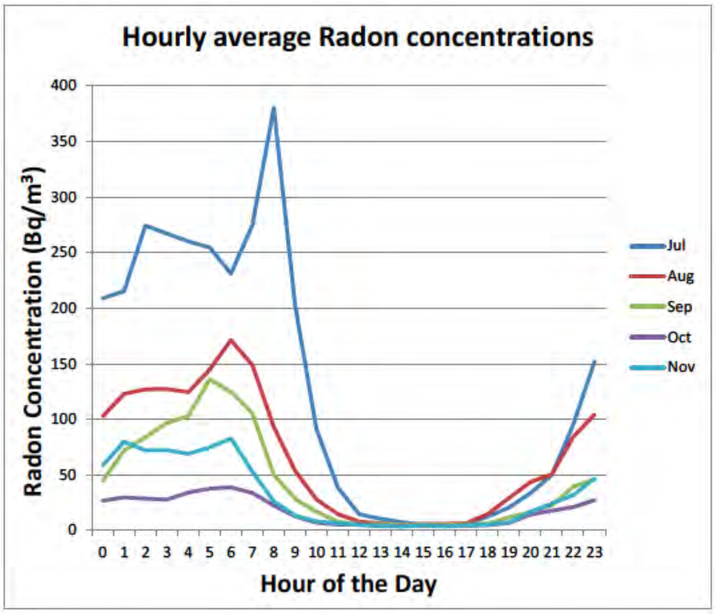


Figure 3 is a plot of hourly averages of radon concentrations for each month and shows the variation that occurs during the day. The daily variation tends to be more pronounced during the colder months of the year and this variation has been observed in data from other projects [Cameco 2013, Toro 2009, BHP Billiton 2009].

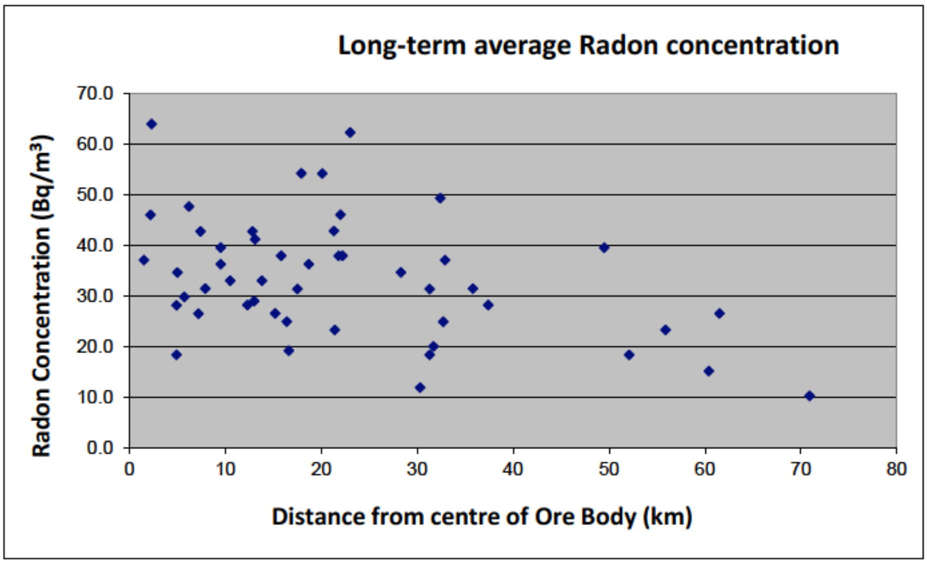
Figure 3: Hourly average Radon concentrations - South gate



In addition to the real-time radon monitoring, passive radon detectors were deployed in the region during 2010. The monitors were placed into the field for three months at 50 locations to determine the long-term averages over approximately the same period as the real-time monitoring.

Figure 4 shows the concentrations with distance from the centre of the main ore body (direction independent).

Figure 4: Passive radon concentrations with distance



The results vary between approximately 10 and 65 Bq/m^3 and show higher levels closer to the orebody. The average concentrations are as follows;

- 0 to 25km from the orebody – 37Bq/m^3
- 25 to 40km from the orebody – 30Bq/m^3
- > 40km from orebody – 22Bq/m^3.

These results confirm the original AAEC assertion that the orebody is the dominant source of radon in the region.

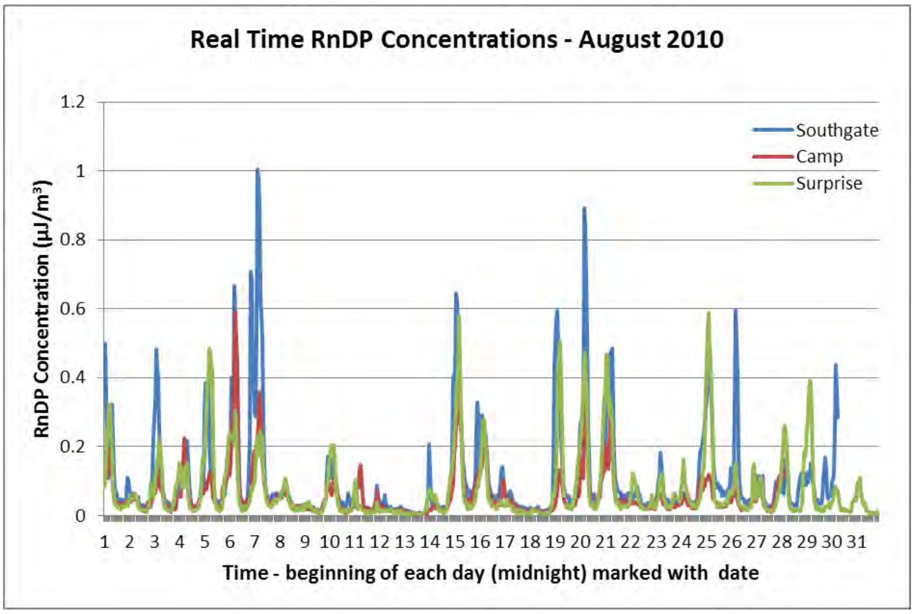
For RnDP, real time monitoring was conducted during 2010 and a summary of the results can be seen in Table 4.

Table 4: Summary statistics of RnDP concentrations

Month of 2010	RnDP Concentration (µJ/m^3)					
	Average			Median		
	Camp	Surprise Bore	South gate	Camp	Surprise Bore	Southgate
June	0.06	0.04	0.21	0.03	0.03	0.06
July	0.09	0.06	0.11	0.04	0.04	0.05
August	0.08	0.06	0.11	0.04	0.04	0.05
September	0.07	0.04	0.03	0.03	0.03	0.02
October	0.03	0.02	0.05	0.02	0.02	0.03
November	0.03	0.03		0.02	0.02	

Figure 5 shows the variation in RnDP concentrations for the month of August 2010, with concentrations peaking on almost a daily basis due to the stable atmospheric conditions.

Figure 5: Variation in RnDP concentrations - August 2010



The data show a similar trend to the radon concentration data as follows;

- average concentrations at the south gate were up to three times higher than at the camp location,
- concentrations at Surprise bore, north-west of the ore body, are on average 50% higher than levels at the camp, and
- peak concentrations at the south gate are up to five times higher than at the camp.

The data shows that there is a marked difference between the atmospherically stable time of day and more turbulent (windy) times of day. Usually the stable time of day is from later evening until late morning, with the more turbulent period at the other times.

The results of the 2010 work are confirmed by more recent RnDP monitoring at the Yeelirrie homestead between May 2013 and Jan 2014. A summary of the results can be seen in Table 5.

Table 5: Hourly average RnDP Concentrations at Yeelirrie homestead 2013/2014

Month	RnDP Concentration (µJ/m^3) as hourly averages		
	Average	Median	Maximum
May 2013	0.08	0.04	0.60
June 2013	0.09	0.05	0.82
July 2013	0.08	0.04	0.50
August 2013	0.09	0.05	0.72
September 2013	0.06	0.03	0.44
October 2013	0.04	0.03	0.40
November 2013	0.02	0.02	0.22
December 2013	0.03	0.02	0.30
January 2014 (to 12th January)	0.03	0.03	0.24

2.2.1 CORRELATION OF RADON AND RNDP DATA (EQUILIBRIUM FACTOR)

The equilibrium factor is a measure of the ratio between the RnDP concentration and the radon concentration. When the ratio is 1, the potential alpha activity of the RnDPs are equal to the activity of the radon. Since RnDP activities are usually measured as the "potential alpha energy concentration", (PAEC), the relationship between radon concentration and RnDP concentration when the equilibrium factor is 1 is expressed as follows;

$$1\ Bq/m^3\ (radon) = 5.56 \times 10^{-6}\ mJ/m^3\ (PAEC)\ [UNSCEAR\ 2000]$$

Therefore, the equilibrium factor can be calculated as follows;

$$Equilibrium\ factor = PAEC\ concentration\ (\mu J/m^3) / 0.00556 / Rn\ concentration\ Bq/m^3$$

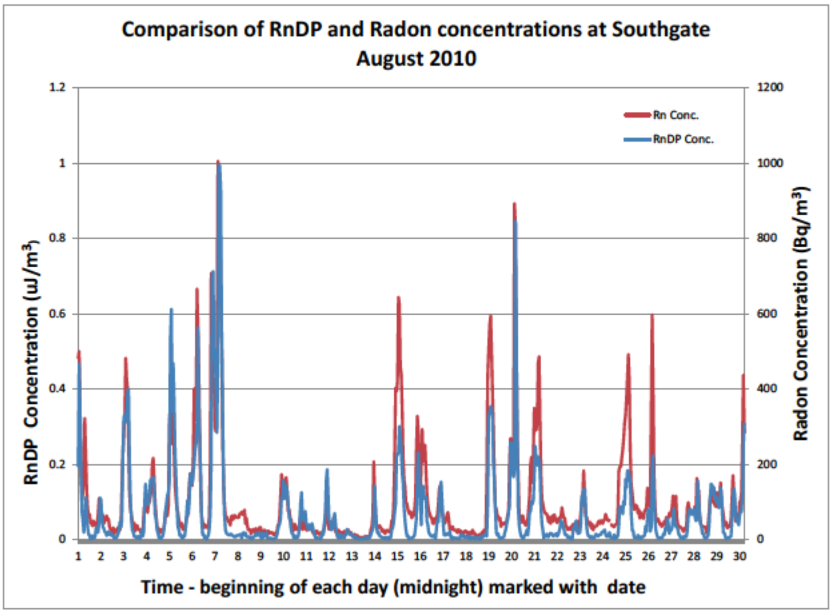
An understanding of the equilibrium factor is particularly important for calculating the RnDP concentrations from radon concentrations that arise from air quality modelling of radon emissions from a project.

The 1978 EIS documents measured radon and RnDP concentrations and these were used by the AAEC to qualitatively calculate an equilibrium factor for the region. The results indicated that the factor was 0.07 over the orebody and 0.24 elsewhere. The AAEC then concluded that the low factor over the orebody indicated that the orebody was the predominant source of radon in the region. This is because the RnDP concentration did not have time to "grow in" to the radon concentration.

The 2010 side by side monitoring of radon and RnDP concentrations at South gate for three months also provided an opportunity to experimentally determine the naturally occurring equilibrium factor.

Figure 6 shows the radon and RnDP concentrations over a representative month in the sampling period on an hourly basis and shows good correlation between the two sets of data, with peaks occurring concurrently over the period.

Figure 6: Comparison of RnDP and radon concentrations at South gate (August 2010)



An analysis of the 2010 radon and RnDP concentration data from South gate was conducted to characterise the equilibrium factor. A summary of the results are shown in Table 6.

Table 6: Monthly average measured equilibrium factors

Monitoring period	RnDP concentration ($\mu J/m^3$)	Radon concentration (Bq/m^3)	Equilibrium factor
July	0.21	131	0.29
July (night only)	0.39	251	0.28
August	0.10	70	0.26
August (night only)	0.17	127	0.24
September	0.11	46	0.43
September (night only)	0.20	87	0.41
October	0.03	18	0.30
October (night only)	0.02	31	0.12
November	0.05	26	0.35
November (night only)	0.08	48	0.30

Despite the clear meteorological differences that occur between day and night, the equilibrium factor is relatively constant and below approximately 0.4 (note that this figure is higher than the original AAEC results but consistent with the UNSCEAR figure).

A value of 0.4 is used in the subsequent dose assessment which is based on the radon concentrations from air quality modelling.

2.2.2 RADON EMANATION

The emission of radon from the project results in exposures to people on site and off site. The radon emission rates from various project areas are used as inputs to air quality modelling.

The AAEC work provided an estimate of radon emanation rates of approximately $37Bq/m^2.s$ per %U for both in situ and broken ore.

The radon emission rate assumed in the 2010 assessment work was based on emission rates published in the Olympic Dam EIS [BHP Billiton 2009]. This work provided a radon emanation rate of $50Bq/m^2.s$ per %U, with an additional factor or 5 applied to account for the larger surface area that occurs when there is broken ore.

Cameco has recently undertaken preliminary testwork to better quantify the radon emission rate from ore and has determined a radon emission rate of approximately $8Bq/m^2.s$ per % U [Unpublished Cameco report].

For the impact assessment, the published figure of $50Bq/m^2.s$ per %U has been used, and, it is noted that this is likely to lead to a conservative estimate of radon emission from the operation.

2.3 RADIONUCLIDES IN DUST

The WMC EIS work [1978] did not provide results for any radionuclide in airborne dust concentrations.

During the second half of 2010, high volume dust sampling was conducted by BHP Billiton at south gate, the Yeelirrie homestead and the existing accommodation camp (see Figure 1 for sampling locations). Samples were analysed both gravimetrically (to determine the mass concentration of dust in air) and radiometrically (to determine the radionuclide concentrations in air).

Both total suspended particles (TSP) and particles less than 10 microns (PM_{10}) were sampled. (PM_{10} is usually recognised as the inhalable fraction of airborne dust, however for radiation assessment, TSP is usually used.) A summary of the results can be seen in Table 7.

Table 7: Summary of high volume dust results at Yeelirrie

Location	Sampling Period & Number of Samples	Sample Type	Radionuclide Concentration (µBq/m^3) [1]			
			U^{238} [2]	Th^{230}	Ra^{226}	Pb^{210}
South gate	Aug 2010 - Dec 2010 (4)	PM10	8.3 (4-15)	67 (18 – 100)	4.5 (1.8 – 7)	518 (360 – 730)
Y Accom	June 2010 - Dec 2010 (5)	TSP	27.4 (3 – 90)	107 (14 – 300)	9.3 (1.7 – 15)	278 (90 – 560)
Y Homestead	May 2010 - Dec 2010 (3)	PM10	2.9 (2 – 3.7)	34 (11 – 50)	3.2 (0.7 – 6.4)	305 (85 – 570)
UNSCEAR [3]			1 (0.02–18)	0.5 (0.02–1.7)	1 (0.8–3.2)	500 (<40 –2,250)

Note 1: The majority of U^{238} and all of the Th^{230} results were less than the detectable limit. For the average, the less than figure was assumed to be the concentration (for example, if the result was <2 µBq/m^3, then the results was assumed to be 20µBq/m^3).

Note 2: Calculated from a measured Th^{234} concentration.

Note 3: UNSCEAR figures have been derived from dust in air and radionuclides in soil concentrations

2.4 GAMMA RADIATION

The WMC EIS work [1978] did not provide results for any environmental or regional gamma monitoring.

