9.6 Human Health - Radiation

Summary

This section discusses the radiological environment of the Project. It includes a summary of the natural levels of background radiation and considers the impacts from operating the Project on human health, including occupational exposures to radiation. As the section introduces radiation terms and units that some readers may not be familiar with, an introduction to radiation is included as Appendix J1.

Cameco will design, construct and operate the proposed Project to ensure that human radiation exposures comply with Australian standards, codes of practice and guidelines. The Project will be managed in accordance with an approved Radiation Management Plan to ensure compliance with the radiation dose limits for workers outlined in the Radiation Safety (General) Regulations 1983 and limit radiation exposure to members of the public to less than 1 mSv per year above background.

9.6.1 EPA Objectives

The objectives agreed to within the ESD with regards to radiation exposure are:

- To ensure that human health is not adversely affected.

9.6.2 Relevant Legislation and Policy

The exploration, mining, use, and transportation of radioactive substances are regulated at State, Federal, National and International levels of government. Key pieces of legislation relevant to the Project are outlined in Section 3.1 of this document.

In Western Australia the current regulatory framework for the management of radioactive substances is the Radiation Safety Act (RSA) 1975 with three subsidiary regulations; Radiation Safety (General) Regulations 1983, Radiation Safety (Qualifications) Regulations 1980, and Radiation Safety (Transport of Radioactive Substances) Regulations 2002.

The Radiological Council is an independent statutory authority appointed under the RSA to assist the Minister for Health to protect public health and to maintain safe practices in the use of radiation. The RSA regulates the possession, storage, use, handling or disposal of, or other dealing with, any radioactive substances, irradiating apparatus and certain products that use radiation, through its registration and licensing system. The Act applies to both ionising and non-ionising radiation.

Under the current system a licence must be issued by the Radiological Council to mine or mill radioactive substances. The RSA also states that a premise, at which radioactive substances are manufactured, used or stored, must be registered. Through subsidiary legislation like the Radiation Safety (General) Regulations 1983, specific guidance is given for radiation safety officers, codes used and a framework for radiation management plans.

Transport of substances is regulated by the State through the Radiation Safety (Transport of Radioactive Substances) Regulations 2002 which requires any person who transports radioactive substances to be licensed or work under the direction and supervision of a licensee. A Radiation Protection Programme is also necessary, which outlines a transport management plan as well a source security transport plan.

The *Australian Radiation Protection and Nuclear Safety Act 1998* (ARPANS Act) complements State legislation by regulating agencies and departments which fall under Commonwealth jurisdiction. As with State legislation, the ARPANS Act creates its own regulatory authority, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). The ARPANS Act promotes uniformity between all Australian jurisdictions in the Commonwealth, States, and Territories, through the Radiation Health Committee (RHC), which is made up of representatives from each jurisdiction. ARPANSA is recognised as the national authority on radiation protection in Australia.

Two main international bodies provide guidance on radiation protection; the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA). The ICRP is an advisory body providing recommendations and guidance on radiation protection which are unilaterally adopted around the world. The IAEA is aligned to the United Nations with a mandate to promote the peaceful use of uranium for nuclear power and provides standards and codes of practice which are generally adopted in local regulations.

Radiation legislation specific to mine sites in Western Australia is regulated through the Mines Safety and Inspection Act 1994 and the Mines Safety and Inspection Regulations 1995 administrated by the DMP. Radiation safety on mine sites is addressed by Part 16 of the Mines Safety and Inspection Regulations. The regulations include requirements for authorised limits, preparation of a radiation management plan, control of exposure to radiation, mining of radioactive material, stockpile management, waste management and mine closure.

In regards to nuclear safety, Australia is a signatory of the international agreements on nuclear materials; the Non-Proliferation of Nuclear Weapons or Non-Proliferation Treaty (NPT) which is enforced in conjunction with Australian Nuclear Safeguard Agreements. This ensures that any nuclear material produced in Australia can only be used for peaceful purposes. Australia has 22 bilateral Safeguard Agreements, covering 39 countries.

9.6.3 Studies and Investigations

Radiation monitoring has been conducted periodically at Yeelirrie since the late 1970s when WMC undertook monitoring for its environmental impact assessment. More recently, BHP Billiton conducted background monitoring for radiation from 2009 to 2011 for its proposed ERMP. Cameco has continued to monitor the background radiation in the region since it acquired the Project at the end of 2012.

The principal purpose of undertaking background monitoring is to understand natural variation in radiation and the impact that an operation might have on this. It is also useful when setting rehabilitation targets. In parallel with direct measurements of various radiation parameters, the background monitoring program included several parameters that are known to influence the radiation environment such as meteorological conditions and groundwater flow.

Background radiation monitoring to date has included:

- activity concentration of long-lived, alpha-emitting radionuclides in dust (LLA);
- concentration of radon in air (Rn);
- concentration of radon decay products in air (RnDP);
- gamma dose rate in air 1 m above ground surface;
- gamma dose rate in air (derived from aerial gamma surveys);
- concentration of radionuclides in soil;
- concentration of radionuclides in groundwater; and
- concentration of radionuclides in surface waters.

Parameters from other data sets that assisted with the description of the background radiological conditions were:

- meteorological data (from on-site weather station and Bureau of Meteorology regional stations), in particular, wind speed, wind direction and atmospheric stability class; and
- traditional food gathering.
- To assess the radiological impacts from the Yeelirrie operation, the potential doses to workers and members of the public from the Project have been calculated.

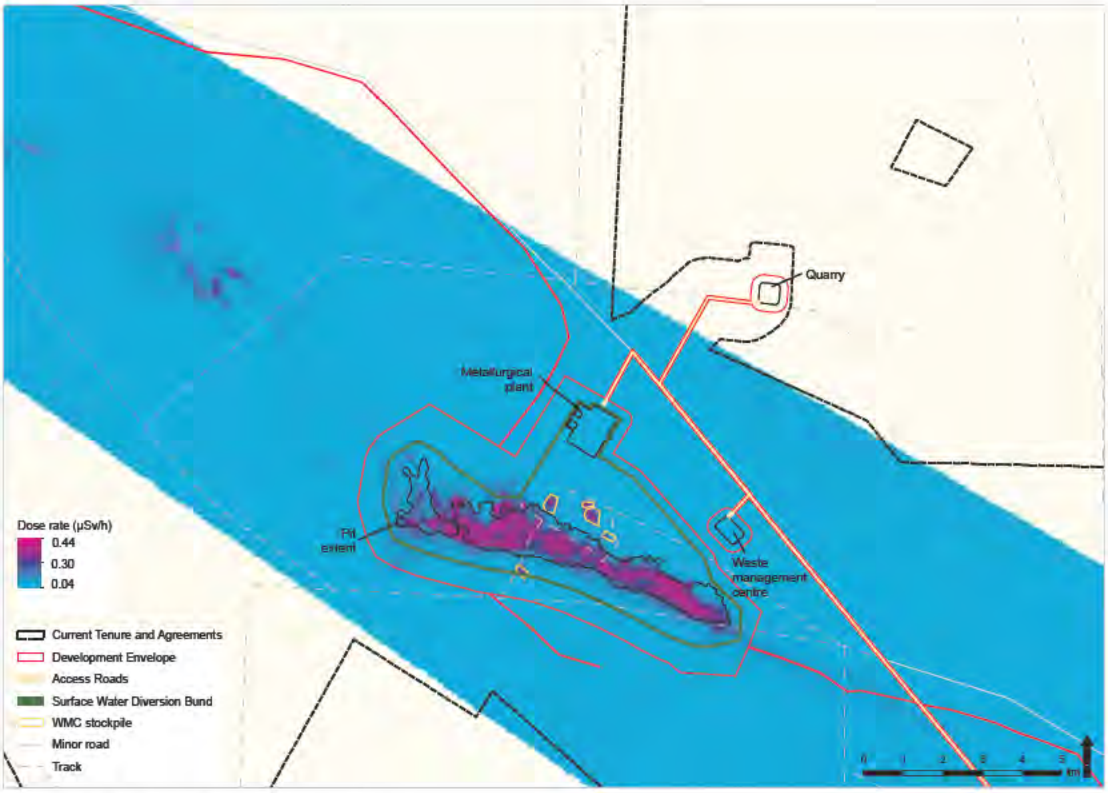

Figure 9-52: Aerial gamma results

Reference is also made to the Air Quality Assessment (Section 9.8), where the sources, methods and results of dust and radon modelling are presented.