However, it was reported in the 1978 EIS that in 1969, WMC commissioned an aerial radiometric survey of the region, which was able to clearly identify the Yeelirrie ore deposit radiometrically via higher gamma radiation levels. BHP Billiton repeated this aerial survey in 2011 using newer technology and the results are shown in Figure 7. The image clearly shows higher levels of gamma radiation over the ore body compared with the surrounding land.

Figure 7: Aerial Gamma Results

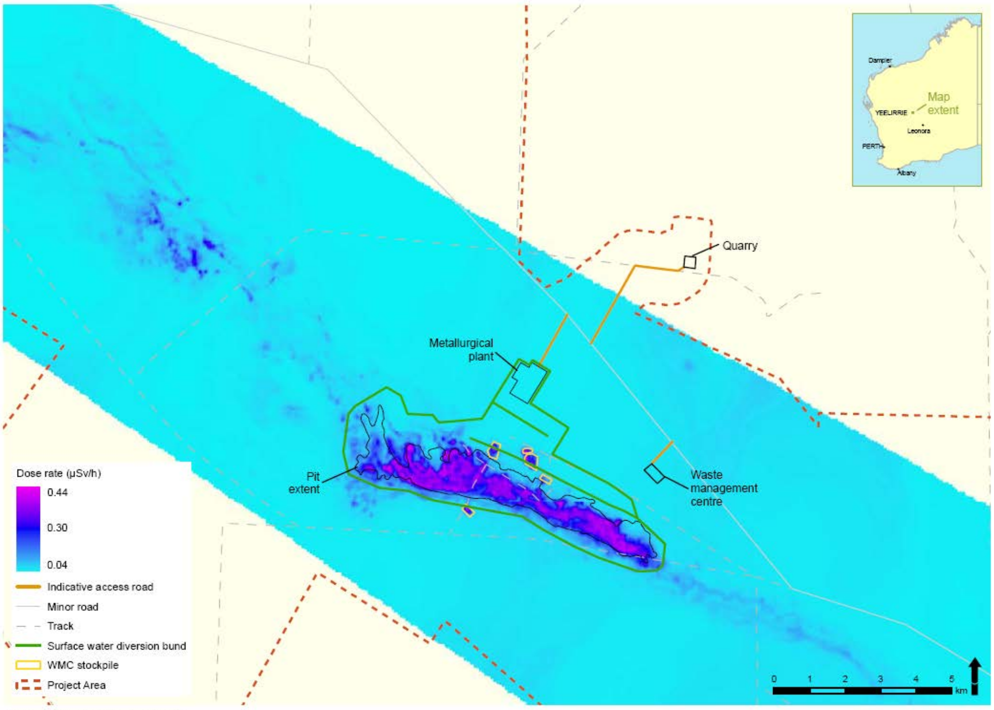


Figure 10.2 Aerial gamma survey

In addition to the 2011 aerial radiometric survey, gamma surveys were undertaken using handheld gamma monitoring instruments and the results are summarised in Table 8 (see Figure 1 for sampling locations).

Table 8: Gamma survey results

Area/Location	Average handheld gamma survey results (µSv/h)	Notes
Proposed accommodation village area	0.09	Average
Yeelirrie Homestead Area	0.07	Average
Existing accommodation camp (greywater area)	0.16	Adjacent to waste water area
Corefarm	0.10	Average
Orebody (average and range)	0.85 (0.1 – 6.3)	1,900 measurements

For comparison purposes, ARPANSA infers an Australian average gamma dose rate of 0.07µSv/h and it is generally accepted that levels across Australia vary between 0.02 and 0.1µSv/h [ARPANSA 2011 and Mudd 2002]. Average dose rates of 0.2µSv/h, ranging up to 0.4µSv/h for the Darling Scarp region of Western Australia have been inferred from Toussaint et al 1996.

No additional gamma monitoring has been undertaken.

2.5 RADIONUCLIDES IN GROUNDWATER

Groundwater generally flows into the Yeelirrie valley and along the palaeochannel and groundwater is recharged following rainfall.

The 1979 EIS reported on radionuclides in groundwater and determined that Ra^{226} concentrations in groundwater were highly variable (between 0.02 and 33Bq/L and typically greater than 0.1Bq/L). Concentrations of U^{238} were also reported to vary widely, with measured concentrations between 3.8 and 17.4Bq/L within the orebody region and levels between 0.02 and 2.2Bq/L within the broader catchment area.

A more extensive program of groundwater monitoring was conducted during 2009 and 2010 to determine the spatial variation of solute, metal and radionuclide concentrations in the groundwater with over 150 samples taken from drill and bore holes from across the region.

The earlier results showed how variable the radionuclide concentrations were in groundwater, and the more recent results confirmed this. To present the data in a meaningful way, the more recent sample results were grouped into broad categories (or bands of results around the orebody) and summary statistics have been provided (see Figure 8). The broad categories are:

- results from within the outline of the mineralised area (referred to as 'pit')
- results from within the area just outside the mineralised area (referred to as 'outline')
- results from within the valley, (referred to as 'valley')
- results from within the south eastern area, (referred to as 'SE area')
- any other results from the broader region (referred to as 'regional' – note that for clarity, this area has not been marked on Figure 8).

Note that the analysis was conducted on each discrete set of data (for example, the 'outline' results are only results from that area and exclude results from the 'pit' area). This way, it is possible to see how the radionuclide concentrations change as the distance from the mineralised zone increases. The results are provided in Table 9.

Figure 8: Categories of Groundwater results

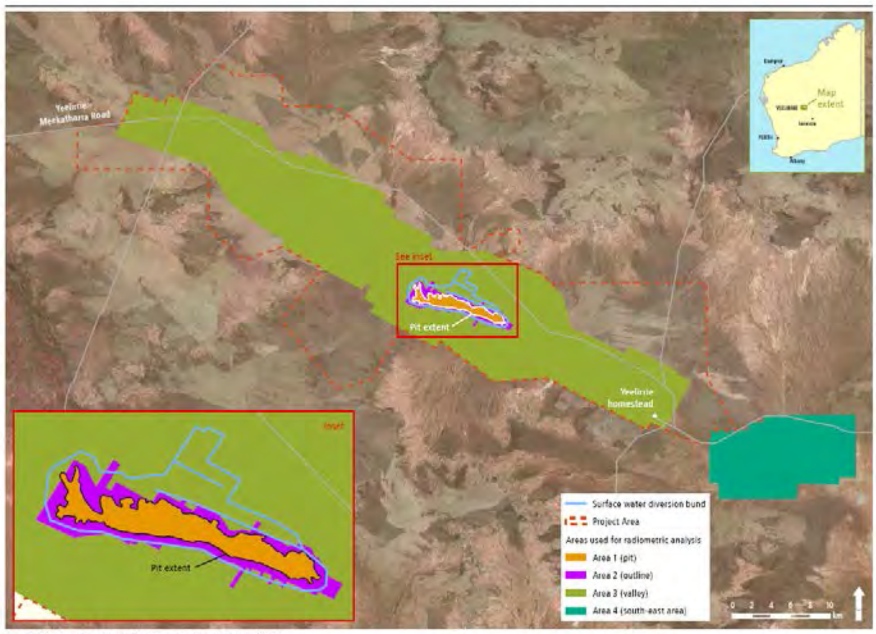


Figure 10.6 Areas used for radiometric analysis of groundwater

Table 9: Average and range of radionuclides in groundwater for different regions

Region	Radionuclides Concentrations in Groundwater, Average and Range (Bq/L)				
	U^{238}	Th^{230})	Ra^{226}	Rn^{222}	Pb^{210}
Pit	8.61 (1.5-31)	17.1 (0.1–63.6)	36 (0–447)	723 (7.3–4210)	2.29 (0.1–11.8)
Outline	6.19 (0.1– 4.5	0.07 (0.05–0.1)	5.9 (0.1–19.3)	86.3 (0.003–356)	6.8 (0.1–39.5)
Valley	5.95 (.03-28.5)	7.5 (0.1–24.3)	5.0 (0.1–58.2)	77.6 (0.94–198)	2.0 (0.1–22.9)
SE area	1.59 (0.13-8.69)	0.57 (0.1–0.87)	2.8 (0.1–27.8)		1.1 (0.1–18.4)
Regional	0.68 (0.06-2.4)		0.95 (0.1–1.82)	98.3 (1.14–491)	5.9 (0.1–29)

In each category there is a wide range of results, however, the average results show that concentrations of radionuclides in groundwater generally are lower the further away from the mineralised zone.

The results show that radionuclides are elevated in the region of the ore body.

There is no value in comparing groundwater concentrations from the Yeelirrie region with other regions because concentrations are dependent upon the presence of the ore body. The important point is that the groundwater is not a source of radiation exposure to humans or animals as the water is highly saline and not potable.

2.6 Radionuclides in Surface Water

The Yeelirrie region is in a semi-arid area of Australia and surface water flow is intermittent, usually only flowing through the broader valley after major rainfall. Drinking water for humans is not sourced from the region, although there are two fresh water pools in the breakaways to the north and upstream of the project area that may occasionally be used as a source of drinking water.

When there is sufficient water to cause a flow in the valley, it would be expected that uranium and radionuclides from the outcropping ore deposit would naturally move with the water as sediments.

During the 2009 - 2010 regional water sampling program, a limited number of surface water samples were taken when water was present. This occurred after rains in June of 2009 and March of 2010 and these are presented in Table 10.

Table 10: Summary of radionuclides in surface water samples

Sampling Location	Radionuclide Concentration (Bq/L)		
	U^{238}	Ra^{226}	Pb^{210}
Breakaway region (upstream)	<0.06	<0.1	4.63
Albion Downs region (downstream)	0.2	<0.1	3.24

The Australian Drinking Water Guidelines [NHMRC2004 and NRMMC 2004] provide a guide for assessing the relative levels of radionuclides in water. Where gross alpha or corrected beta activity concentrations exceed 0.5Bq/L, then further analysis is recommended to assess potential dose. At the measured radionuclide concentrations, a person would need to consume 300 litres of the water sampled in Breakaway region water or 400 litres of the water sampled in the Albion Downs region to receive a dose of 1mSv. However, surface water is generally not used for drinking, stock, irrigation or water supply because of its infrequent flow and lack of any suitable collection areas such as dams. In common with other arid environments of inland Australia, it also has high salinity.

2.7 RADIONUCLIDES IN SOILS

The 1978 EIS presented the results from the analysis of approximately 60 soil samples (plus 3 ore samples), specifically for concentrations for U^{238}, Ra^{226} and Pb^{210}. Samples were chosen to represent defined soil-type units. A summary of the results is provided in Table 11.

Table 11: Soil Radionuclide Concentrations

Soil Unit	Number of Samples	Average Concentration (Bq/kg)		
		U^{238}	Ra^{226}	Pb^{210}
Lake bed [1]	12	230	40	470
Lake margin [1]	6	380	70	90
Water influenced	11	160	2,550	1,520
Dry Valley fill	19	50	50	100
Calcrete valley fill	12	40	170	200
Mineralised calcrete	3	45,400	37,000	35,100

Note 1 – “Lake bed” and “Lake margin” were categories used in AAEC 1978 and refer to the region approximately 10km south of the Yeelirrie homestead.

The soil unit’s referred to in Table 11 are related to physical characteristics of the soils and geographic location. The ‘water-influenced’ soils are those onto which groundwater was discharged from the mine slots during test work.

The results show an obvious signature of the ore body in the mineralised calcrete. The remaining soil types show the influence of proximity to the lake or are water-influenced.

Soil sampling for radionuclides was also undertaken in 2010 in conjunction with a flora sampling program (see Figure 1 for sample locations).

A summary of the 2010 results are provided in Table 12 along with an average of the results from the 1978 EIS (not including those affected by water and mineralised calcrete). (Note that <10km refers to samples within 10 km of the centre of the proposed pit and >10km refers to samples beyond this.)

Table 12: Radionuclide concentrations in different soil types

Soil Sample Location	Radionuclide concentration - Average and Range (Bq/kg)				
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
1978 EIS (All Samples)	43 - 375		48 - 310	37 - 466	
All samples	50 (6-370)	62 (15-210)	129 (7.5-960)	182 (13-1,060)	88 (57-165)
>10km samples	50 (6-370)	78 (57-123)	85 (7.5-560)	144 (40-590)	42 (15-110)
<10km samples	51 (10-131)	124 (37-210)	208 (11-960)	249 (13-1,060)	114 (62-165)

2.8 FAUNA MONITORING

Fauna sampling provides an indication of the natural radionuclide concentrations that exist in animals. Care should be taken when drawing conclusions from fauna sampling as the results represent individual animals, and the behaviour of that individual, for example, the range of the animal and the percentage of time it spent grazing in various areas, which may not necessarily represent the species as a whole. The following sampling has been conducted:

- for the WMC EIS in 1978 (4 kangaroos and sheep)
- as part of a Traditional Owner ceremony in 2010 (3 kangaroos)
- further survey in 2011 (4 kangaroos).

An analysis of the data was conducted by Cameco. A summary of the 1978 data is provided in Table 13.

Table 13: Radionuclide concentrations in kangaroo - 1978 survey

Sample Type	Radionuclide Concentration – Average and Range Bq/kg		
	U^{238}	Ra^{226}	Pb^{210}
Bone	<0.03	139 (23 –463)	40 (11 –91)
Flesh	0.04 (<0.03 – 0.08)	0.12 (0.02 – 0.40)	7.5 (1.7 – 20))
Liver	<0.03	1.8 (<0.1 – 5.2)	291 (55 – 947)
Kidney	0.27 (0.09 – 0.62)	0.8 (0.2 – 1.8)	108 (83 – 138)

Samples from the 2010 survey were analysed and a summary of the results are shown in Table 14.

Table 14: Radionuclide concentrations in kangaroo - 2010 survey

Sample Type	Radionuclide Concentration – Average and Range Bq/kg				
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
Bone	0.3 (0–0.9)	0.0 (*)	238 (47–457)		47 (25–76)
Flesh	0.0 (*)	0.0 (*)	4.2 (2.4–7.1)	33.4 (13–50)	0.6 (0.1–1.8)
Kidney and liver	0.0 (*)	0.3 (0.25–0.73)	7.8 (2.5–34)	41 (12–87)	39 (14–72)

Note: * indicates that all results recorded as zero.

Samples from the 2011 survey were analysed and a summary of the results are shown in Table 15.

Table 15: Radionuclide concentrations in kangaroo - 2011 survey

Sample Type	Radionuclide Concentration – Average and Range Bq/kg				
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
Bone	0.3 (0.1–0.3)	1.8 (0.8 - 3)	15.4 (8.1–23.5)	26.7 (9.1 – 37.2)	24.5 (2.3 – 53.3)
Muscle	0.1 (0.1 – 0.2)	0.1 (0.05 – 0.1)	0.3 (0.3 – 0.4)	2.3 (2.0 – 3.0)	1.7 (0.1–3.2)
Liver	0.1 (0.1 – 0.2)	1.0 (0.7–1.4)	0.4 (0.3 – 0.5)	2.7 (2.0 – 3.0)	3.9 (3.2–5.2)

There is a high degree of variability between the sample sets. Quality control documentation is available only for the 2011 data set.

2.9 Flora Monitoring

Sampling of flora for radionuclide analysis was conducted for 1978 and in 2010.

In 1978, samples of vegetation were taken at the same sites as soil samples. It was intended that the correlation between soil and vegetation radionuclide concentrations be conducted, however, the AAEC noted that derivation of an uptake factor is complicated, because not all metals (or radionuclides) in soils are chemically or physically available for plant uptake.

Results are provided in Table 16. Note that some species names of vegetation may differ from those used now.

Table 16: Vegetation radionuclide concentrations

Genus	Species	Number of Samples	Mean wet concentration (Bq/kg)		
			U^{238} [1]	Ra^{226}	Pb^{210}
Xerophyte shrubs (with phyllodes	*Acacia stowardii*	5	0.4	0.4	48
	Acacia burkittii	12	0.5	0.4 *	69
	Acacia tetragonophylla	4	0.6	1.8	64
	Group mean		0.6	0.7	69
Xerophyte shrubs (with leaves)	*Eremophila longifolia*	4	0.3	0.9 *	9 *
	Grevillea sp.	3	1.3	0.4	60
	Ptilotus obovatus	8	3.9 *	18 *	83 *
	Group mean		1.2	3.6	36
Halophyte shrub – sodic	*Arthrocnemum leiostachyum*	3	13	4.2	17
	Atriplex sp.	4	2.9	13 *	13 *
	Atriplex bunburyana	3	1.7	3.7	20
	Cratystylis subspinescens	7	0.5	1.7 *	18 *
	Maireana pyramidata	6	0.7 *	2.5 *	39
	Maireana sp.	1	3.4	55	74
	Bassia sp.	3	4.6	5.7	28
	Melalecua sp.	4	2.2	7.2	181
	Group mean		2.8	7.7	68

Genus	Species	Number of Samples	Mean wet concentration (Bq/kg)		
			U^{238} [1]	Ra^{226}	Pb^{210}
Halophyte shrubs – calcic	*Frankeria* sp1	6	102 *	25	59
	Frankeria sp2	3	7.1	7.1	18
	Group mean		9.1 *	11	26
Grasses	*Stipa scabra*	1	4.8	81	112
Hydrophyte	*Ruppia maritima*	1	109	260	171

Note * - refers to median value
Note 1 - reported concentrations were for elemental uranium. U^{238} concentration has been calculated from the elemental values provided.

In 2010 an additional more focussed flora study was conducted which sampled three species, being the relatively long-lived *Acacia aneura* and the shorter-lived *Acacia ayersiana* and *Ptilotus obovatus*. Samples locations are identified in Figure 1 and results are summarised in Table 17, Table 18 and Table 19. Note that not all samples were analysed for all radionuclides.

Table 17: Flora sample analyses – *Acacia aneura*

Distance from centre of ore body	Number of Samples	Mean wet concentration (Bq/kg)				
		U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
<10 km	4	7.3		2.2	70.5	
	1		2.1			43
>10 km	12	4.0		1.8	52.6	
	1		1.2			54
All samples	16	4.8		1.9	57.1	
	2		1.7			49

Table 18: Flora sample analyses – *Acacia ayersiana*

Distance from centre of ore body	Number of Samples	Mean wet concentration (Bq/kg)				
		U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
<10 km	4	4.3		1.7	67.3	
	1		1.2			53.0
>10 km	6	6.0		2.1	64.0	
	1		2.6			44.0
All samples	10	5.3		1.9	65.3	
	2		1.9			49.0

Table 19: Flora sample analyses – *Ptilotus obovatus*

Distance from centre of ore body	Number of Samples	Mean wet concentration (Bq/kg)				
		U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
<10 km	5	9.6		9.1	41.8	
	1		6			27.0
>10 km	3	6.3		5.5	25.7	
	1		2.1			7.7
All samples	8	8.4		7.8	35.8	
	2		4.1			17.4

In addition, opportunistic sampling of recognised bush food from the area occurred during 2010 as part of the flora survey. Table 20 shows the species sampled with the corresponding common name [Leyland 2002]. Average radionuclide concentrations in these species are provided in Table 21.

Table 20: Bush food descriptions

Species	Common name	Part eaten	Part sampled
Acacia aneura	Mulga	Seeds, edible gum, edible insects and galls	Seed pods
Acacia ramulosa var. *linophylla*	Bowgada	Seeds and young seed pods	Seed pods
Enchylaena tomentosa	Ruby Salt Bush	Ripe berries	Fruit
Eremophila longifolia	Berrigan	Fruit	Green fruit
Lycium australe	Australian Boxthorn	Berries	Berries
Santalum acuminatum	Quandong	Nut (seed of fruit) and fruit	Fruit
Santalum lanceolatum	Bush Plum	Flesh of fruit	Fruit

Table 21: Radionuclides in bush foods

Distance from centre of ore body	Mean wet concentration (Bq/kg)				
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
<10 km	3.9	2.6	2.4	5.1	8.8
>10 km	3.0	1.7	2.0	3.0	4.7
All samples	3.7	2.4	2.3	4.7	7.6

The 2010 results indicate that concentrations are generally higher closer to the mineralised area as would be expected with outcropping mineralisation. It is worthy to note that results for the bush tucker species examined show significantly lower concentrations of Pb^{210} than for general flora.

Comparison of results from the 1978 sampling program and the 2010 sampling program is difficult due to changes in analysis techniques and the sensitivity of analysis. However, on average, the recent Ra^{226} and Pb^{210} levels appear to be consistent with the earlier results. The U^{238} concentrations for the 2010 study are higher than the results of the earlier study, although this may be due to the improved sensitivity of analyses.

2.10 CONCENTRATION RATIOS

Measured radionuclide concentrations in flora, fauna and soils provide an opportunity to determine concentration ratios which can be used for an assessment of the impact of radionuclides on non-human biota.

Concentration ratios represent the ratio of organism whole body radionuclide activity concentration in fresh weight, compared to the activity concentration of that radionuclide in the media (soil or water) that where it the organism lives. For a terrestrial assessment this is the Bq/kg whole organism (fresh weight) per Bq/kg soil (dry weight). Where individual tissues have been sampled, whole organism values can be obtained by applying whole-body to tissue ratios published by Yankovich [2010]. Johansen and Twining [2010] have previously analysed earlier kangaroo data from Yeelirrie and a summary of the concentration ratios can be seen in Table 22.

Table 22: Kangaroos Concentrations Ratios

Sample Type	Concentration Ratio (x 10^{-3}) – average & range		
	U^{238}	Ra^{226}	Pb^{210}
Muscle	0.17 (<0.09 – 0.41)	0.13 (0.01 – 0.46)	3.4 (0.75 – 9)
Kidney	1.3 (0.42 – 3.0)	1 (<0.2 – 2.4)	150 (43 – 340)
Liver		2.3 (<0.16 – 6.7)	132 (29 – 400)
Bone		180 (30 – 600)	54 (13 -120)

A similar assessment was conducted using the more recent kangaroo results (from 2011) as outlined in Section 2.8 and the soil sample results from Section 2.7 to produce average concentration ratios and these are seen in Table 23.

Table 23: Kangaroos Concentrations Ratios (from 2011 survey)

Sample Type	Concentration Ratio (x 10^{-3}) – average & range				
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
Muscle	2.5 (2.0 – 4.0)	1.4 (0.8 – 1.6)	2.7 (2.1 – 3.1)	12.4 (11.0 – 16.5)	18.7 (0.7 – 37.5)
Liver	2.6 (2.6 – 4.0)	15.4 (10.6 – 22.6)	3.2 (2.5 – 3.9)	14.6 (11.0 – 16.5)	44.1 (35.9 – 58.6)
Bone	5.0 (2.6 – 6.0)	28.2 (12.4 – 48.4)	119.6 (62.8 – 182.2)	141.1 (50 – 204.4)	278.1 (30.5 – 605.7)

The differences between Table 22 and Table 23 tend to highlight the variability that exists in the natural environment.

Concentration ratios for flora sampled during 2010 is presented in Table 24. These figures were obtained by taking the all average results from Section 2.9 and combining with the all average soil concentration results from Section 2.7.

Table 24: Summary of Concentration Ratios for Sampled Vegetation

Species	Concentration Ratios				
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
Acacia aneura	0.10	0.30	0.01	0.31	0.56
Acacia ayersiana	0.11	0.03	0.01	0.36	0.56
Ptilotus obovatus	0.17	0.07	0.06	0.20	0.20

2.11 SUMMARY

The more recent background sampling and the results from 2010 and 2011 are consistent with those from the earlier AAEC monitoring undertaken for the 1978 EIS. The main points are;

- clear variation in radon and RnDP concentrations, reflecting stable atmospheric night-time conditions that facilitate the build-up of concentrations,
- the ore body has a significant radiological signature for radon and radionuclides in water and soils when compared to surrounding areas,
- the naturally occurring background radiation levels are elevated close to the orebody, and
- naturally occurring background radiation levels are detectable in ground and surface water and in plants and animals.

3. RADIOLOGICAL CHARACTERISTICS OF THE YEELIRRIE PROJECT

3.1 INTRODUCTION

This section describes the criteria and assumptions used in the impact assessments.

The potential radiological impacts of the project are assessed as potential radiation exposures to workers, members of the public and the environment.

Impacts are estimated or calculated using recognised methods including, consideration of actual radiation levels and impacts in other similar operations and using standard assessment methods as outlined by the ICRP or ARPANSA.

For occupational doses, estimates are made for mining and processing plant personnel for the following exposure pathways;

- gamma radiation,
- inhalation of radon decay products (RnDP) (taking into account the effects of stable atmospheric conditions), and
- inhalation of radionuclides in airborne dust.

Doses for the public are based on a reference person permanently inhabiting each of the sensitive receptor locations defined below. Each of the main exposure pathways are assessed as well as the ingestion pathway.

For the public, the sensitive receptor locations are defined as;

- the Yeelirrie homestead, (also the location of the project accommodation village) and located approximately 16.4km to the southeast of the ore body,
- Ululla homestead, located approximately 28.5km north of the ore body,
- Yeelirrie Pool, located approximately 10.2km north east of the ore body, and
- Palm Springs located approximately 50.4km east-south east of the ore body.

The environmental impact is assessed based on determining a change in exposure rates to standard species of flora and fauna.

3.2 METHODS OF IMPACT ASSESSMENT

The impact to workers and the public is via dose assessment and Table 25 provides a summary of the dose assessment methods for the different exposure pathways.

Table 25: Dose Estimation Methods

Dose Pathway	Miners	Surface Workers	Member of Public
Gamma Radiation	Estimation based on recognised conversion factor	Comparison with similar operations	Negligible due to distance – not calculated
Inhalation of radionuclides in dust	Estimation based on ore dust at concentration of $1mg/m^3$	Comparison with similar operations	Estimation based on air quality modelling results
Inhalation of RnDP	Box model applied to one operational mining cell	Estimation based on air quality modelling	Estimation based on air quality modelling results
Ingestion of radionuclides	Not calculated – hygiene practices expected to ensure dose is negligible	Not calculated – hygiene practices expected to ensure dose is negligible	Estimation based on modelled dust deposition and transfer factors

For flora and fauna, the assessment method is via the ERICA assessment software which uses changes in the radionuclide concentration of media (such as soil and water) as a result of the operation to determine a risk quotient. The method for determining the change in media concentration is via modelled dust deposition results.

3.3 DOSE ASSESSMENT CRITERIA

The following criteria have been used in the radiological impact assessment

Production Factors:

- average total mining rate – 8mtpa (ore and waste rock)
- average ore mining rate – 3mtpa
- average uranium grade of mined ore – 1,600ppm
- average uranium grade of waste rock – 100ppm
- average uranium grade of all material mined – 660ppm (approximately and calculated as a weighted average)
- mine depth - 10m
- mine has 12 cells, with each cell approximately 50Ha
- average annual production of uranium – 3,600t
- average annual tailings production rate – 2.4mtpa.

Exposure Factors:

- member of the public exposure hours – 8,670h/y
- member of the public breathing rate – $1.0m^3/h$
- worker exposure hours (working year) – 2,000h/y
- production workers – 50% night shift, 50% day shift
- worker breathing rate – $1.2m^3/h$

Physical Property Factors:

- relationship between uranium grade and radionuclide activity is 1ppm U = 12.3mBq(U^{238})/g
- ore is in secular equilibrium when mined
- specific activity of all dust emissions is 9.4Bq/g (per radionuclide)
- specific activity of mine dust is 8.25Bq/g (per radionuclide)
- the majority of radionuclides, apart from uranium, report to tailings
- the concentration of radionuclides in tailings is approximately equal to the concentration in the ore (apart from uranium)
- deposited dust will mix in the top 1 cm of soil [Kaste 2007]
- specific gravity (density) of soil in the environment is $1m^3$ = 1.5 tonne
- radon emission rate from ore is $50Bq/m^2.s$
- radon emission rate from tailings is the same as for ore

Dose factors:

- the RDP dose conversion factor recommended in ICRP 65 (1993) is $1.1\mu Sv/(\mu Jh/m^3)$ (for radon in equilibrium with progeny) for members of public
- RnDP dose conversion factor $1.4mSv.m^3/mJ.h$ (workers) [ARPANSA 2005]
- 7.2μSv/αdps (ARPANSA 2005) for radionuclides in dust (αdps is alpha disintegrations per second. For ore in secular there are 8 alpha emitting radionuclides)
- 65μSv/h per %U for 2π gamma exposure geometry (Thompson 1980)

3.4 RADIONUCLIDE ANALYSIS

Radionuclide assessments of ore and tailings have been conducted and are summarised in Table 26 and Table 27. The processing of the ore will use a standard milling, leaching and precipitation process and the deportment of radionuclides through this flowsheet are well known with the majority of uranium reporting to final product and remnant radionuclides reporting to tailings.

Table 26: Radionuclide analysis of ore

Material	Radionuclide Concentration(Bq/g)							
	U^{238}	U^{234}	Th^{230}	R^{a226}	Pb^{210}	Po^{210}	U^{235}	Ac^{227}
Ore[1]	6.0	6.0	6.6	5.6	5.5	N/A	0.30	0.23

Note 1: Sample was reported to contain approximately 700ppm U_3O_8

Table 27: Radionuclide analysis of tailings

Material	Radionuclide Concentration							
	U^{238}	U^{234}	Th^{230}	R^{a226}	Pb^{210}	Po^{210} [3]	U^{235}	Ac^{227}
Solids (Bq/kg)[1]	1,600	1,600	13,000	10,000	14,000	9,000	<100	560
Liquor (Bq/L)[2]	1,520	1,520	<130	17	<20	40	90	<2

Note 1 - The testwork was conducted on material containing approximately 1,100 ppm of uranium.
Note 2 - The activity concentration for solid tailings is in units of Bq/kg for volumetric comparison with the liquor portion of the tailings.
Note 3 - The Po^{210} concentration was not analysed for this particular sample. However an estimate has been made based on the analysis of Cameco Kintyre ore. The processing of both ores is similar and it is expected that the radionuclides would behave in a similar manner (which is the case for U^{238}, Th^{230}, Ra^{226} and Pb^{210}).

The results in Table 26 are not comparable with the results in Table 27 because different samples were used. The tables do show that the ore is approximately in secular equilibrium. Table 27 shows that the majority of radionuclides report to the solid phase of the tailings.