9.6.4 Existing Environment

The existing radiological environment at Yeelirrie and in the general region has been monitored and characterised periodically over a period of more than 30 years. Over this period, techniques and technology have improved with measurements becoming more accurate and more precise.

The first radiation monitoring results are from the 1978 WMC Environmental Impact Statement, which were based on a report by the Australian Atomic Energy Commission (AAEC 1978). The main finding in this report was that the Yeelirrie deposit exists in an area of naturally occurring elevated radiation levels.

Between 2009 and 2011 BHP Billiton conducted extensive background monitoring. The raw results from this work have been reviewed and analysed and are used in this assessment. When Cameco acquired Yeelirrie in 2012, some monitoring continued in locations consistent with the BHP Billiton monitoring. The detailed results of this monitoring are provided in the radiation appendix (Appendix J1) and a summary is provided below.

9.6.4.1 Gamma Dose Rates

Surface gamma dose rates arise principally from soil radionuclides and cosmic rays. As the cosmic ray flux is generally quite uniform, the gamma dose rates provide a measure of the underlying soil radionuclide concentrations.

An airborne gamma survey of the Project Area was conducted in 2011. The results of the survey are shown as Figure 9-52.

The figure shows the gamma signature in the Project Area in units of µSv/h, together with the conceptual Project layout superimposed. In addition to the aerial survey, gamma monitoring using a handheld gamma detector was conducted. A survey of 1,900 measurements over the orebody gave an average dose rate of 0.85 µSv/h (range 0.1 to 6.3 µSv/h).

Results off the orebody were much lower, with average levels of approximately 0.09 µSv/h and 0.07 µSv/h at the proposed accommodation area and Yeelirrie homestead respectively. These off site results are consistent with average background gamma dose rates observed elsewhere in Australia (inferred from ARPANSA 2012).

9.6.4.2 Radionuclides in Soils

Sampling and analysis of radionuclides in soils occurred in 2010 with results provided in Table 9-45. (Note that <10 km refers to samples within 10 km of the centre of the proposed pit and >10 km refers to samples beyond this).

Table 9-45: 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}
All samples	50 (6-370)	62 (57-210)	129 (7.5-960)	182 (13-1,060)	88 (15-165)
>10 km samples	50 (6-370)	78 (57-123)	85 (7.5-560)	144 (40-590)	42 (15-110)
<10 km samples	51 (10-131)	124 (37-210)	208 (11-960)	249 (13-1,060)	114 (62-165)

The results indicate that radionuclides in soil (apart from uranium) are higher closer to the orebody..

9.6.4.3 Airborne Dusts

A program of sampling airborne dusts was undertaken at Yeelirrie during the second half of 2010, with analyses of radionuclide concentrations conducted. Both total suspended particles (TSP) and particles less than 10 microns in equivalent aerodynamic diameter (PM10) were sampled. The average activity concentration can be seen in Table 9-46.

Table 9-46: Summary of high volume dust results at Yeelirrie

Location	Sample Type	Radionuclide Concentration (µBq/m³) (Average and range)			
		U^{238}	Th^{230}	Ra^{226}	Pb^{210}
South Gate	PM_{10}	8.3 (4-15)	67 (18-100)	4.5 (1.8-7)	518 (360-730)
Yeelirrie Homestead	PM_{10}	2.9 (2-3.7)	34 (11-50)	3.2 (0.7-6.4)	305 (85-570)
Proposed Accommodation Area	TSP	27.4 (3-90)	107 (14-300)	9.3 (1.7-15)	278 (90-560)

9.6.4.4 Radon

Radon concentration monitoring has been conducted in the region using real time monitoring equipment and passive radon detectors.

The real time monitoring indicates that there is locational, seasonal and diurnal variation in radon concentrations. Higher average and peak radon concentrations occur:

- closer to the orebody;
- during the winter months of the year;
- during stable atmospheric conditions, mainly at night.

The 2010 monitoring results confirmed the findings of the 1978 monitoring which noted that the "undisturbed orebody affects the quality of air in its immediate neighbourhood" (AAEC 1978). The orebody has a significant radon signature when compared to surrounding areas. A summary of the real time monitoring results from 2010 can be seen in Table 9-47.

Table 9-47: Radon concentrations (Bq/m^3)

	Above Orebody		3 Mile Bore (10 km east of orebody)	
	July	November	July	November
Average	127	33	46	30
Median	23	8	18	11
Maximum	1720	783	320	304

Fifty passive radon monitors were placed into the region for a three month period during 2010. The results vary between approximately 10 and 65 Bq/m^3 and again show higher levels closer to the orebody. The average concentrations are as follows:

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

9.6.4.5 Radon Decay Products

Radon decay products (RnDPs) behave in a similar manner to radon, exhibiting large concentration variation depending upon the stability of the atmospheric conditions. This results in seasonal and diurnal variations. Higher concentrations are also noted closer to the orebody. A summary of background monitoring can be seen in Table 9-48 and in Figure 9-53.

Table 9-48: Radon decay product concentrations (µJ/m^3)

	Above Orebody		Adjacent to Yeelirrie Homestead (15 km east of orebody)	
	July	November	July	November
Average	0.21	0.06	0.06	0.03
Median	0.05	0.03	0.03	0.02

The diurnal and seasonal variation is naturally occurring and recorded elsewhere (Cameco 2013, BHP Billiton 2009). The diurnal variation is due to a reduction in atmospheric mixing of radon emitted from the ground as a result of temperature inversions and very stable conditions. This causes the radon to effectively be trapped in layers in the atmosphere, until turbulent conditions return.