3.5 PROJECT RADON EMISSIONS

For radon emissions from the project, the following criteria are used;

- The U grade is used to estimate the radon emission rates. This is based on the assumption that there is secular equilibrium, meaning that the activity concentration of uranium is the same as the activity concentration of Ra^{226} and Rn^{222} in the ore.
- Published emission data has been used to determine the unit emission rate of 50Bq/m^2.s per %U [Mason 1982, BHP Billiton 2009, ERA 2014].
- No difference in emission rates between broken and unbroken ore has been used. This is based on other recent EIS assertions [ERA 2014] which note that emission rates from ore and broken ore are practical identical. (Note that the physical justification is that at the atom level, there is no physical difference between broken and unbroken rocks.)
- For tailings, generally, all Ra^{226} in ore will report there, and therefore the activity concentration of Ra^{226} in tailings is approximately the same as that for the ore.
- Note that published data indicates that the radon emission rate for tailings is significantly lower than for ore due to consolidation and higher moisture content of tailings, however for this assessment, the conservative value is used.
- No emissions are allocated for the processing plant because it is assumed that the majority of the radon in the rock will be emitted during mining and this is accounted for in the mining emission rates.

For the air quality assessment, [Katestone 2014a], the radon emission estimates were made for year 10 of operations which is the year when most ore is exposed, and therefore the highest amount of emission would occur. These figures are useful for assessing the maximum probable impacts to people at the sensitive receptors. A summary of the radon emission sources for year 10 of operations can be seen in Table 28.

Table 28: Estimated Radon Releases

Source of Radon	Emission Rate (MBq/s)
Pre-Strip	12.3
Active Pit	27.5
Tailings (in pit)	14.0
Stockpiles	5.9
Overburden Stockpile	1.1
ROM Stockpile	0.1
Processing Plant	0.0
Total	60.9

3.6 PROJECT DUST EMISSION FACTORS

The dust sources for the air quality assessment [Katestone 2014b] are based on standard emission factors for equipment and processes. The air quality assessment calculates an increase in dust concentration at the sensitive receptors for total suspended solids (TSP) in units of $\mu g/m^3$ and for dust deposition in units of g/m^2.month.

The dust emission rates can be used to calculate radionuclide emission rates. The conversion factor is calculated from the uranium concentration and makes the assumption that the major emission from the operation is dust from mining which is in secular equilibrium. The conversion factor is 12.3mBq/g per ppmU (for each radionuclide). The emission rates are taken from the air quality assessment [Katestone 2014b] and converted, via the conversion factor, to radionuclide emissions as shown in Table 29.

Table 29: Dust emission

Emission Source	Emission Rate kg/y (TSP)	Specific Activity Bq/g	Emission Rate kBq/y
Mining – Ore[1]	450,381	20.0	9,007,620
Mining – Overburden[1]	731,537	1.3	950,998
Mining – Topsoil[1]	33,982	0.0	0
Processing Plant (ore)	146,909	20.0	2,938,180
Other (quarry, generators)	14,887	0.0	0
Total (mined material)	1,215,900	8.2	9,958,618
Total (all material)	1,377,696	9.4	12,896,798

Note 1: Emission rate (kg/y) determined as percentage of total material mined.

Potential emissions of dust containing higher concentrations of uranium from the processing plant are unlikely to occur and therefore not considered for long term modelling. This is because once the ore is crushed and ground, it becomes a slurry and therefore unable to dust.

The final product packaging area would be self-contained with exhaust scrubbing systems to eliminate emissions.

3.7 AIR QUALITY MODELLING

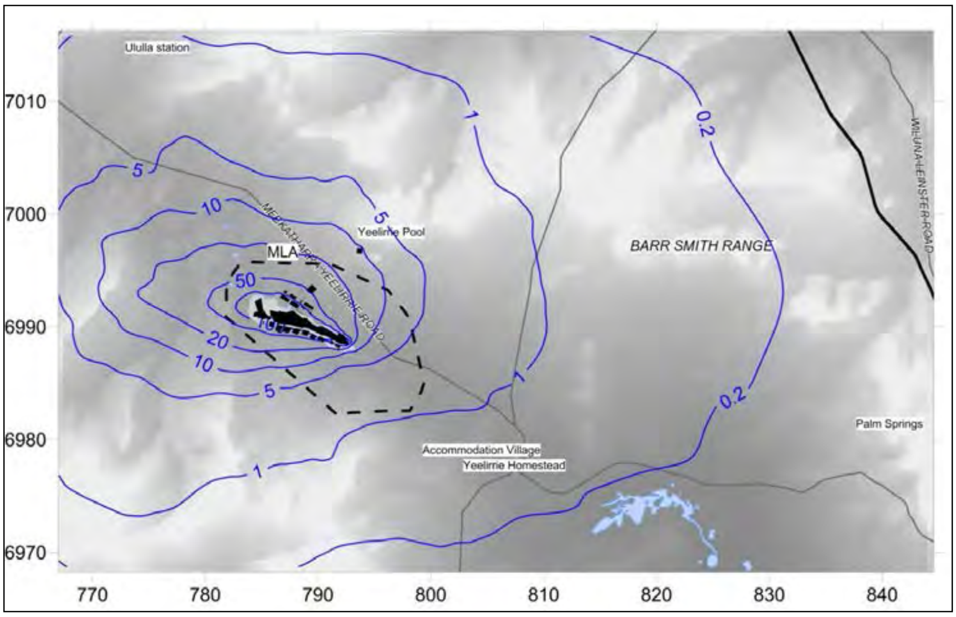
3.7.1 BACKGROUND

During 2014, Cameco commissioned air quality modelling to determine the potential impacts of airborne emissions from the Yeelirrie project. The modelling utilises the emissions profiles outlined in Sections 3.5 and 3.6 to calculate concentrations of radon and dust (as total suspended solids) at various locations. The modelling method and more detail are available in the air quality reports Katestone 2014a and Katestone 2014b.

3.7.2 MODELLED RADON IMPACTS

Figure 9 shows the incremental annual average radon concentration from the modelling.

Figure 9: Annual Average Modelled Radon Concentrations Bq/m³



The predicted annual average ground level concentrations at each of the main receptor locations can be seen in Table 30.

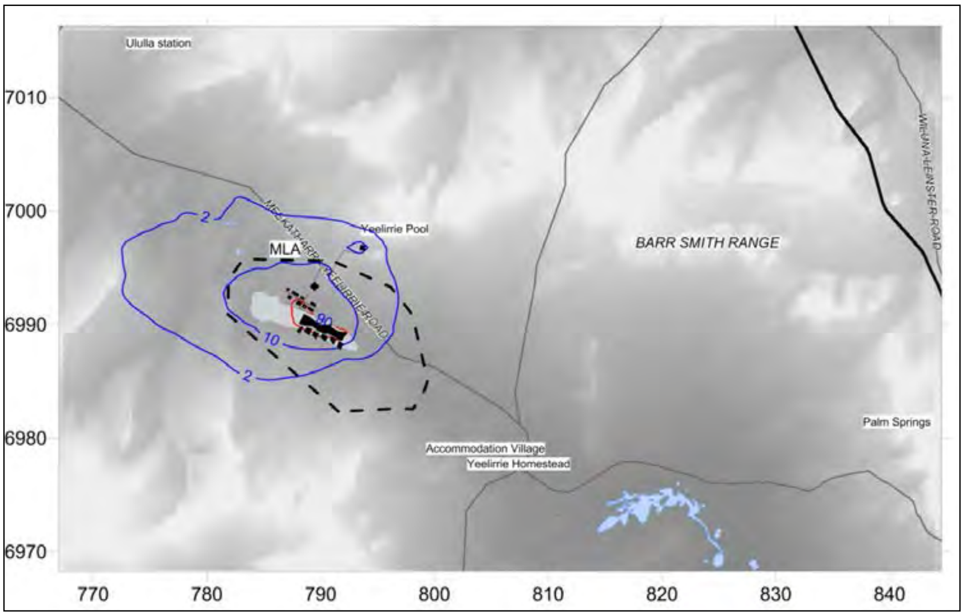
Table 30: Annual Radon Ground Level Concentrations

Location	Distance from Orebody	Ground Level Concentrations Annual Average (Bq/m^3)
Yeelirrie Pool	10.2km northeast	10.0
Accommodation Village	16.4km south east	0.4
Yeelirrie Homestead	16.4km southeast	0.4
Ululla Homestead	28.5km north	1.2
Palm Springs	50.4km east-southeast	0.06

3.7.3 Modelled Airborne Dust Impacts

Figure 10 shows the incremental annual average TSP dust concentrations.

Figure 10: Modelling TSP Dust Concentrations (µg/m^3)



The predicted annual average TSP concentrations at the main receptor locations can be seen in Table 31.

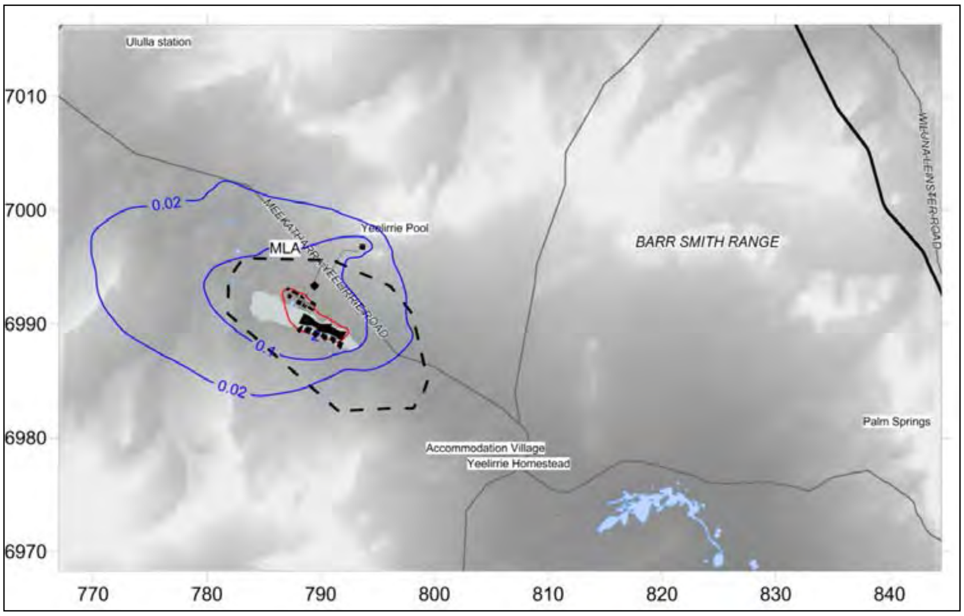
Table 31: Annual TSP Ground Level Concentrations

Location	Distance from Orebody	Ground Level Concentrations TSP Dust (µg/m^3)
Yeelirrie Pool	10.2km northeast	1.1
Accommodation Village	16.4km south east	0.1
Yeelirrie Homestead	16.4km southeast	0.1
Ululla Homestead	28.5km north	0.2
Palm Springs	50.4km east-southeast	0.01

3.7.4 MODELLED DUST DEPOSITION

Figure 11 shows the incremental dust deposition from the air quality modelling.

Figure 11: Modelled Dust Deposition (g/m^2.month)



The predicted annual average ground level concentrations at the main receptor locations can be seen in Table 32.

Table 32: Annual Dust Deposition Rates

Location	Distance from Orebody	Ground Level Concentrations Dust Deposition (g/m^2.month)
Yeelirrie Pool	10.2km northeast	0.013
Accommodation Village	16.4km south east	0.002
Yeelirrie Homestead	16.4km southeast	0.002
Ululla Homestead	28.5km north	0.006
Palm Springs	50.4km east-southeast	0.0004

4. OCCUPATIONAL DOSES

4.1 MINERS

4.1.1 GAMMA DOSES

Estimates of gamma radiation dose are based on predictions from first principles and dose data from other operational uranium mines.

The main factor used in gamma dose assessment is the conversion factor provided by Thompson 1980, who quote a theoretical gamma dose rate of 65µSv/h per percent of uranium from an extended plane of exposed ore.

The average of material in the Yeelirrie deposit is 1,600 ppm (0.16%) uranium for ore and 660ppm (0.066%) uranium for all material mined (including ore and un-mineralised overburden). A miner would be required to work in both ore and un-mineralised material over the course of a year, therefore using an average uranium grade of 660ppm provides an accurate basis for assessment of average annual gamma doses.

The gamma dose rate is calculated to be;

65 µSv/h per percent of uranium x 0.066% uranium = 4.3µSv/h

Based on a working year of 2,000 hours, the expected maximum dose is calculated to be 8.6mSv/year. However, this figure does not take into account the shielding provided by the mining equipment, or that most workers do not spend all of their working day in or near the open pit which significantly reduces gamma radiation dose. For this assessment it has been conservatively assumed that the average dose is half the theoretical maximum gamma dose.

Therefore, it is estimated that mine workers would on average receive approximately 4mSv/y from gamma radiation. It is noted that workers who do not work on equipment may be exposed to higher gamma radiation levels and could receive up to 8.6mSv/y if they work for a full year under these conditions and, as outlined in Section 6, management of exposures is necessary.

The Ranger open cut mine has similar uranium grades and the actual gamma doses received by miners at Ranger uranium mine [ERA 2014] are reported as approximately 1mSv/y confirming that the shielding factor used in this assessment (50%) is reasonable.

4.1.2 DUST DOSES

Estimation of radiation exposure from the inhalation of ore dust is based on predicted airborne dust concentrations. Note that mining at Yeelirrie is not expected to generate significant levels of dust. The reasons for this include; a small mining fleet, the mining and handling of damp material and dust suppression as required.

For this assessment, a conservative estimate of the long term average dust concentrations in the mine has been made. Published data of 3,000 personal dust samples from 157 quarrying operations has been used (Creely et al., 2006). From this data 99% of the 3,000 measurements taken were of a concentration less than 3 mg/m^3.

For an average mined material grade of 660ppm of uranium, a dust cloud of the mined material of 3mg/m^3 would have an activity concentration of approximately 25mBq/m^3 of uranium (as U^{238}). Since the ore is in secular equilibrium, the activity of each of the decay radionuclides will also be approximately 25mBq/m^3. There are eight alpha emitting radionuclides, giving a total long-lived alpha-emitting radionuclides activity concentration of approximately 200mαdps/m^3.

The calculated dose for 2,000h/y and a dust dose conversion factor of 7.2µSv/αdps is:

$$Dose\ (mSv/y) = 0.2\alpha dps/m^3 \times 1.2m^3/h \times 2000h/y \times 7.2\mu Sv/\alpha dps = 3.5mSv/y$$

In practice, this is likely to be the maximum dose, with average doses lower due to operational dust control measures and the time workers spend in air-conditioned offices and cabins on mining vehicles.

4.1.3 Radon decay product (RnDP) doses

Atmospheric Considerations

The baseline monitoring shows clear differences between day time and night time RnDP concentrations and also seasonal effects. The overall effect is that there are higher concentrations of RnDP during nights in the colder months of the year. These effects have been taken into account when assessing doses.

Assessment method

To assess the potential doses, the following calculation methods were used:

- Doses under turbulent atmospheric conditions;
  - determine the amount of radon emanating into a typical mining void
  - determine the ventilation rate (the time it takes for the air to turn over in the pit), based on the average surface wind speed
  - calculate the equilibrium concentration of radon under these conditions in the mining void
  - use a standard equilibrium factor to determine RnDP concentration, then calculate doses using the standard method.
- Doses under stable atmospheric conditions;
  - determine ratio between average RnDP concentrations and stable RnDP concentrations for naturally occurring levels
  - apply the factor to the modelled average concentration to determine a “stable” concentration.