Seasonal variations are usually aligned to the broader weather patterns with lower Radon Decay Product Concentrations being associated with periods of higher mixing especially during the

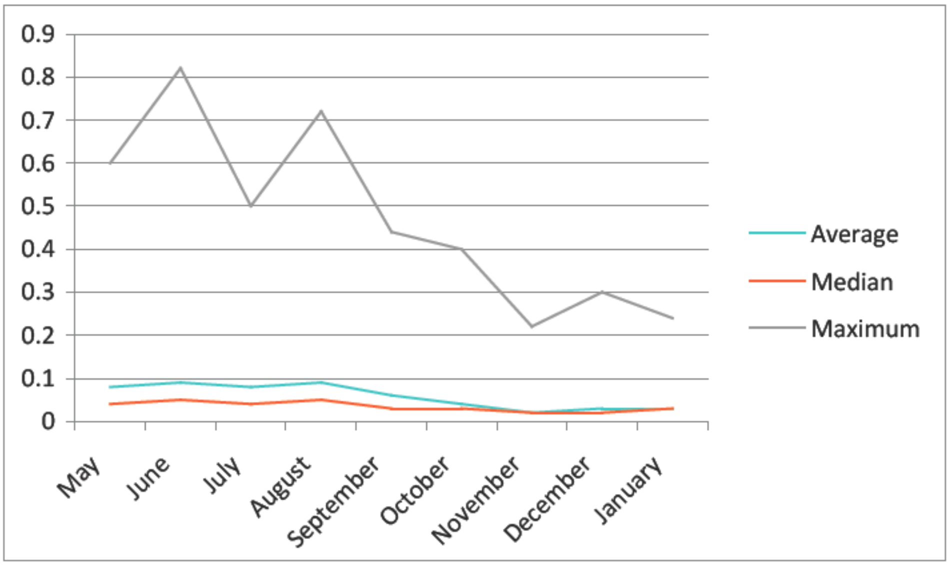

Figure 9-53: Radon decay product concentrations at Yeelirrie Homestead

summer months where there is an increase in thermal turbulence (primarily due to more daylight hours and strong solar radiation).

9.6.4.6 Radionuclides in Groundwater

Earlier monitoring results (AAEC 1978) indicated a high level of variability in groundwater Ra226 concentrations, between 0.02 and 33 Bq/L, together with U^{238} concentrations varying between 3.8 and 17.4 Bq/L within the orebody region and levels between 0.02 and 2.2 Bq/L within the broader catchment area.

An extensive program of groundwater monitoring was conducted during 2009 and 2010 with over 150 samples taken from drill and bore holes from across the region. The data have been grouped and a summary is provided in Table 9-49.

The grouping of data is as follows and as shown in Figure 9-54:

- 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 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.

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

9.6.4.7 Radionuclides Surface Water

Surface water flow in the Yeelirrie region 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.

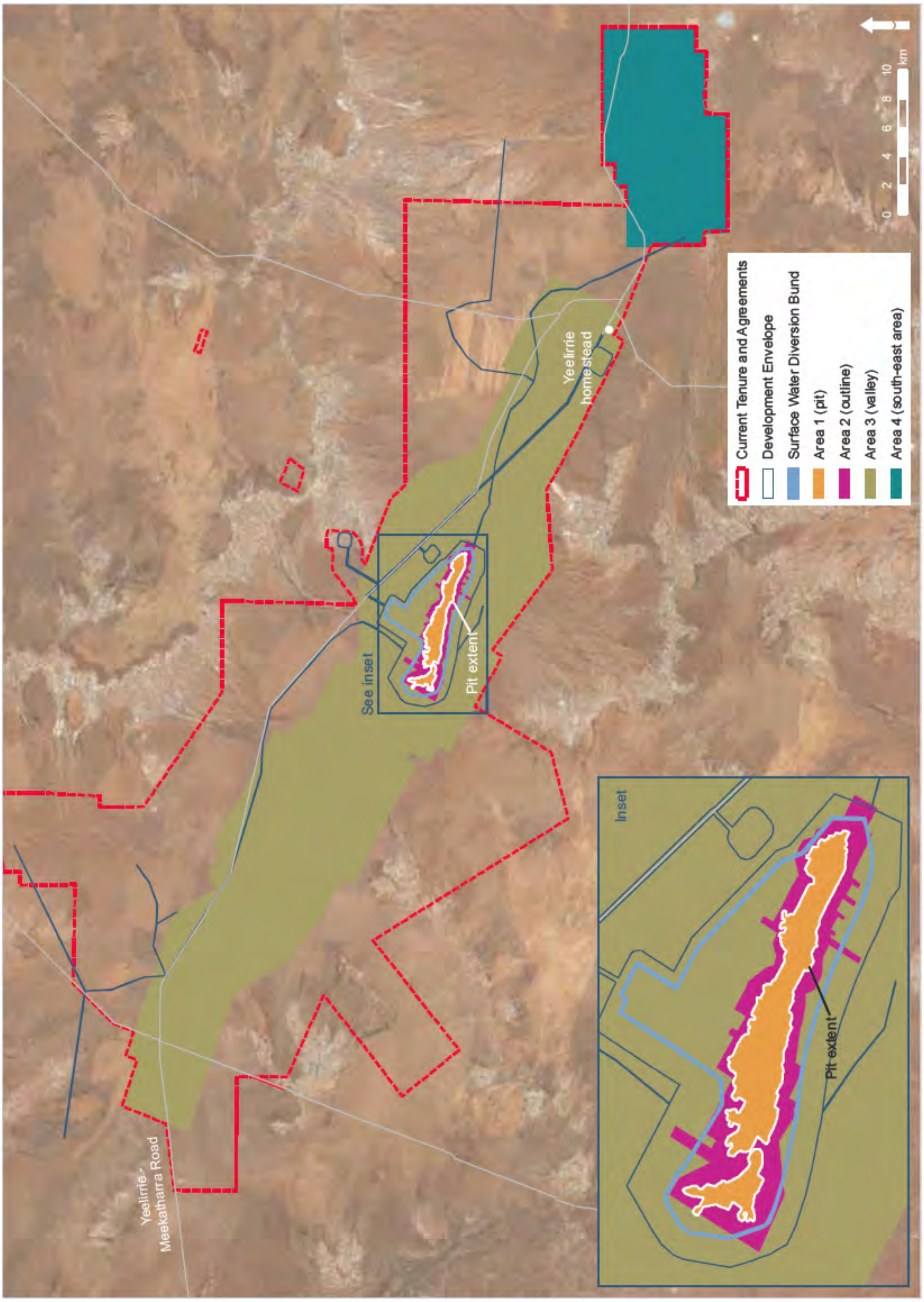

Figure 9-54: Categories of groundwater results

Table 9-49: Average and range of radionuclides in groundwater for different regions

Region	Radionuclide Concentration in Groundwater, Average and Range (Bq/L)				
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
Pit	8.6 (1.5 - 31)	17.1 (0.1 – 63.6)	36 (0 – 447)	723 (7.3 – 4210)	2.29 (0.1 – 11.8)
Outline	6.2 (0.1 – 24.3)	0.07 (0.05 – 0.1)	5.9 (0.1 – 19.3)	86.3 (0.003 – 356)	6.8 (0.1 – 39.5)
Valley	5.9 (0.03 – 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	1.6 (0.13 – 8.69)	0.57 (0.1 – 0.87)	2.8 (0.1 – 27.8)		1.1 (0.1 – 18.4)
Regional	0.7 (0.06 – 2.4		0.95 (0.1 – 1.82)	98.3 (1.14 – 491)	5.9 (0.1 – 29)

During the 2009 - 2010 regional water sampling program, a limited number of surface water samples were taken when water was present and results are presented in Table 9-50.

Table 9-50: Summary of radionuclides in surface water samples (Bq/L)

Sample Location	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

Note that surface water is not generally used permanently for human or stock consumption due to the lack of availability and salinity.

9.6.4.8 Summary

Measured radioactivity levels in environmental media (water, soils, air and biota) in the vicinity of the Yeelirrie deposit are generally higher than those observed from the wider region. The orebody affects the quality of air in its immediate neighbourhood, with “peaks” in radon and RnDP concentrations during stable atmospheric conditions.

Radioactivity in soils and vegetation along the central drainage channel is elevated locally but generally much less elsewhere.

9.6.5 Potential Impacts

9.6.5.1 Radiation Exposure of Workers

As discussed in more detail in Appendix J1, there are three main pathways for radiation exposures of workers: external gamma exposure, inhalation of radioactive dusts and inhalation of radon decay products. This section discusses the estimated doses that will received by Cameco’s Yeelirrie workforce.

Miners

Assessment of doses to miners has been based on a mining rate of 8 Mtpa of ore and waste rock, of which 3 Mtpa is ore. The average uranium grade of the mined ore is expected to be 1,600 ppm and 100 ppm for the waste rock, giving an average mined material grade of 660 ppm. Mining will be from shallow "cells", approximately 10 m deep with areas of approximately 50 ha.

Mining is expected to occur for 15 years, and the mine will be operated on a continuous roster for 24 hours/day, seven days a week.

External Gamma Exposure

Mine workers will be exposed to gamma radiation from the uranium mineralisation in the rock on which they work. The expected dose rate from standing on mineralised material can be expressed as 65 μSv/h per 1% of uranium in the material (Thomson and Wilson 1980).

For the mine as a whole, the average concentration of uranium in all excavated material is 660 ppm (0.066%). Therefore the calculated dose rate is 4.3 μSv/h. A worker who spends 2,000 hours per year on "average" material is expected to receive an annual dose of about 8.6 mSv.

This estimate does not take into account shielding that is provided by the mining equipment or the fact that miners do not spend all of their time in the mine (for example truck drivers, mine surveyors and other workers would likely only spend about half of their time in the mine). Therefore, the calculated dose is a worst case estimate. Actual doses are expected to be no more than half the maximum estimated dose.

On this basis the maximum probable gamma dose to mine workers is estimated to be approximately 4.3 mSv/year.

Inhalation of Radionuclides in Dusts

Drilling, blasting and handling of the ore and waste rock produces dusts containing radionuclides which have the potential to result in exposure to workers. The dust generating activities at the Project will be similar to those found at any open pit mining and quarrying operation. Data from dust monitoring in open pit uranium mining is limited, and an estimate of dose may be made based on dust levels recorded at other mining operations and calculating the radiation dose.

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.

Assuming that the uranium content of dust is that of the average of all mined material (660 ppm uranium), then the radionuclide content of the dust is calculated to be 25 mBq/m^3. If it is assumed that the radionuclides are in secular equilibrium, then the activity of each radionuclide in the U^{238} decay chain is 25 mBq/m^3. Assuming a breathing rate of 1.2 m^3/h for 2,000 hours per year, the radionuclide dust intake is calculated to be 19.2 Bq/y (per radionuclide). Using the recognised dust conversion factors (ICRP 1994), the resulting dose received from inhaling that dust cloud for a full (working) year is approximately 3.6 mSv on the basis that the dust concentration being on average 3 mg/m^3 for the full year.

Again, this estimate is considered to be worst case as most mine workers are not exposed to dusty conditions for the full working day. Most spend much of the day in air-conditioned equipment. It is also unlikely that dust levels remain at the estimated concentrations for a full year. Cameco will ensure that dust suppression strategies will be a priority during operations as part of an overarching occupation health and hygiene program.

Inhalation of radon decay products

Exposures to radon decay products are dependent on two main factors: the amount of radon that is being introduced into the mine air and the rate of ventilation.

The radon release rate from the Yeelirrie deposit has been estimated to be 50 $Bq/m^2/s$ per %U (Mason 1982, BHP Billiton 2009, ERA 2014). For an average uranium grade of ore of 1,600 ppm U, the radon emission rate is 8 $Bq/m^2/s$. (Note that the uranium grade of ore is used because it is assumed that the base of the open cell from which the radon is emitted is ore).

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

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

The ventilation rate was calculated from the following expression (Thompson 1994):

$$T=33.8*(V/U.L.W)*(0.7\cos(x) +0.3)$$

where T is the air residence time;

- V is the pit volume (m^3);
- U is the wind velocity (m/s);
- L and W are the pit length and width (m); and
- x is the angle between the mine axis and the wind velocity.

The annual average wind speed for the region is 2.7m/s. Using the above formula, together with the mine dimensions, gives a ventilation rate approximately 29 times an hour.

The radon equilibrium concentration is calculated using the following equation (derived from Cember 2009):

$$\text{Radon concentration } (Bq/m^3) = ER/ (PV \times VR)$$

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 104 Bq/m^3. Assuming that the equilibrium factor between radon decay products (RnDP) and radon is 0.4 (based on the results from baseline monitoring) then the resulting annual average RnDP concentration is 0.24 $\mu J/m^3$. Using the dose conversion factor in ARPANSA (2005), the RnDP dose for a miner in the mine for a full working year is approximately 0.7 mSv.

The baseline monitoring indicated that there are periods of very stable atmospheric conditions which cause atmospheric radon (and RnDP) concentrations to increase, although these conditions would be taken into account in the annual average calculation. However, an additional calculation was undertaken to consider the potential dose under very stable atmospheric conditions

Using the ratio of stable condition RnDP concentrations and the overall average RnDP concentrations from the baseline monitoring, an estimate of the dose under stable atmospheric conditions when the mine is operating can be made. The calculated scaled dose for stable conditions was 1.5 mSv/y.

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

It is noted that the ICRP (ICRP 2015) has recently recommended a new dose conversion factor for RnDP, which is equivalent to 2.8 Sv/J and is an increase by a factor of 2.4 over the current dose conversion factor. While the new factor has yet to be adopted in Australia applying the new factor to the estimated doses for the Yeelirrie worker dose estimates, results in an estimated dose of 2.6 mSv/y.

Total Dose - Miners

The estimated average annual dose to miners is 4.3 mSv from gamma, 3.6 mSv from inhalation of radioactive dust, and 2.6 mSv from inhalation of radon decay products, resulting in a total of approximately 10.5 mSv/year.

The assumptions used in this assessment are very conservative. A minimal allowance for such factors as shielding of gamma radiation by heavy equipment has been allowed for and it is expected that a lower dust exposure due to cab air-conditioning would occur. In practice it is expected that the maximum probable dose to miners will be approximately 5 mSv/year, similar to doses measured at other uranium mines.

Cameco commits to achieving a very high standard of exposure management to maintain gamma doses at acceptable levels. Using the radiation management experience developed over 20 years of mining uranium in Canada, Cameco will establish a series of control processes which are discussed further in this section to ensure that doses remain well controlled.

The radiation dose history of all Australian uranium mine workers are recorded on the Australian National Radiation Dose Register (ANRDR). More than 31,700 individual workers from the uranium mining industry are recorded on the database which is maintained and managed by ARPANSA.

The register tracks a workers cumulative dose based on data provided by the employer. It assists in minimising the possibility of a worker receiving a dose greater than the Australian dose limit when moving from one employer to another. The data is available to workers and is also used to generate annual statistics relating to exposure trends to assist in the optimisation of radiation protection.

In 2013, approximately 95% of workers received a dose less than 3.5mSv/y and 67% of workers received a dose below 0.5 mSv/y. (ARPANSA, 2013)

Processing Plant Workers

The processing plant will be located to the north east of the mine. Ore will be trucked to the plant from the mine for treatment. The processing facility will consist of three main areas and doses were estimated for workers in these areas as follows:

- 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.

The Yeelirrie processing facilities will be practically identical to existing facilities currently in operation, for example, at Olympic Dam and Ranger. Actual doses from these facilities provide the best estimate of the potential doses to Yeelirrie processing plant operators.

For this dose assessment, a combination of actual doses from other operations and estimates based on modelling has been used.