The doses under the two conditions are added together in a time weighted manner to give an annual RnDP dose for mine workers.

Doses – Turbulent Conditions

Using the factors noted above, the quantity of radon entering the mining void can be calculated from the emanation rate and the surface areas. For a 50Ha mining void (including the walls and assuming they are ore bearing as a conservative assessment), the radon entering the void is calculated from:

Rn production rate = emanating surface area(m^2) x emanation rate ($Bq/m^2/s$)

For a mining void area of 50Ha, the emanating surface area is 50Ha plus the wall surface area. Assuming the void is square, the walls of the cell will be approximately 700m long and the design depth is 10m. This gives a total surface area of 528,000m^2.

For an average ore grade of 1,600ppm uranium, and an emanation rate factor of 50$Bq/m^2.s$ per %U, the cell emanation is 8$Bq/m^2.s$. This gives a total emanation into the cell of 4.2MBq/s.

The ventilation rate for the cell is calculated using the formula of Thompson (1994) as follows:

$$T = 33.8(V/UrLW) \times (0.7 \cos(x) + 0.3)$$

In this equation 'T' is residence time of the air in the pit, 'Ur' is the wind velocity in metres per hour, 'L' is the length of the pit and 'W' is the width of the pit. The term (0.7 cos(x) + 0.3) is used to take into account the shape of the pit and since it is approximately square, the term 'cos(x)' is assumed to be 1.

The air quality report provides an annual average wind speed of 2.7m/s for the region (which is equivalent to 9,720m/h). Using the above formula, together with the pit dimensions, gives a calculated air residence time of 0.035h. This is the same as saying that at the average wind speed, the air in the pit would turn over approximately 29 times an hour.

The radon equilibrium concentration is calculated using the following equation:

Radon concentration (Bq/m^3) = ER/(PV x VR) (derived from Cember 2009)

where 'ER' is the radon generation rate for the pit in Bq/h, 'PV' is the pit volume and 'VR' is the number of air changes per hour. This gives an average concentration of 104Bq/m^3.

The equivalent RnDP concentration can be calculated using the following relationship;

Equilibrium factor = [PAEC concentration ($\mu J/m^3$)] / [0.00556] / [Rn concentration Bq/m^3]

For an equilibrium factor of 0.4 (as determined from background monitoring), the equivalent RnDP concentration is therefore calculated to be 0.24$\mu J/m^3$.

Using the factors is Section 3.3, the dose is calculated as follows;

Dose (mSv/y) = RnDP Conc (mJ/m^3) x working hours (h/y) x dose factor ($mSv.m^3/mJ.h$)

For a working year of 2,000 hours, the dose is calculated to be 0.7mSv/y.

Doses – Stable Conditions

The air quality modelling for RnDP takes into account both stable and unstable conditions by providing an annual average concentration. However, for the purposes of providing a conservative assessment of miner's exposure to RnDP, the potential doses under stable atmospheric conditions were calculated. This was based on a comparison was made between "night" RnDP concentrations and "average" RnDP concentrations.

Table 6 in section 2.2.1 of this report shows that for natural background RnDP, the average "night" concentrations are approximately twice the average concentrations.

If it is assumed that this ratio will be similar for project generated RnDP, then the potential doses under stable conditions can be calculated.

Total RnDP Dose

The total RnDP dose for a miner is therefore conservatively calculated as the weighted sum of the dose from “average” conditions and the dose from “stable” conditions. Assuming 50% of the time in each, the total RnDP dose is calculated to be 1.1mSv/y.

ICRP (ICRP 2015) has recently recommended a new dose conversion factor (DCF) for RnDP, which is equivalent to 2.8Sv/J. This represents an increase in the DCF by a factor of 2.4 over the current DCF. The new factor has yet to be adopted in Australia however the new factor has been applied to the estimated doses for the Yeelirrie worker dose estimates, giving an estimated dose of 2.6mSv/y.

4.1.4 Miners – Total Doses

The total estimated doses for miners are as follows;

- Gamma dose of 4.3mSv/y (up to 8.6mSv/y for workers not in equipment and full time on ore)
- Inhalation of radionuclides in dust dose of 3.6mSv/y
- Inhalation of RnDP dose of 2.6mSv/y
- Total dose of 10.5mSv/y.

4.1.5 Comparison of Mine Worker Doses from Elsewhere

Table 33 presents actual doses from other similar operating mines. Note that “Max” refers to reported individual maximum doses in each exposure pathway.

Table 33: Comparison of mine worker doses in uranium mines [BHP Billiton 2009]

Mine and type of worker	Ore grade (%U_3O_8)	Dose (mSv/y)							
		Total		Gamma		RnDP		Dust	
		Avg	Max	Avg	Max	Avg	Max	Avg	Max
Ranger mine worker	0.29	1.0	4.8	0.5	4.2	0.1	0.4	0.3	0.9
Rössing pit equipment operator	0.035	2.2		0.6		1.2		0.4	
McLean Lake open pit workers	1.6	<1							
Nabarlek open pit worker	2	6.6		2.3	10	0.3		4	
Yeelirrie mine worker (estimated)	0.16	10.5		4.3		2.6		3.6	

4.1.6 SUMMARY OF MINE WORKER DOSES

The mine worker dose estimates are considered to be conservative and represent the probable maximum doses that would be received. The dose estimates were based on maximum exposure hours and partial shielding factors for equipment (for example the dose assessment assumed that the mining equipment would only shield workers from 50% of the gamma radiation, when in fact it would be much higher as most of the gamma radiation comes from ground upon which the equipment is working).

4.2 OCCUPATIONAL DOSES – NON MINING WORKERS

4.2.1 BACKGROUND

The processing plant will be located to the north side of the mine and ore would be trucked to the plant from the mine for treatment.

For the processing facility dose estimates have been made for workers in the following areas;

- concentrator section which consists of ore handling, ore crushing and grinding areas,
- hydrometallurgical section, which consists of alkali leach circuits and precipitation of final product uranium, and
- final product handling.

Maintenance personnel doses will be estimated from averages of all area estimates.

It should be noted that processing facilities are generally very similar and comparisons with existing operating facilities provides the best estimate of the potential doses. For this assessment, a combination of actual doses from other operations and estimates based on modelling has been used. Table 34 shows the average doses by exposure pathway for processing plant workers at other operations.

Table 34: Processing plant doses from other facilities

Operation and plant area	Dose (mSv/y) – average & max				Source
	Gamma	RnDP	Dust	Annual Dose	
Olympic Dam (concentrator)	1	0.2	0.8	2	BHP Billiton 2009
Olympic Dam (hydrometallurgical plant)	0.6	0.15	0.75	1.5	BHP Billiton 2009
Ranger Uranium Mine (Processing Production)	0.6 (2.6)	0.1 (0.4)	0.5 (2.2)	1.3 (4.1)	Pers Comm.
Ranger Uranium Mine (Maintenance)	0.3 (1.9)	0.1 (0.3)	0.7 (2.3)	1.1 (3.5)	Pers Comm.

4.2.2 GAMMA RADIATION

Gamma radiation levels in processing facilities are generally low because the radioactive material is crushed and diluted with water to form a slurry which is contained in steel tanks which provide some attenuation of the gamma radiation. The processing facility is not generally permanently occupied and operators are required to check on the process rather than be present in exposure areas for extended periods.

The main area where the gamma radiation levels may be elevated involves areas where there is handling of ore, such as the concentrator area. The Yeelirrie uranium ore grade is approximately 3 times higher than the Olympic Dam grade therefore it has been conservatively assumed that the gamma doses for Yeelirrie concentrator workers would be three times higher than for Olympic Dam concentrator workers.

Gamma doses for workers in the hydrometallurgical area and final product handling areas are expected to be similar to the dose received by Olympic Dam hydrometallurgical plant workers. This is because the concentration of radionuclides in these process streams is similar.

4.2.3 INHALATION OF RADIOACTIVE DUSTS

Dust concentrations in modern processing facilities are generally low due to a number of factors including; a focus on dust minimisation in design and operations and process materials being in slurry form (also known as wet processing).

It is assumed that the dust concentration in the concentrator area of the processing facility is $2mg/m^3$. As noted in the Section 4.1.2, at this level the dust would be noticeable and active controls would be implemented to reduce dust. The potential dose from dust can be calculated using the methods outlined in Section 4.1.2. The processing facility will be processing ore (containing 1,600ppmU), therefore, for a dust cloud of $2mg/m^3$, the potential annual inhalation dose would be approximately 2.4mSv/y.

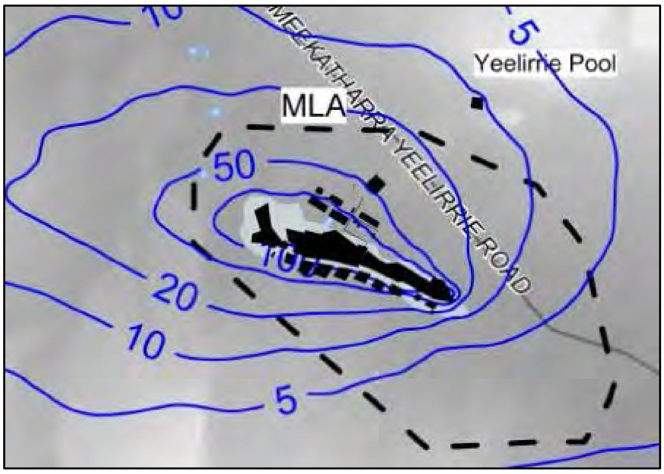
For dust in the hydrometallurgical section, it has been assumed that average concentrations are less that for the concentrator area (due to process materials only being in a slurry form). The dust dose in these areas is conservatively assumed to be half of the dust dose for concentrator area.

Due to the relatively high specific activity of the final product, inhalation of dusts in the product packaging area may result in elevated doses. Cameco would utilise standard technology for the packaging of uranium oxide which includes a totally self-contained packing facility, with safety interlocks to prevent access into the packing area during actual packing of product into drums. Therefore dust concentrations are expected to be minimal with low doses as a result.

4.2.4 INHALATION OF RADON DECAY PRODUCT (RNDP)

Although the air quality modelling is recognised to be relatively inaccurate close to source terms, it does provide an indication of the potential radon concentrations in the region of the processing plant which can be used to make an assessment of the potential RnDP doses there. Therefore, RnDP doses to processing plant workers have been estimated from the air quality modelling (Katestone 2014a), which indicates that the annual average radon concentration is approximately of 100Bq/m^3 at the location of the processing, plant as shown in Figure 12.

Figure 12: Air Quality Modelling Annual Radon Concentration (Bq/m^3)



The equivalent RnDP concentration can be calculated using the following relationship;

Equilibrium factor = [PAEC concentration (µJ/m^3)] / [0.00556] / [Rn concentration Bq/m^3]

For an equilibrium factor of 0.4 (as determined from background monitoring), the equivalent RnDP concentration is therefore calculated to be 0.23µJ/m^3.

Using the factors is Section 3.3, the dose is calculated as follows;

Dose (mSv/y) = RnDP Conc (mJ/m^3) x working hours (h/y) x dose factor (mSv.m^3/mJ.h)

For a working year of 2,000 hours, the dose to processing plant workers is calculated to be 0.6 mSv/y using the dose conversion factor from ARPANSA (2005). Using the proposed new ICRP dose conversion factor (ICRP 2105), the estimate dose is 1.4 mSv/y.

Any RnDP variation that may occur at night is accounted for by using the air quality modelling results which are annual averages.

4.2.6 TOTAL DOSE TO PROCESSING PLANT WORKERS

Estimated total doses to processing plant workers can be seen in Table 35.

Table 35: Estimated Processing Plant Doses

Occupation	Dose (mSv/y)			
	Gamma	**RnDP**	**Dust**	**Total**
Concentrator	3.0	1.5	1.2	5.6
Concentrator (ore handling)	3.0	1.5	2.4	6.8
Hydrometallurgical Processing	0.6	1.5	1.2	3.2
Maintenance Personnel[1]	1.8	1.5	1.6	5.2

Note 1 - As noted in the text, the maintenance worker doses are estimated to be an average of the main work area doses.

4.3 OTHER WORKGROUPS

The main other workgroups for which doses have been estimated are:

- administration workers
- construction workers
- transport workers
- camp workers.

Administration workers

The administration area is located to the north of the processing facility. It is likely that administration workers will be exposed to low quantities of RnDP and dust from the operations. Gamma radiation exposure is expected to be negligible because administration workers are not in a production area and sources of gamma radiation (for example ore) would be located well away from the administration work areas.

The main exposure pathway for administration workers is via inhalation of RnDP. The administration area is located to the north of the processing facility and the air quality modelling indicates that annual average radon concentrations would be 50 Bq/m3. Using the new ICRP dose factors, the calculated RnDP dose is 0.7 mSv/y. Total doses to administration workers would be less than 1 mSv/y.

Routine monitoring would be conducted to confirm this.

Construction workers

A construction workforce of up to 1,200 workers would be employed to build the accommodation village, processing plant and associated infrastructure. Processing of materials is not expected to occur during construction activities, therefore, radiation exposure, above natural background levels, would be much less than the member of the public limit of 1mSv/y. If construction activity is to occur within the designated radiation areas once operations commence, then the construction workers would be managed and monitored, as per the production workforce.

Transport workers

Uranium oxide final product is to be trucked to Port Adelaide for export. Doses to truck drivers are based on a 36 hour trip between Yeelirrie and Port Adelaide. Gamma dose rates in cabins have been reported in BHP Billiton (2009) as 1µSv/h. Therefore drivers may receive up to 36µSv for each trip. Drivers would make no more than 12 trips each year resulting in a potential dose of approximately 0.5mSv/y.

Camp workers

The accommodation village will be located approximately 16.4km to the southeast of the orebody, adjacent to the Yeelirrie homestead. Doses to camp workers would therefore be less than the doses received by the residents of the Yeelirrie homestead because of the limited time that they would be present there (for example, camp workers would work 2,000 hours per year at the camp and reside there for up to another 2,000 hours per year, compared to full time occupants of the homestead who would reside there for 8,760 hours per year).

Dose estimates for the Yeelirrie homestead residents are provided in Section 4.4.

4.4 Public Doses

4.4.1 Background

Doses to members of the public occur when emissions from inside the operation impact upon people outside the operation. It is usual to identify a representative person at a sensitive receptor location and determine the potential dose for that person from project emissions.

The sensitive receivers that have been identified for the project are (as detailed in Section 3),

- the Yeelirrie homestead, (also the location of the project accommodation village) and located approximately 16.4km to the southeast of the ore body,
- Ululla homestead, located approximately 28.5km north of the ore body,
- Yeelirrie Pool, located approximately 10.2km north east of the ore body, and
- Palm Springs located approximately 50.4km east-south east of the ore body.

The potential exposure pathways for members of the public are;

- irradiation by gamma radiation,
- inhalation of radioactive dust,
- inhalation of the decay products of radon,
- inhalation of radionuclides in dust, and
- ingestion of animals or plants that have come in contact with emissions.

Doses from the exposure pathways have been estimated based on the results of the air quality modelling as presented in Section 3.7.

4.4.2 GAMMA RADIATION

Gamma radiation exposure to members of the public from sources within the project area is considered to be negligible due to the distance between the sources and the public. The sources of gamma radiation (for example ore stockpiles) are well within the project boundary and at least 1km from the closest publicly accessible area (the Yeelirrie Meekatharra Road).