External Gamma Exposure

Gamma radiation exposures have been based on reported gamma doses of 2.4 mSv/y for processing plant workers at Olympic Dam.

The Yeelirrie uranium ore grade is approximately three times higher than the Olympic Dam uranium grade, however, 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.

Inhalation of Radioactive Dusts

For the assessment, average annual dust concentrations of 2 mg/m^3 have been assumed to exist in the crushing area. This assumption is based on dust concentrations in modern processing facilities being generally low because there is a focus on dust minimisation in design and operations and during actual operations, process materials are usually in slurry form (also known as wet processing).

For the wet processing part of the concentrator and in the hydrometallurgical section, it has been assumed that average dust concentrations are less than for the crushing and ore handling parts of the concentrator area (due to process materials only being in a slurry form). The dust dose in this area is conservatively assumed to be 1 mg/m^3.

In the final product packing area, dust doses have the potential to be high due to the high specific activity of the final product. However, the technology used for handling and packaging of final product ensures that these workplaces are practically dust free. 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.

Inhalation of Radon Decay Products

The estimated doses from inhalation of RnDP for plant workers are based on the modelled radon concentrations from the air quality modelling. This shows an annual average radon concentration of 100 Bq/m^3 at the processing plant location.

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 1.5 mSv/y.

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

Total Dose – Processing Plant Workers

- The maximum probable annual doses to processing plant workers (using the new ICRP RnDP dose factor) are as follows;
- concentrator ore handling workers – 6.8 mSv;
- concentrator other workers – 5.6 mSv;
- hydrometallurgical plant workers – 3.0 mSv;
- maintenance personnel – 5.2 mSv.

Other Workgroups

Administration workers

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. Therefore it is expected that total doses to administration workers would be less than 1 mSv/y.

Construction workers

A construction workforce of up to 1,200 workers would be employed to build the accommodation village, processing plant and associated infrastructure. While some mine pre-stripping and mining will occur during construction, it will be away from the construction activities and therefore doses to construction workers are expected to be negligible. 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.

Regular area monitoring would be conducted during construction to ensure that construction worker doses remain well below the public limit of 1mSv/y.

Transport workers

The final uranium oxide product is to be trucked to Port Adelaide for export. All final product would be contained in sealed drums in sealed containers during transport and therefore not present a potential dust source. The main exposure pathway during routine transport operations will be from gamma radiation. Gamma dose rates in truck cabins have been measured to be 1uSv/h (BHP Billiton 2009). Based on the exposure time, and the number of typical trips that a driver would make each year, the calculated annual doses to drivers would be approximately 0.5 mSv/y.

Note that potential doses to the public during transport are addressed later in this section.

Camp workers

The accommodation village will be located approximately 16 km to the southeast of the orebody, adjacent to the Yeelirrie homestead. Cameco will employ a catering contractor to manage the camp. Doses to the camp workers would be approximately one half of the calculated doses for residents of 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. Doses to camp workers are expected to be approximately 0.1 mSv/y.

Comparison with Other Projects

Appendix J1 provides a comparison of occupational doses received at other similarly configured uranium mines around the world.

Rossing uranium mine is a large open pit mine in Namibia. The average dose to equipment operators in the mine is 2.2mSv/y.

In Canada, the McLean Lake open pit mine has been operating for a number of years and the average measured dose to pit workers is less than 1mSv/y.

Doses to workers at the Olympic Dam are reported as averaging 4mSv/y for underground workers and 2.4mSv/y for processing plant workers. Exposure situations are different for open pit and underground operations.

In Australia, the best comparison is with the Ranger mine in the Northern Territory which is an open pit uranium mine which has operated since 1980. The grade of ore in the mine is higher than that at Yeelirrie, however actual measured doses are relatively low.

Annual occupational dose data from Ranger Mine for the period 2009 to 2011 show that average doses to miners is 0.81 mSv/y, with the maximum being 2.3 mSv/y. For the miners, on average, gamma made up approximately 50% of the total dose and approximately 30% of the dose coming from inhalation of radon decay products (ERA, pers. comm., September 2012).

9.6.5.2 Off-site Exposure

Exposure to members of the public occur when emissions from inside the operation impact upon people outside the operation. Assessments have been conducted for representative people located at:

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

Potential pathways

The primary potential exposure pathways for members of the public are:

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

Sources

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).

Appendix J1 shows that potential dose to a member of the public at this location, for a full year, is 0.03µSv/y.

Dust Inhalation

Dust emissions from the Project are expected to be primarily generated from mining and materials movement, such as, drilling, excavating, stockpiling and materials movement. Dust may also occur from ore crushing in the processing plant.

The estimated emission of radionuclides (for each work area) was calculated from the dust emission rates and is shown in Table 9-51.

Dust emissions are not expected to be generated from tailings deposition because it will be deposited to a series of cells in the in-pit TSF, as a slurry. Deposition of tailings to TSF cells would be rotated to allow for sufficient consolidation before the next round of deposition. The TSF will be actively managed in accordance with the TSF Operating Plan. If necessary a moist cover will be maintained over the tailings to minimise the risk of dust generation. Final drying and closure of the in-pit TSF will be undertaken to minimise dust generation as outlined in Section 9-12.

Table 9-51: Estimated radioactive dust releases

Dust source	Emission Rate (Bq/s)
Mining - Ore	286
Mining - Overburden	30
Mining - Unmineralised Topsoil	0

Dust source	Emission Rate (Bq/s)
Processing Plant	93
Other (quarry, roads)	0

Exhaust gases from the product drying building will be scrubbed before release to the atmosphere, therefore emissions of concentrated uranium bearing dusts are expected to be negligible.

Radon

The main radon sources for the operation are the mine and tailings. The amount of radon released during operations is based on a radon emission rate of 50 $Bq/m^2/s$ per %U for uranium bearing rocks and ore. For tailings, since the source of radon is radium and the majority of radium in the ore reports to the tailings, the emission rate is also estimated to be 50 $Bq/m^2/s$ per %U. The estimated radon releases are shown in Table 9-52.

Table 9-52: Estimated radon releases

Dust source	Emission Rate (MBq/s)
Mine Pre-strip	12.3
Mine	27.5
Tailings	14.0
Stockpiles	7.1
Processing Plant	0.0

Dispersion modelling

Dust Concentrations

The dust sources identified were used as sources in the air quality modelling and a contour plot of dust concentrations can be seen in Figure 9-49.

The predicted annual average dust concentrations at the main receptor locations can be seen in Table 9-53. The ground level radionuclide activity concentrations have been calculated from the average of all mined material (including ore and overburden). This gives an activity concentration of 9.4 Bq/g for each radionuclide in the uranium decay chain.

Table 9-53: Annual TSP ground level concentrations

Location	Distance from Orebody	Ground Level Concentrations Dust ($\mu g/m^3$)	Ground Level Concentrations Radionuclide activity ($\mu Bq/m^3$)
Yeelirrie Pool	10.2 km northeast	1.1	10.3
Accommodation Village	16.4 km southeast	0.1	0.9
Yeelirrie Homestead	16.4 km southeast	0.1	0.9
Ululla Homestead	28.5 km north	0.2	1.9
Palm Springs	50.4 m east-southeast	0.01	0.1

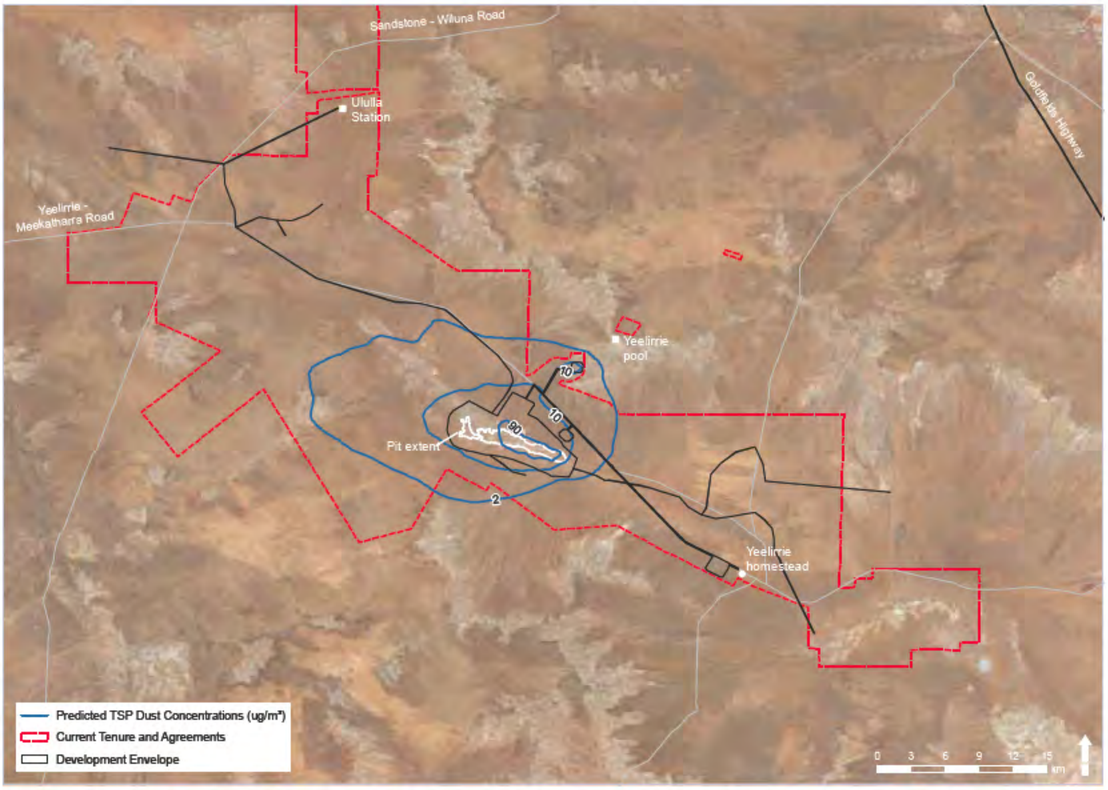

Figure 9-55: Predicted TSP dust concentrations (μg/m³)

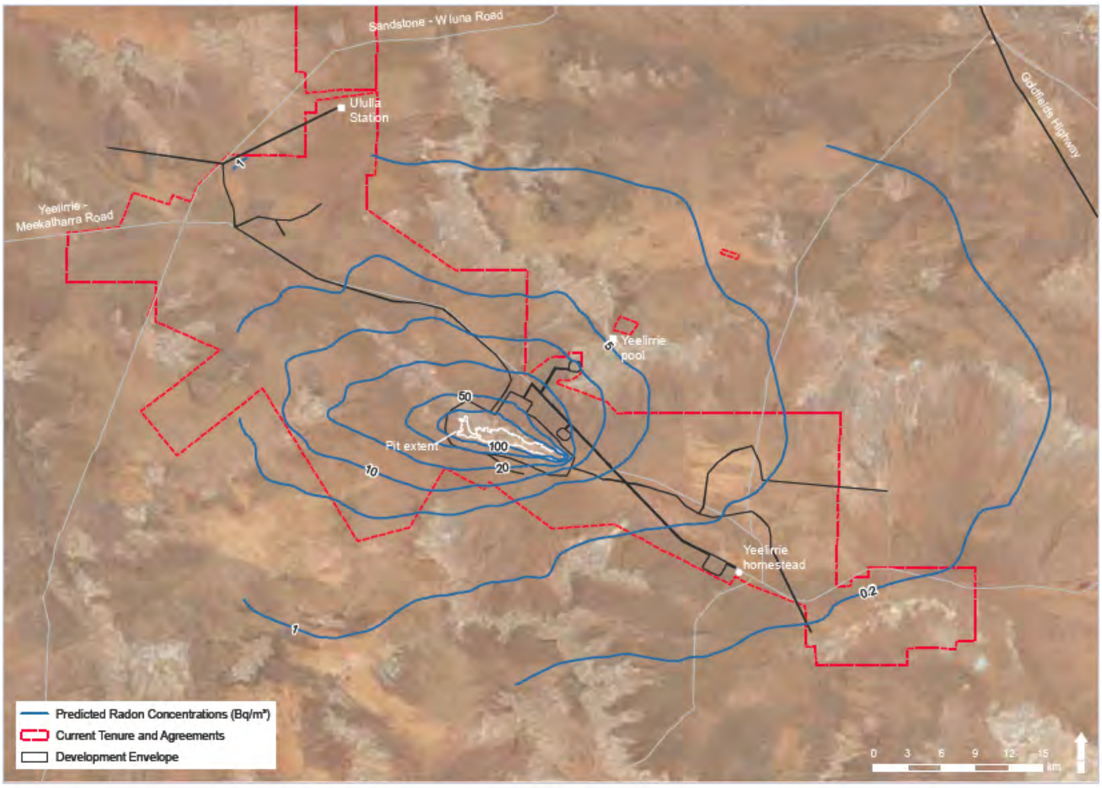

Figure 9-56: Predicted annual average radon concentrations Bq/m³

Radon Concentration

The air quality modelling provides contours of average annual radon concentrations as shown in Figure 9-56.

The predicted annual average ground level concentrations at the main receptor locations can be seen in Table 9-54, together with the calculated RnDP concentration based on an equilibrium factor of 0.4.

Table 9-54: Annual radon and RnDP ground level concentrations

Location	Distance from Orebody	Ground Level Annual Average Radon Concentrations (Bq/m^3)	Ground Level Annual Average RnDP Concentrations ($\mu J/m^3$)
Yeelirrie Pool	10.2 km northeast	10.0	0.022
Accommodation Village	16.4 km southeast	0.4	0.001
Yeelirrie Homestead	16.4 km southeast	0.4	0.001
Ululla Homestead	28.5 km north	1.2	0.003
Palm Springs	50.4 km east-southeast	0.06	0.0001

Dust Deposition

The air quality modelling provides contours of average annual average dust deposition as shown in Figure 9-57, and deposition rates (for dust and radionuclides) as shown in Table 9-55. The radionuclide deposition (per radionuclide) is based on a dust specific activity of 9.4 Bq/g.

Table 9-55: Annual dust deposition rates

Location	Distance from Orebody	Average Annual Ground Level Dust Deposition (g/m^2.month)	Average Annual Ground Level Radionuclide Deposition (Bq/m^2/month)
Yeelirrie Pool	10.2 km northeast	0.013	0.122
Accommodation Village	16.4 km southeast	0.002	0.019
Yeelirrie Homestead	16.4 km southeast	0.002	0.019
Ululla Homestead	28.5 km north	0.006	0.056
Palm Springs	50.4 km east-southeast	0.0004	0.004

Total Inhalation Dose Estimates

The radionuclide concentrations in air and RnDP concentrations are used as the basis for the calculation of inhalation dose using the dose factors and methods recommended by the IAEA (IAEA, 1996) and ARPANSA (ARPANSA 2005). The method is outlined in detail in Appendix J1. A summary of the results can be seen in Table 9-56.