Gamma radiation intensity reduces significantly with distance (as one divided by the distance squared when the source is at a distance to be considered to be a point source). The gamma levels at the closest accessible area would not be detectable.

By way of example, using the WISE radiation dose calculator software [WISE 2015], the gamma dose rates can be calculated at distances from a 100,000t ore stockpile, similar to the stockpile sizes that will be used). At 1m from this stockpile, the gamma dose rate is approximately 10µSv/h. At 1km, the gamma dose rate is calculated to be approximately 3pSv/h. For a member of the public at this location, for a full year, the gamma dose is calculated to be 0.03µSv/y.

4.4.3 AIRBORNE DOSE ESTIMATES

Doses from inhalation are based on the modelled annual average concentrations at each of the sensitive receptor locations.

For dust emitted from the project, Section 3 notes that the average radionuclide content is 9.4Bq/g. Note that this is higher than the average radionuclide content of the mined material because it takes into account dust generated from the processing of the ore.

The dust dose is calculated for 8,760h/y (full time occupancy), a breathing rate of $1m^3$/h and a dust dose conversion factor of 7.2µSv/αdps and the formula is:

Dose (µSv/y) = Dust concentration (µg/m^3) x

Specific activity of dust (Bq/µg) x

Number of long lived alpha per Bq (8αdps/Bq) ×

Breathing rate (1.0m^3/h) ×

Hours per year (2,000h/y) ×

Dose Conversion Factor (7.2µSv/αdps)

The RnDP dose is calculated from the modelled radon concentration at the sensitive receptor locations. The first step is to convert the modelled radon concentration to a RnDP concentration as follows;

RnDP Concentration (µJ/m^3) = Equilibrium factor (unit less) x

0.00556 µJ/Bq x

Rn concentration Bq/m^3

For this assessment, an equilibrium factor of 0.4 (as determined from background monitoring), has been used. The RnDP dose is then calculated using the following formula:

Dose (mSv/y) = RnDP Conc (mJ/m^3) x

Exposure hours (8,760h/y) x

Dose Conversion Factor (1.1mSv.m^3/mJ.h)

A summary of the inhalation dose estimates can be seen in Table 36.

Table 36: Public Inhalation Dose Estimates

Location	TSP Dust		Radon/RnDP	
	Concentration (µg/m^3)	Dose (mSv/y)	Radon Concentration (Bq/m^3)	RnDP Dose (mSv/y)
Yeelirrie Pool	1.1	0.006	10.0	0.210
Accommodation Village	0.1	0.0005	0.4	0.009
Yeelirrie Homestead	0.1	0.0005	0.4	0.009
Ululla Homestead	0.2	0.0009	1.2	0.026
Palm Springs	0.01	0.00005	0.06	0.0001

4.4.4 Ingestion Dose Estimates

An estimate of the potential dose from the ingestion exposure pathway has been made for a representative person at the sensitive receptor locations. This is a worst case scenario calculation based on the assumption that all food consumed in a year is obtained from the sensitive receptor location. The assumed consumption quantities are:

- 30kg of non-leafy vegetables
- 30kg of leafy vegetables
- 30kg of root vegetables
- 100kg of meat.

The annual rates of consumption are estimates only. The vegetable consumption rates are based on information published by the Food and Agriculture Organization of the United Nations [WHO 2003], which notes that the world annual average consumption of vegetables in the year 2000 was approximately 100kg. The meat consumption rates are based on information provided at https://sustainabletable.org.au which notes that in Australia people consume approximately their own weight in meant every year. (Note that a calculation was conducted for an infant using the same method, with reduced consumptions rates, and dose estimates for the adult and infant were similar.)

The calculated dust deposition rates from the air quality modelling were used to provide an estimate of the radionuclide deposition rates at each of the sensitive receptor locations. The increase in soil radionuclide concentration was calculated and uptake factors [IAEA 2010] were used to determine vegetation radionuclide concentration and transfer factors (Compendium of Transfer Factors 2003) were used to determine radionuclide concentrations in meat.

Using the estimates of annual consumption, the intake of radionuclides can be used to calculate the dose to individuals using the human ingestion dose conversion factors from the ICRP [ICRP 72].

A summary of the method is as follows;

- determine the change in soil radionuclide concentration due to deposition of radionuclides in dust from the operation for a nominal period (assumed to be 15 years for this assessment),
- determine the uptake of radionuclides into different plants and animals from the soil (including the uptake of radionuclides from the plants to animals) using recognised factors [IAEA 2010],
- estimate the consumption of plants and animals, and
- determine the dose that is received by the consumption the plants and animals using recognised dose conversion factors [ICRP 72].

Section 3.7.4 provides a summary of the estimated dust deposition from the project at the sensitive receptors and Section 3.3 provides the factors used in the assessment.

The calculated change in soil radionuclide concentrations at each of the sensitive receptor locations can be seen in Table 37.

Table 37: Change in Soil Radionuclide Concentration (after 15 years of operations)

Location	Dust Deposition (g/m^2.month)	Change in Soil Radionuclide Concentration (Bq/kg) (for each radionuclide)
Yeelirrie Pool	0.013	1.46
Accommodation Village	0.002	0.23
Yeelirrie Homestead	0.002	0.23
Ululla Homestead	0.006	0.67
Palm Springs	0.0004	0.05

For this assessment the uptake factors are taken as the maximum of the individual species uptake factors for vegetables from temperate climate from IAEA 2010. A summary of the uptake factors is shown in Table 38.

Table 38: Summary of Uptake Factors

Type of Vegetables	Vegetable Uptake Factors (Dry weigh vegetation)/(dry weight soil)					
	U^{238}	U^{234}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
Non leafy	0.053	0.053	0.0022	0.061	0.015	0.0002
Leafy	0.020	0.020	0.0012	0.091	0.080	0.0074
Root	0.028	0.028	0.0087	0.071	0.063	0.077

For the assessment, it was conservatively assumed that all vegetables types contained 50% water. Bowes [1994] report vegetables as having 79 – 96% water. Thus if 90kg of vegetables were consumed, the conservative assumption is that 45kg of this is dry matter whereas using Bowes water contents, the dry matter is only 3.6-19kg.

For meat, it was assumed that the animal would consume 200kg of soil and 3.2t of vegetation per year. This provided a measure of the radionuclide intake. The concentration ratios for the radionuclides for intake to flesh were obtained from Compendium 2003 and are summarised in Table 39.

Table 39: Transfer Factors for Meat

Transfer Factors for Meat (Bq/kg (muscle) per Bq/day (intake))					
U^{238}	U^{234}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
0.0002	0.0002	0.0001	0.0005	0.001	0.003

Using the standard ICRP ingestion dose conversion factors [ICRP 72], the human doses can be calculated for residents at the sensitive receptor locations, with results shown in Table 40.

Table 40: Data for Ingestion Dose Assessment

	Ingestions Dose (µSv/y)		
Location	**Vegetable**	**Meat**	**Total**
Yeelirrie Pool	6.3	0.9	7.2
Accommodation Village	1.0	0.1	1.1
Yeelirrie Homestead	1.0	0.1	1.1
Ululla Homestead	2.3	0.4	2.7
Palm Springs	0.2	0.0	0.2

4.4.5 TOTAL DOSE ESTIMATES

The total dose estimates at the sensitive receptors can be seen in Table 41. Note that the doses are based on 100% occupancy (that is 8,760 hours per year) at these locations.

Table 41: Public Total Dose Estimates

Location	Exposure Pathway Dose (mSv/y)[1]			
	Dust	**RnDP**	**Ingestion**	**Total Dose**
Yeelirrie Pool	0.003	0.210	0.007	0.215
Accommodation Village	<0.001	0.009	0.001	~0.011
Yeelirrie Homestead	<0.001	0.009	0.001	~0.011
Ululla Homestead	<0.001	0.026	0.003	~0.028
Palm Springs	<0.001	<0.001	0.000	<0.003

Note 1: As noted in Section 4.4.2, the gamma dose is negligible (<0.001mSv/y).

4.4.6 POTENTIAL DOSE FROM DRINKING YEELIRRIE POOL WATER

Radionuclide concentrations in groundwater in the region vary widely as seen through the background monitoring results and it is unlikely that radionuclides would migrate from the site as a result of seepage.

In the event that radionuclide migration was to occur, then potential exposure is limited as there are no pathways for exposure. The groundwater is, and would remain, highly saline downstream of the project area and consequently is unsuitable for human consumption. In addition, there is no natural expression of the groundwater at the surface meaning that exposure would be very limited.

One way that water may be affected by the operation is through dust deposition. The closest watering hole to the operation is Yeelirrie Pool and the air quality dust deposition modelling (see Section 3.7.4) indicates that the deposition rate is of dust would be $0.013g/m^2$.month.

If it is assumed that the pool has an average surface area of approximately $100m^2$ (10m by 10m) and is on average 0.5m deep, then the total volume of contained water is $50m^3$.

For 15 years of operation, the total deposition of dust into the pool is calculated as follow;

Total Deposition (g) = 15 years x 12 months/year x 0.013g/m².month x 100m²

This gives 234grams. If it is assumed that the dust evenly distributed through the whole pool and is not dispersed, then the concentration is approximately $4.7g/m^2$, (or 4.7mg/L). Assuming the dust is the average mine dust, then the radionuclide content of the dust is approximately 8.3Bq/g per radionuclide. This gives an increase in radionuclide concentration of 0.04Bq/L.

For an annual water consumption of $1m^3$/y (just over the recommended 2 litres per day), the today dose would be 0.01mSv/y for an adult. (Note that this has not been added to the public dose assessment as it is unlikely to occur and is presented here for information only.)

4.4.7 PUBLIC DOSES DURING TRANSPORT

During the routine trucking of final uranium product to Port Adelaide, there is the potential for members of the public to be exposed to gamma radiation. The exposure is limited due to relatively low gamma dose rates and also the limited exposure situations.

Based on gamma dose rates of 5µSv/h at 1m from a container of uranium oxide, and 1µSv/h and 0.2µSv/h at a distance of five and 10 metres respectively (BHP Billiton 2009) from a container, doses for the following exposure scenarios were estimated:

- The dose to a person in a car travelling behind a product container on a truck for six hours at a distance of 5m is calculated to be 0.006mSv.
- The dose to a person standing on side of road as every truck passes in a year (assume 50 occasions and one minute per occasion for the truck to pass, and a distance of 1 m from truck) is calculated to be 0.004mSv/y.

In the event of an accident and a release of radioactive material, an emergency response plan (ERP) would be initiated. The priorities of the ERP are first aid and containment of any product spillage. The area would be segregated and any spilled product covered.

The potential dose from such an incident is expected to be low due to the relatively short exposure period.

5. Flora and Fauna Impact

5.1 Background

This section discusses the potential radiological effects on non-human biota (NHB) of the Project. As noted above, the only plausible pathways for off-site effects are airborne ones; specifically the deposition of radioactive dusts on the soil, and so that is the only one discussed here.

5.2 Radionuclide Concentrations

The only pathway of significance in this assessment is dispersion of project-generated radioactive dust. As noted above, water-borne pathways are not considered, and the only other pathway of potential significance is the dispersion of radon. However, radon, being gaseous, is widely dispersed in the environment and its subsequent decay products would not accumulate near the project.

The air quality modelling has produced dust deposition estimates as shown in Section 3.7. This assessment has been conducted at the 0.4g/m^2.month (see Figure 11) contour which approximates the project boundary. For a 15 year project, the total predicted dust deposition is calculated to be 72 grams per m^2. For the whole operation, Table 29 shows that the average radionuclide content of the emitted dust is 9.4Bq/g per radionuclide.

Once deposited, the project dust would mix with the soil through a combination of physical, chemical and biological processes. For this assessment, it has been assumed that the mixing depth is 10 mm [Kaste 2007]. The soil density was assumed to be 1.5t/m^3.

Therefore the increase in radionuclide concentration in the soil at the project boundary after 15 years of operations can be calculated as follows;

- Total radionuclide deposition per m^2 = 72g x 9.4Bq/g = 677Bq
- Total mass of soil per m^2 = 1m x 1m x 0.01m x 1.5t/m^3 = 15kg
- Increase in soil radionuclide concentration = 677Bq/15kg = 45Bq/kg

Note that as shown in Section 2.7, this increase is less than the existing naturally occurring levels.

5.4 The ERICA Tool

The ERICA assessment tool (Environmental Risk from Ionising Contaminants) was developed under the European Commission to provide a method of assessing the impact of radiological contaminants on the natural environment [Brown et al., 2008; Larsson, 2008]. The tool contains two major data sources. The first, the database FREDERICA, contains information on the effects of radiation exposure on populations, and includes data on four main 'endpoints': morbidity, mortality, reproduction and mutation [Copplestone et al., 2008]. The second is a collection of databases that allows estimation of the radiation doses that will accrue to biota from radiological contaminants in their environment.

The International Commission on Radiological Protection (ICRP) has recommended that environmental radiological effects should be assessed on a series of 'reference organisms', and these are incorporated into the ERICA tool [ICRP, 2003].

The starting point for an ERICA assessment is the radionuclide concentrations of the medium in or on which the reference organisms are living, in this case soil. This allows the external dose rate for the organisms to be derived, and in addition 'concentration ratios' from the ERICA database are used to calculate the radionuclide concentrations in the organisms, and hence the internal dose rates.

The assessment process can be carried out in three 'tiers':

- Tier 1 is a simple, highly conservative assessment, designed to easily identify whether situations need further review or can be considered of negligible radiological concern.
- Tier 2 is used where a Tier 1 assessment indicates that there may be organisms at risk, and allows the use of more realistic and less conservative parameters to allow the estimation of dose rates to the organisms. These dose rates are then assessed against a screening dose rate to determine whether populations are likely to suffer harm.
- Tier 3 is not a screening tier but is designed to provide guidance in further investigation of situations where Tier 2 indicates that there may be a significant concern of radiological harm.

The default screening dose rate adopted by ERICA is 10µGy/h. This rate, described as the 'predicted no-effect dose rate' (PNEDR), was derived from the dose estimated to give a 10% effect (i.e. to one of the endpoints noted above) to 5% of the species present by applying a safety factor of 5. This screening rate is thus expected to protect the most radiosensitive organisms likely to be present in an environment. The ERICA tool allows other screening dose rates to be adopted. For example, several organisations have suggested that no measurable effects would be observed for dose rates of 40µGy/h (terrestrial animals) and 400µGy/h (terrestrial plants). The ERICA tool presents the results as the dose rates to the organisms, and also in terms of the 'Risk Quotient' (RQ): the ratio of the dose rate to the screening rate. Dose rates and risk quotients are presented both for the 'expected value (expt)' and a 'conservative value (cons)'. The default conservative value is three times higher than the expected value and represents the value at which there is only a 5% chance that the calculated dose rate exceeds the screening level. This then represents a further level of conservatism.

The results of an ERICA assessment can then be described in terms of three dose rate bands:

- $RQ_{Cons)}$ <1 (expected dose rate <3.3µGy/h)
  Low probability that screening dose rate will be exceeded. Risk of environmental impact is arguably negligible.
- RQ_{Expt} >1 (expected dose rate >1)
  Screening dose is exceeded. Further assessment needed.
- RQ_{Cons} >1 but RQ_{Exp} <1 (expected dose rate 3.3–10µGy/h)
  Substantial probability that screening dose rate is exceeded. Assessment should be reviewed.