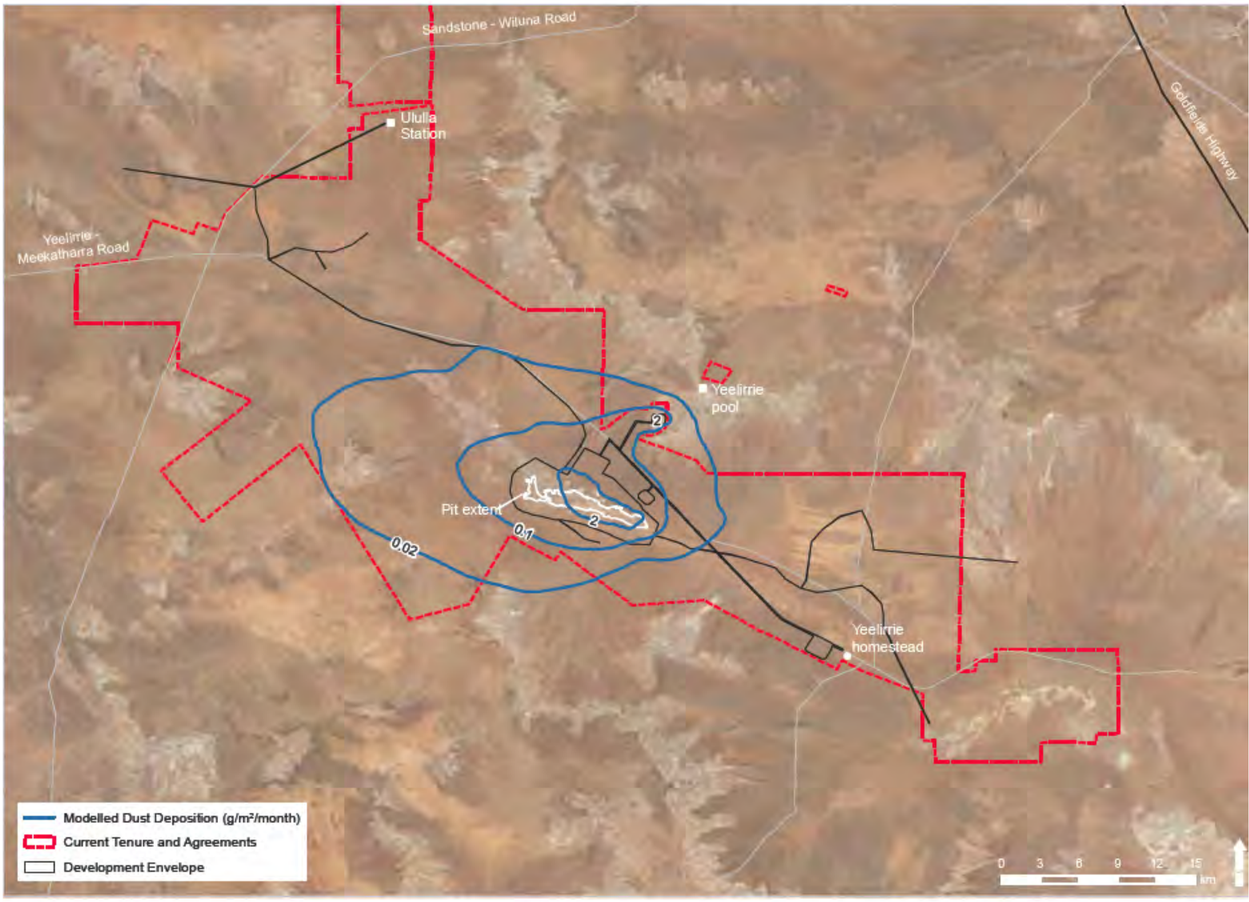

Figure 9-57: Predicted dust deposition (g/m²/month)

Table 9-56: Public inhalation dose estimates

Location	Dose (mSv/y)	
	Radionuclides in Dust	Radon Decay Products
Yeelirrie Pool	0.006	0.210
Accommodation Village	0.0005	0.009
Yeelirrie Homestead	0.0005	0.009
Ululla Homestead	0.0009	0.026
Palm Springs	0.00005	0.0001

Ingestion Dose Estimates

A potential pathway of exposure is through ingestion of food that has been in contact with or contaminated by emissions from the operations. This has been assessed for two types of diets as follows:

- locally cultivated produce; and
- locally sourced bush tucker.

For this assessment, it has been assumed that a person would consume both diets in one year. This will significantly overestimate the calculated potential exposure.

For the cultivated produce, the assessment is based on the following annual food type consumption:

- 30 kg of non-leafy vegetables;
- 30 kg of leafy vegetables;
- 30 kg of root vegetables;
- 100 kg 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, 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.

The calculated doses from the cultivated diet at each of the main receptor locations are shown in Table 9-57.

Table 9-57: Data for cultivated diet

Location	Vegetation Ingestion Dose (mSv/y)	Meat Ingestion Dose (mSv/y)	Total Ingestion Dose (mSv/y)
Yeelirrie Pool	0.006	0.0009	0.007
Accommodation Village	0.001	0.0001	0.001
Yeelirrie Homestead	0.001	0.0001	0.001
Ululla Homestead	0.002	0.0004	0.003
Palm Springs	0.0002	0.0	0.0002

The bush tucker assessment was based on a survey during 2011, involving Traditional owners of the area. The edible vegetation sampled is shown in Table 9-58.

The consumption rate of traditional bush foods is assumed to be 155 kg/y of plant material and 125 kg/y of animal material based on figures for traditional owners of the Maralinga lands (AAEC 1985). The bush tucker assessment is based on:

- 125 kg/y meat (assumed to be all 110 kg kangaroo flesh and 15 kg kangaroo liver)
- 155 kg/y vegetable (assumed to be 40 kg/y seeds, 115 kg/y berries and fruit)

Table 9-58: Sampled bush foods

Common name	Part eaten	Part sampled
Mulga	Seeds, edible gum, edible insects and galls	Seed pods
Bowgada	Seeds and young seed pods	Seed pods
Ruby Salt bush	Ripe berries	Fruit
Berrigan	Fruit	Green fruit
Australian Boxthorn	Berries	Berries
Quandong	Nut (seed of fruit) and fruit	Fruit
Bush Plum	Flesh of fruit	Fruit
Kangaroo	Flesh, liver	Flesh, liver

Note that this is considered to be a very conservative assessment because it is unlikely that all food consumed would be just from the Yeelirrie area alone. However, this does provide a "worst case" assessment.

From the estimates of bush tucker diet, the intakes of radionuclides are calculated. The intakes are then converted to dose using the IAEA recommended ingestion dose conversion factors (IAEA 1996).

To determine the impact of the operation on bush foods, the dust deposition figures were used to determine the percentage increase in soil radionuclide concentrations after 15 years of dust deposition (compared to baseline). The percentage increase was then factored against the existing dose to provide an estimate of the potential incremental operation originated dose from consumption of bush tucker.

The results in Table 9-59 show the incremental increase in dose after 15 years of operation due to emissions from the Project.