A potential disadvantage of using the ERICA tool for Australian situations is that many of the parameters are derived for temperate northern hemisphere flora and fauna which do not directly equate with Australian flora and fauna - the most obvious is the kangaroos. The standard ERICA factors are generally used because there is a lack of specific Australian data. However, a recent publication has provided some concentration ratio data which enables a more focussed assessment for Australian plants and animals [ARPANSA 2014]. The data set is incomplete however, it does provide information for a broad assessment.

5.5 ERICA ASSESSMENT

The ERICA assessment was conducted for the full set of reference animals and plants in the ERICA system. An additional assessment was conducted for a user defined species called 'Kangaroo' with input physical dimensions of mass; 50kg, height 1.5m, width 0.75m and depth 0.75m. A combination of ERICA default, Cameco derived and ARPANSA 2014 concentration ratios were used to perform the ERICA assessment:

- Kangaroo – ARPANSA 2014 for all radionuclides except Th^{230} where the ERICA default Large mammal Th^{230} was used (ARPANSA 2014 does not have a Th^{230} concentration ratio)
- Plants (shrub and tree) – Cameco derived (ARPANSA 2014 only has a Ra^{226} concentration ratio),

and these are detailed in Table 42.

Table 42: Concentration Ratios (Cameco, ARPANSA and ERICA default)

Organism	Source	Concentration Ratio (Bq/kg(fresh weight) per Bq/kg(soil)) Shaded numbers not used in assessment				
		U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
Kangaroo	Cameco derived (average whole of organism)	0.005	0.0086	0.062	0.0165	0.0308
	ARPANSA 2014– maximum of reported arithmetic means	**0.007**	no data	**0.041**	**0.02**	**0.55**
Large Mammal	ERICA default	**0.005**	**0.000136**	**0.044**	**0.037**	**0.089**
Plant (shrub and tree)	Cameco derived (Section 2.10) NB ARPANSA 2014 only provide CRs for Ra	**0.13**	**0.13**	**0.03**	**0.29**	**0.44**
Shrub	ERICA default	0.061	0.061	0.330 [1]	0.320	0.33
Tree	ERICA default	0.007	0.001	0.012	0.07	0.073

Note 1 – A sensitivity check was undertaken using the ERICA default Ra^{226} concentration ration and the final conclusions were unchanged.

A Tier 2 ERICA assessment was conducted using a soil radionuclide concentration of 45Bq/kg (for each uranium series radionuclide) and the resulting risk quotients are shown in Table 43. The Risk Quotient is the ratio of the derived dose rate to the screening level. When the risk quotient is less than 1, no additional assessment is required.

Table 43: Tier 2 ERICA Assessment

Organism	Concentration Ratio source	Risk Quotient (expected value)	Risk Quotient (conservative value)
Lichen & bryophytes	ERICA default	1.06	3.18
Arthropod - Detritivorous	ERICA default	0.04	0.11
Flying insect	ERICA default	0.03	0.10
Grasses & herbs	ERICA default	0.20	0.60
Mollusc - Gastropod	ERICA default	0.04	0.12
Shrub	CAMECO derived	0.13	0.38
Bird	ERICA default	0.03	0.08
Amphibian	ERICA default	0.05	0.14
Reptile	ERICA default	0.05	0.15
Kangaroo	ARPANSA 2014 [1]	0.05	0.14
Tree	CAMECO derived	0.13	0.38
Mammal (small burrowing)	ERICA default	0.04	0.13
Mammal (large)	ERICA default	0.04	0.13

Note 1 - ERICA default large mammal for Th^{230}

The assessment identified lichen and bryophytes as a species that would trigger the screening level of 10µGy/h.

The expected dose rate derived for lichen and bryophytes is just higher than the screening level of 10µGy/h. The reason for this is likely to be that lichens (in particular) do not have a well-developed root system, and derive most of their nutrients from dust falling on them. Consequently, they receive a higher dose from the deposition of dusts than other organisms.

Lichen and bryophytes are known to be particularly radioresistant and a threshold no-effect dose rate has been estimated at approximately 125,000µGy/h, with some diversity reduction observed at 1.1Gy/h [UNSCEAR 1996]. These dose rates are over 10,000 times the default screening dose rate used in ERICA, and indicate that no effect would be expected from any potential dust emissions from the project.

During the 2010 and 2011 regional flora surveys, general observations for lichen were made which showed that it was relatively abundant through the region.

Yeelirrie Specific Species Assessment

In the Yeelirrie region, there are specific species of flora and fauna which are important and these species have been mapped against the reference animals and plants used in the ERICA assessment. Due to the close mapping, it was not necessary to develop species ellipsoid models for further assessment via ERICA.

The flora assessment notes five vegetation communities, all occurring on the Central calcrete system of the study area, that are considered to be significant. These have been allocated as follows;

- Atriplex sp – Shrub (ERICA Reference Animal and Plant)
- Rhagodia sp – Shrub (ERICA Reference Animal and Plant)
- Eucalyptus gypsophila – Tree (ERICA Reference Animal and Plant)
- Casuarina pauper – Tree (ERICA Reference Animal and Plant)
- Melaleuca xerophila – Tree (ERICA Reference Animal and Plant).

As noted the results of the ERICA assessment indicate that no species are at radiological risk and it is concluded that none of the Yeelirrie species are at risk either.

5.6 IMPACT FROM RADON AND RADON DECAY PRODUCTS

An impact assessment on fauna from radon and its decay products was conducted using the tool of Vives i Batlle et al. (2008 & 2012). The default values were used and the input radon concentration was 10Bq/m3, based on the modelled average annual radon concentration at the project boundary.

The output of the calculator indicated that none of the 70 species assessed would be exposed to more that 10uGy/hr under the default conditions, with the highest being less than 1uGy/h. Further assessment was therefore not deemed to be necessary.

6. PROPOSED MANAGEMENT OF RADIATION

6.1 BACKGROUND

Cameco has extensive experience in managing radiation exposures in uranium mining, and has a strong commitment to radiation protection. Cameco maintains a corporate Radiation Protection Programme that is used as the basis for setting minimum management requirements for radiation protection at Yeelirrie. The Cameco corporate function also provides services and technical advice on radiation protection programs for individual operations.

As part of the approval and authorisation process, a detailed Radiation Management Plan (RMP) will be developed for the Project. The RMP includes details of radiation protection and radioactive waste management for the operation. A Transport Radiation Management Plan (TRMP) will also be developed which includes an Emergency Response Assistance Plan (ERAP).

Note that the management plans will be consistent with the plans developed for Cameco's Kintyre operation.

This section provides an overview of the principles, methods and monitoring that will be applied in managing radiation exposure and radioactive waste.

6.2 PRINCIPLE

The overall approach by Cameco towards the management of radiation is consistent with the recommendations of the ICRP, in particular, the principle of optimisation, which aims to ensure that radiation doses to workers and the public are As Low As Reasonably Achievable (social and economic factors taken into account). This is also known as the ALARA principle.

This approach is also applied to the environment, where a priority is to minimise any radiological impacts to the natural environment.

6.3 RADIATION CONTROL IN DESIGN

Hazards and risks, including radiation, are most effectively controlled through good design decisions. Cameco will undertake a design optimisation (or ALARA) process, which will be based on risk assessments to identify areas and situation where radiation controls will be required.

This will involve;

- Reviewing the initial plans of plant and equipment to determine where radiation protection may be required,
- Quantifying the potential radiation impacts, and
- Determining options for control will be developed.

The options will be examined for the degree of protection they afford, and the optimum option will then be identified. Further refinements of control measures will then be considered before the final design is produced.

A similar approach will be used in the development of operating procedures. The specific work and tasks will be examined to identify what tasks may require protection measures, the options will be identified and considered and from these an optimum procedure will be developed.

The ALARA principle is also be applied during operations. Monitoring will collect data on radiation exposures and waste management, and as this data is accumulated, it will be examined to determine if there are ways in which further reductions in exposure can be reasonably achieved. Where such changes can be identified, the physical project and the management measures will be adapted to incorporate these.

In addition, Cameco has a formal set of design standards that will be used as the basis for certain plant and equipment.

6.4 RADIATION CONTROL IN THE MINE

Access to the main mining areas will be restricted to ensure that only appropriately trained and qualified personnel are able to enter the work areas.

Gamma radiation levels will be relatively low in the mine, however estimates for workers spending all of their working hours unshielded on ore, could receive doses up to 9mSv/y. However, as noted, this is highly unlikely to occur in practice. Work areas and worker gamma doses in the mine will be monitored and rostering and scheduling of workers will occur if necessary. For production drill operators and charge up crews who may be required to spend extended time directly on the ore, a workplace exposure plan will be developed based on actual dose rate measurements. The plan would estimate doses (based on exposure time and dose rate) and if necessary require a pad of inert material to be placed to provide some shielding during drilling and charging activities.

Workers will be monitored with the traditional TLD gamma monitors and some modern direct-reading personal electronic dosimeters will be issued workers who may be in higher exposure situations. These will allow real-time readout and dose assessment. The results of this monitoring will be regularly reviewed and individuals whose doses may be approaching the target levels will be assigned to other duties. Results will also be used to improve other radiation management measures where necessary.

At night, levels of RnDP can increase due to natural processes (e.g. formation of temperature inversions) and these are not directly amenable to control. However, measures will be taken to limit the exposures arising from such situations. All heavy equipment operating in the pit will have air-conditioned cabs. Continuous RnDP monitors may be installed in the pit during times when inversion are likely to occur. Should essential work be required when high concentrations exist, then respiratory protection will be utilised.

Routine mine dust suppression measures will minimise doses from inhalation of radioactive dust.

6.5 RADIATION CONTROL IN THE PROCESSING FACILITY

The main aspects of processing facility that will require attention to radiation protection are the crushers and associated facilities, and the uranium product handling.

Crushers and conveyor systems will be fitted with appropriate dust control measures, including dust extraction at dust generating sources, with cleaning of the exhaust air using scrubbers or bag houses. During start-up the area will be subject to dust monitoring, to establish exposure levels and to identify any remaining dust sources. Based on the results of monitoring, additional dust control measures may be implemented. In situations where engineering solutions cannot be found, respiratory protection will be used

After crushing, water will be added to the ore to produce a slurry and at this stage spillage control becomes important. All areas will be bunded, with facilities to collect spillage and pump it back to vessels or to the tailings management system. Tanks containing radioactive process slurries will be suitably bunded to capture at least the volume of the tank in the event of a catastrophic failure.

The plant will be designed for ease of access, so that spillages can be effectively cleaned up before they become dust sources. Ample wash-down water points and hoses will be supplied for spillage clean-up.

The uranium precipitation, drying, calcining and packing section of the plant handles a product with uranium concentrations of up to approximately 85%. Due to the concentration of uranium in the product, there are specific radiation protection requirements in this area, and in particular, control of dusts arising from this material is very important. The technology for the safe and secure packing of final uranium product into drums has been used for many years at all uranium production facilities in Australia. It consists of a totally enclosed packing booth, with an automated drum filling process, operating under negative pressure to prevent any releases of dust. The negative pressure is maintained by an extraction ventilation system, with all air being scrubbed prior to release. Typically, uranium product packing scrubbers remove more than 99% of exhausted dusts and particulates.

The product packing workers would change into dedicated overalls prior to entry to the area, and then be required to change when leaving, including for lunch breaks.

Access to the product drying and packing area will be by 'swipe-card', with only authorised personnel allowed access. The swipe-card system will also log entry and exit and will record names and the total amount of time each person spends in this controlled area.

6.7 General Management Measures

The following section outlines the general management controls that would be applicable across the whole site.

6.7.1 Access control

Access to all operating areas will be controlled to ensure that only those who have been properly trained and are aware of any specific radiological protection measures that are necessary can be admitted. As part of this process, controlled and supervised areas will be established for radiation control purposes. A supervised area is one in which working conditions are kept under review but in which special procedures to control exposure to radiation are not normally necessary. The estimated radiation exposures indicate that the supervised areas will include offices, laboratory and administrative areas, the processing plant (except for controlled areas listed below), and the overburden stockpiles.

A controlled area is one in which employees are required to follow specific procedures aimed at controlling exposure to radiation. Controlled areas are likely to include the mine, ore handling, crushing and grinding circuit, product precipitation drying and final product packing and storage areas.

To facilitate the control of people, vehicles and contamination, the operation area will be divided into 'clean' and 'potentially-contaminated' areas. Access to the potentially-contaminated area will be via a security gate. Egress from the potentially contaminated area by vehicle will be via a wheel-wash to ensure that contaminated material will not be transported off-site by vehicles. In general, vehicles that are likely to be regularly in contact with high grade uranium mineralisation (for example mine vehicles) will be kept within the contaminated area. Equipment that must be taken off-site (for example for specialist servicing or repair) will be required to be cleaned and checked for contamination by suitably trained staff.

Change-room facilities will be established which will have a clean side and a dirty side. Workers will come to work through the clean side and change into work clothes and exit through the dirty side. At the end of shift workers will enter the dirty side, remove their work clothes and shower, then proceed to the clean side where they will change back into clean clothes before returning to camp. All work clothes will be laundered on site.

6.7.2 Radiation safety expertise

Cameco has access to suitably qualified and experienced radiation safety professionals to assist it during the design, construction and operational phases of the Project. Cameco is the world's largest producer of uranium, and has considerable corporate experience that it brings to the Yeelirrie Project.

Sufficient appropriately qualified radiation protection personnel would be employed to implement the RMP. The nominated radiation safety officer would directly report to the site general manager.

6.7.3 INDUCTION AND TRAINING

All employees will receive an induction informing them of the hazards associated with the workplace, of which radiation is one hazard. The level of the induction material will reflect the magnitude of the potential risk, so for example, workers who may enter higher exposure areas will receive more intensive radiation training. Specific training will be provided to personnel involved in the handling of uranium concentrates.

Managers and supervisors will receive additional training in the recognition and management of situations that have the potential to increase a person's exposure to radiation.

A radiation safety work permit system will be implemented and before any non-routine work in a potentially high exposure situation is undertaken, such as maintenance in the product packing area, a work permit will be required, and all conditions on it must be complied with.

6.7.4 RECORD KEEPING

A computer-based data management system will be used to store and manage all information relating to radiation management and monitoring.

The system will allow the recording of 'raw' and processed data, together with all relevant supplementary information such as calibration records, dose conversion factors and formulae used to estimate doses and employee occupation, work area, and time spent in various exposure situations.

Information that can be used to identify a person is considered confidential, and only authorised personnel will be able to access such data (including the relevant authorities).

Periodic and Statutory reports will be prepared from information stored in the electronic database. Dose reports would be provided to individuals as a matter of course.

6.7.5 INCIDENT RESPONSE

It is not expected that radiological emergencies would arise. However, plans for incidents or accidents that may result in exposure radiation or loss of containment of radioactive material will be prepared as part of the overall site emergency response plan and include:

- immediate response to medical conditions;
- evacuation of non-essential personnel;
- stabilisation of the source(s) of radiation;
- assessment of the likely source(s) of radiation exposure and the types of radiation; and
- contamination of the person(s) and the area.

The plan will also include requirements for post-incident response, including counselling of all people involved or affected by the incident, detailed investigation of the incident, including root-cause analysis to prevent recurrence, and procedures for estimating any radiation doses that may have arisen. Appropriate external experts will be used to assist as required.

6.7.6 REVIEW OF PERFORMANCE

Radiation results will be reviewed on an ongoing basis to determine the adequacy and effectiveness of engineering and management controls to reduce radiation exposures of people and the environment.

6.7.7 MONITORING

An occupational and environmental radiation monitoring programme would be developed and implemented. The final programmes will form part of the RMP and would be submitted to the appropriate authority for approval prior to operations. The plans would include support systems such as servicing and calibration of monitoring instruments.

Monitoring will depend on the expected levels of exposure. For those who may receive more than 5 mSv per year (sometimes called 'designated' employees) monitoring will be more intensive, and directed to determining the doses that individuals receive. For those not expected to receive as much as 5 mSv/y (non-designated) monitoring will be less intensive, and doses will be assessed from the average results of workgroups.

Occupational Monitoring Program

Occupational Radiation monitoring will be conducted to fulfil two major aims;

- to determine the effectiveness of radiation protection controls, and
- to provide data to assess the doses received by workers.

Table 44 provides an outline of a proposed occupational monitoring program.

Table 44: Outline of the proposed occupational radiation exposure monitoring program

Pathway	Measurement method	Area of operations
Direct (external) gamma	Thermo-luminescent dosimeter (TLD)	Individual monitoring for people working in areas where their total annual dose is likely to exceed 5 mSv/y. Representative monitoring of other work groups.
Direct (external) gamma	Personal electronic dosimeter	Workers in higher dose rate areas.
Direct (external) gamma	Hand-held, calibrated gamma survey meter	Periodic spot measurements to detect changes in gamma dose rate.
Inhalation of dust containing long-lived, alpha-emitting radionuclides	Personal dust monitors Alpha counters	Routine individual monitoring for people working in areas where their total annual dose is likely to exceed 5 mSv. Representative monitoring of work groups.
Inhalation of radon decay products	Continuous radon decay product monitor	Representative monitoring of work groups.
Ingestion of water containing radionuclides	Gamma or Alpha spectroscopy or chemical analysis by external laboratory	Annual check on potable water supplies.

As part of the operational ALARA program, a series of action levels would be established to ensure that exposures remain controlled. Action levels are a management tool for reducing exposures, and do not form any part of the dose limitation system. An action level system requires that personnel take specified remedial action when monitoring results exceeded the specified level. In some cases the action would a formal reporting and investigation procedure. It can also involve moving an individual from one task to another to reduce exposure. Table 45 provides an indication of action levels that may be set, and the remedial actions that would be required.

Table 45: Examples of action levels and responses

Radiation	Action Level	Actions
Gamma dose rates	5µSv/h	Review occupancy, consider relocation if occupied, consider shielding if practicable.
Surface Contamination	4000Bq/m^2	Immediate cleanup
Dust Concentrations	3mg/m^3	Identify source and suppress (e.g. water suppression, housekeeping and ventilation)
Personal electronic dosimeter	100µSv in one week	Review tasks, review occupancy of high exposure situations, consider job rotation.
TLD - (¼ly result)	1mSv	Investigate and identify source. Redesign workplace or tasks to reduce exposure. Shield if necessary.
RnDP Concentrations	2 µJ/m^3	Limit occupancy to air conditioned cabins, require respiratory protection

Environmental Monitoring Program

In addition to the occupational monitoring program, an environmental radiation monitoring program will continue at sites established during the baseline studies and at other sites considered to be locations where the highest dose might be recorded. The aims of this program are to provide data for the assessment of doses to the public to measure any radiological impacts on the off-site environment, and to ensure that the radiation controls for off-site impacts are effective.

A detailed environmental monitoring plan will be prepared for approval prior to construction commencing. An outline of the elements of such a plan is shown in Table 46.

Table 46: Outline environmental radiation management programme

Environmental Pathway	Measurement Method	Location and Frequency
Direct (external) gamma	Handheld environmental gamma monitor	Annual survey at perimeter of operational area.
Radon Decay Product Concentrations	Real time monitors	Monitors will rotate between off-site locations.
Dispersion of dust containing long-lived, alpha-emitting radionuclides	High volume samplers	Monitors will rotate between approved off-site locations.
Dispersion of dust containing long-lived, alpha-emitting radionuclides	Dust deposition gauges	Sampling at identified locations. Samples composited for one year then radiometrically analysed.
Seepage of contaminated water	Groundwater sampling from monitoring bores	A network of monitoring bores will be sampled quarterly and analysed for radionuclides and other constituents.
Run off of contaminated water	Surface water sampling	Opportunistic surface water sampling will occur following significant rainfall events.
Radionuclides in potable water supplies	Sampling and radiometric analysis	Annually

Appropriate meteorological monitoring will continue to support both the broader environmental monitoring program, and the environmental radiation monitoring programme.

Support Systems

The support system for the monitoring programs will also include:

- recognised sampling methodologies that are documented and regularly reviewed,
- routine instrument calibration programs, including auditing of calibration sources,
- instrument maintenance and repair programs,
- the purchase and use of appropriate monitoring equipment,
- provision of appropriately trained and qualified monitoring personnel,
- review of latest practices, procedures and equipment, and
- regular external audits of the monitoring program and system.

7. RADIOACTIVE WASTE MANAGEMENT

7.1 OVERVIEW

There are four main categories of radioactive waste that will be generated at Yeelirrie:

- mineralised waste material that contains uranium at an average grade of less than 530ppm which may be blended with higher grade ore and processed or may be encapsulated for long term storage at the conclusion of mining;
- process tailings, which is the residue from processing, being material that has passed through the processing plant and had uranium extracted, leaving the remaining radionuclides in the uranium decay series;
- water that may have come into contact with radioactive materials including surface run off, from areas which may contain uranium bearing materials, and leachate that has infiltrated such materials; and
- miscellaneous wastes that may have become contaminated through contact with ores and process residues (referred to as contaminated waste), including discarded conveyor belts, rubber lining material, pipes, filter media and used protective equipment.

7.2 WASTE ROCK MANAGEMENT

Standard grade-control methods will be used to identify the general type of material during mining. Overburden will be trucked to the waste rock facility. At the end of mining, mineralised waste (very low grade ore) will be returned to the pits as part of the closure program and then capped with unmineralised waste material to minimise radiation at the surface of the rehabilitated open pits.

7.3 RADIOLOGICAL CONTROLS FOR TAILINGS MANAGEMENT

Tailings will be disposed into the mined out voids. Tailings material would ultimately be capped with unmineralised waste material to minimise radiation at the surface of the rehabilitated open pits.

7.4 WASTE WATER MANAGEMENT

Water that has come in contact with mineralised material, such as stormwater runoff from the ore stockpile or the mineralised overburden stockpile may contain entrained radioactive dusts and sediments. The site will be designed to retain surface water runoff from a 1-in-100 year 72-hour storm event on site. The method of control will involve the construction of sedimentation and evaporations ponds, and appropriate collection bunds and channels.

All operational areas in the plant will be bunded with facilities for collecting spillage and returning it to the processing vessels or storage areas.

Waste water (water contaminated by contact with radioactive material) collected from the site including washdown areas and cleanup water would be either reused in the treatment plant or evaporated from the evaporation pond.

7.5 MISCELLANEOUS WASTE CONTROL

This material includes contaminated equipment and wastes from operational areas that would be disposed in an approved manner. A system of separate collection of potentially contaminated wastes from operational areas will be instituted. Where practical, potentially contaminated wastes will be decontaminated and disposed of with normal waste streams. Contaminated waste will be collected and initially held in a secure, bunded area. Depending on the nature of the waste several disposal options will be available. These include:

- disposal within the WRL in a similar manner to mineralised overburden;
- disposal into the mine pit at the end of operations; or
- storage on a purpose built pad and encapsulation within the footprint of the waste rock landform at the time of mine closure.

In all cases records of the disposal, including type of material, quantities and locations will be kept.

8. CLOSURE AND REHABILITATION

A Mine Closure and Rehabilitation Plan for the operation will be submitted to DMP for approval before commencement of operations. The radiation closure design aim is to ensure that all radioactive material is contained in the long-term so that radiation exposures are low and consistent with natural background levels.

At the end of mining, all equipment will be tested for contamination. Where recycling is practicable, items will be decontaminated to approved radiation levels before leaving site. Items that cannot be properly decontaminated, or where recycling is impracticable, will be buried in an approved manner.

The tailings will be allowed to dry sufficiently within the mined out voids and then covered with inert waste rock to a depth agreed to minimise the emanation of radon. A detailed mine closure plan for the facility will be included in the Conceptual Mine Closure Plan.

The site will be monitored after rehabilitation to ensure that it is free of contamination. Monitoring, including surface monitoring and monitoring of groundwater would continue for a period of time post-closure until agreed Completion Criteria had been achieved to the satisfaction of the regulators.

It is expected that under those conditions radiation exposures to the public would be minimal, and certainly significantly less than those during operation.

9. REFERENCES

AAEC 1978	Three baseline studies in the environment of the uranium deposit at Yeelirrie, Western Australia, Brownscombe, A. J et al, Australian Atomic Energy Commission, 1978
ARPANSA 2005	Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing (2005), Australian Radiation Safety and Nuclear Safety Agency
ARPANSA 2011	http://www.arpansa.gov.au/radiationprotection/Basics/understand.cfm
ARPANSA 2014	A review of existing Australian radionuclide activity concentration data in non-human biota inhabiting uranium mining environments, Technical Report 167 May 2014
BHP Billiton 2009	Olympic Dam Expansion Draft Environmental Impact Statement (DEIS) 2009, Supplementary Environmental Impact Statement (SEIS) 2011.
Bowes 1994	Bowes and Church's Food Values of Portions Commonly Used
Brown et al., 2008	The ERICA Tool, Journal of Environmental Radioactivity, 2008, 99, pp. 1371–1383.
Cameco 2013	Kintyre Uranium Project Environmental Review and Management Programme, Cameco Australia 2013
Cember 2009	Cember 2009 - Introduction to Health Physics (4th Edition) Herman Cember & Thomas E Johnson.
Compendium of Transfer Factors 2003	A Compendium of Transfer Factors for Agricultural and Animal Products, Lissa H. Staven, Bruce A. Napier, Kathleen Rhoads, Dennis L. Strenge, Pacific Northwest National Laboratory (U.S.), United States. Department of Energy Pacific Northwest National Laboratory, 2003
Copplestone et al., 2008	Copplestone D, Hingston J & Real A, 'The development and purpose of the FREDERICA radiation effects database', Journal of Environmental Radioactivity, 2008. 99, pp. 1456–1463)
Creely 2006	Creely, KS, Van Tongeren, M, While, D, Souter, AJ, Tickner, J, Agostini, M, De Vocht, F, Kronhout, H, Graham, M, Bolton, A, Cowie, H and Cherrie JW, Trends in Inhalation Exposure – mid 1980s till present, HSE Research Report 460, HSE Books, Sudbury, UK.
IAEA 2010	Handbook of parameter values for the prediction of radionuclide transfer in terrestrial and freshwater environments. – Vienna: International Atomic Energy Agency, 2010. Technical reports series, no. 472
ERA 2014	Ranger 3 Deeps Draft Environmental Impact Statement (accessed from http://www.energyres.com.au/whatwedo/3108_draft_eis.asp November 2014)
ICRP 2003	ICRP, 'A Framework for Assessing the Impact of Ionising Radiation on Non-Human Species', International Commission on Radiological Protection Publication 91, Annals of the ICRP, 2003, 33 (3): pp. 201–270.

ICRP 2014	'Protection of the environment under different exposure situations. ICRP Publication 124', Annals of the ICRP 43 (1): 58.
ICRP 2015	http://www.icrp.org/admin/Summary%20of%20April%202015%20Main%20Commission%20Meeting%20Sydney.pdf
Johansen and Twining 2010	Johansen MP & Twining JR, 'Radionuclide concentrations in Australian terrestrial wildlife and livestock: data compilation and analysis', Radiation and Environmental Biophysics, 2010. 49, pp. 603–611.
Kaste et al., 2007	Kaste JM, Heimsath AM & Bostick BC, 'Short-term soil mixing quantified with fallout radionuclides', Geology, 2007, 35, pp. 243–246.
Katestone 2014b	Air Quality Assessment of the Yeelirrie Uranium Project Prepared for Cameco Australia Pty Ltd December 2014 Final, Katestone Environmental Pty Ltd
Katestone 2014a	Radon Assessment of the Yeelirrie Uranium Project Prepared for Cameco Australia Pty Ltd December 2014 Draft, Katestone Environmental Pty Ltd
Larsson, 2008	An overview of the ERICA Integrated Approach to the assessment and management of environmental risks from ionising radiation, Journal of Environmental Radioactivity, 2008, 99, pp. 1364–1370.
Mason, 1982	Mason, C., Elliot, T. & Hong Gan, T., 1982. A study of Radon Emanation in Waste Rock at Northern Territory Uranium Mines, Melbourne: Australian Radiation Laboratory
NHMRC 2004/NRMMC 2004	Australian Drinking Water Guidelines 6, 2004 National Health and Medical Research Council and Natural Resource Management Ministerial Council
Thompson 1980	Thompson, J. E. and O. J. Wilson Calculation of Gamma Ray Exposure Rates from Uranium Ore Bodies, 1980 Australian Radiation Laboratory.
Thompson 1994	Thompson, RS 1994, 'Residence Tome of Contaminants Released in Surface Coal Mines – a Wind-tunnel Study', proceedings. 8th Air Pollution and Meteorology Conference, American Meteorological Society
Toussaint et al 1996	Toussaint, L. F., Alach, A. J., Breheny, B. M., Broun, B. M. Radionuclide Concentrations in the Darling Scarp of Western Australia, Radiation Protection in Australia (1996), Vol 14, No.2
UNSCEAR 1996	Report to the General Assembly, Scientific Annexe: Effects of radiation on the environment, 1996, United Nations Scientific Committee on the Effects of Atomic Radiation, New York.
UNSCEAR 2000	UNSCEAR, Report to the General Assembly, Annex B: Exposures from natural radiation sources. 2000, United Nations Scientific Committee on the Effects of Atomic Radiation: New York.
Vives i Batlle et al 2008	Vives i Batlle J, Jones SR, Copplestone D. 2008. Dosimetric approach for biota exposure to inhaled radon daughters. Environment Agency Science Report, SC060080. Bristol: Environment Agency. http://publications.environment-agency.gov.uk/pdf/SCHO0908BOPA-e-e.pdf)
Vives i Batlle et al 2012	Vives i Batlle J, Copplestone D, Jones SR. 2012. Allometric methodology for the assessment of radon exposures to wildlife. Sci Tot Environ., 427-428, 50-59.

WHO, 2003	Diet, Nutrition and the Prevention of Chronic Diseases, WHO Technical Report Series 916
WISE 2015	www.wise-uranium.org/calc.html
Yankovich et al 2010	Yankovich, TL, Beresford, NA, Wood, M, Aono, T, Andersson, P, Barnett, CL, Bennett, P, Brown, J, Fesenko, S, Fesenko, J, Hosseini, A, Howard, BJ, Johansen, M, Phaneuf, M, Tagami, K, Takata, H, Twining, J & Uchida, S (2010) 'Whole-body to tissue concentration ratios for use in biota dose assessments for animals.', *Radiation and Environmental Biophysics* 49: 549-565.