Table 9-59: Bush tucker dose estimates

Location	Distance from Orebody	Estimated Annual Dose (mSv/y)
Yeelirrie Pool	10.2 km northeast	0.040
Accommodation Village	16.4 km south east	0.006
Yeelirrie Homestead	16.4 km southeast	0.006
Ululla Homestead	28.5 km north	0.017
Palm Springs	50.4 km east-southeast	0.002

For transient visitors to the area, the potential dose would be proportionally lower. For example, over a two month period, a visitor to the area would receive 1/6 of the predicted doses.

Total Dose Estimates

The total dose estimates at the sensitive receptors can be seen in Table 9-60. Note that the doses are based on 100% occupancy (that is 8,760 hours per year) at these locations.

Table 9-60: 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, the gamma dose is negligible (<0.001mSv/y).

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 from a container (BHP Billiton 2009), 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.

9.6.6 Proposed Management

Cameco has extensive experience in managing uranium mining, and is committed to maintaining high standards of radiation protection. The basis of the approach is the corporate Radiation Protection Programme which will be used to set minimum requirements for radiation protection at Yeelirrie. Cameco's Corporate operation provides services and technical advice to support the radiation protection programs of individual operations.

As part of the approval and authorisation process, a draft Radiation Management Plan (RMP) will be developed for the Project, which will be provided to the DMP and Radiological Council prior to construction. The RMP would include details of radiation protection and radioactive waste management specific to the plant and addresses the requirements of the Western Australian NORM Guidelines (DMP 2010) and the ARPANSA Mining Code (ARPANSA 2005)

A Transport Radiation Management Plan (TRMP) would also be developed which will include an Emergency Response Assistance Plan (ERAP). The transport carrier will be required to develop a plan consistent with Cameco's ERAP.

This section sets out the principles that will be applied in managing radiation exposure and radioactive waste, and outlines the way these principles will be applied to the Project, including an outline of the radiation control methods and an overview of the proposed monitoring.

Note that the management plans will be consistent with the plans developed for Cameco's Kintyre operation (Cameco 2013).

9.6.6.1 Principles for the Management of Radiation

The overall approach by Cameco towards the management of radiation is consistent with the recommendations of the ICRP (ICRP 2003), 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 releases which may result in radiological impacts to the natural environment.

Radiation and radioactive waste will be optimally managed and controlled at Yeelirrie through good design and appropriate ongoing operational management systems. The final design detail is yet to be decided, however, the Cameco approach is to establish design criteria and minimum requirements to ensure that radiation is properly managed.

9.6.6.2 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 and developing options for control.

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.

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

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 will also be applied during operations. Radiation data will be collected via the regular monitoring program and will be examined to determine if there are ways in which radiation levels can be reasonably reduced. Where such changes can be identified, the physical project and the management measures will be adapted to incorporate these.

9.6.6.3 Radiation Control in the Mine

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

Gamma radiation levels will be relatively low in the mine, however estimates for workers spending all of their working hours for a full year on ore, are up to 8 to 9 mSv/y. However, this is highly unlikely to occur in practice due to shielding from equipment and work areas and because mine workers do not spend their full shift in locations where they are exposed to ore.

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

Worker gamma doses will be monitored and rostering and scheduling of workers will occur if necessary.

Workers will be monitored with TLD gamma monitors and direct-reading personal electronic dosimeters will be issued to workers who may be in higher exposure situations, allowing 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.

Active radon (and therefore RnDP) control in the mining areas is unlikely to be necessary during mining operations. The evidence for this is the reported doses to mine workers in the Ranger mine. The Ranger mine is deeper and contains a higher uranium grade than the proposed Yeelirrie project, and the doses are a maximum of 2.3mSv/y (see earlier in this chapter).

However, during stable atmospheric conditions (night time in winter months), RnDP concentrations 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 will be installed in the pit at times when stable atmospheric conditions 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.

9.6.6.4 Radiation Control in the Processing Facility

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

For dust, crushers and conveyor systems will be fitted with appropriate dust control measures, including dust extraction at dust generating sources, and cleaning of the exhaust air using scrubbers or bag houses. During commissioning, the area will be subject to dust monitoring, to establish exposure levels and to identify dust sources. Based on the results of monitoring, additional dust control measures may be implemented. In situations where engineering solutions cannot be found, procedures will be used (such as work permits) and as a final measure, respiratory protection will be utilised.

After crushing, water will be added to the ore to produce a slurry. At this stage spillage control becomes important and all areas will be bunded. Spilled material will be collected and pumped back to vessels or to the tailings management system as required. 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 tailings pipeline corridor will bunded, and designed to contain spillage from tailings pipeline failures. Pressure sensors will be installed on pipelines to give early warning of failure and to automatically cut-off flow to affected areas.

The uranium precipitation, drying and packing section of the plant handles a product of up to 85% uranium concentration, requiring specific radiation protection measures, particularly dust control. The technology for the safe and secure packing of uranium concentrate into drums has been used for many years at 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, and all air is scrubbed prior to release. Typically, uranium product packing scrubbers remove more than 99% of exhausted dusts and particulates.

The standard operating procedure requires all product packing workers to change into dedicated overalls prior to entry to the area, and then change when leaving the area.

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 of personnel and the total amount of time each person spends in this controlled area.

During operations, the emission of dust and radon from tailings cells will be controlled by the inherent moisture levels within the tailings. Elevated moisture levels reduce the amount of radon that is emitted because the radon is unable to escape from the pore space of the tailings particles. The moisture also prevents dusting. As the tailings itself dries and becomes competent and safe to drive on, it will be progressively covered. The dose estimates to workers and the public have been based on the conservative assumption that all cells are uncovered. This provides a worst case assessment of potential dose.

9.6.6.5 General Management Measures

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

Access Control

Access to operating areas will be controlled to ensure that only those who have been properly trained in specific radiological protection measures 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 supervised areas will include offices, laboratories and administrative areas, the hydrometallurgical plant (except for controlled areas listed below), the waste rock landforms, and the mineralised overburden stockpile.

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 (both mining areas and tailings management areas), ore handling, crushing and grinding circuit and product precipitation drying and packing areas.

To facilitate the control of people, vehicles and contamination, the operations area will be divided by fencing into 'clean' and 'potentially-contaminated' areas. Access to the potentially-contaminated area will be via a security gate.

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 into the "potentially-contaminated' areas. 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.

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 higher 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 then checked for contamination by suitably trained staff.

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.

Qualified radiation protection personnel would be employed to implement the RMP.

Induction and Training

All employees will receive an induction informing them of the hazards associated with the workplace, of which radiation is one hazard. Area inductions will provide further information on the radiation risks associated with the particular work area. For example, workers who will work in the mine will receive more detailed information on radon, radon decay products and controls. 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. This is similar to the Hazard Observation (HAZOB) reporting system, and will also contribute to the annual review of performance of the plans.

A specific radiation safety work permit system will be implemented for use before any non-routine work in a potentially high exposure situation is undertaken. This includes work such as maintenance in the product packing area, where the work permit would list all controls and instructions on radiation protection.

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 and all relevant supplementary information such as calibration records, dose conversion factors, 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.

Worker radiation monitoring records would be made available to the CEO of ARPANSA via the Australian National Radiation Dose Register (ANRDR), in accordance with confidentiality requirements.

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.

Review of Performance

Radiation monitoring 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.

Targets for the following year will be set and progress towards these targets will be monitored (at quarterly intervals).

Monitoring

An occupational and environmental radiation monitoring program would be developed and implemented. The final programs 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.

Occupational Monitoring Programme

Occupational radiation monitoring will be conducted to fulfil two major aims:

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

Table 9-61 provides an outline of a conceptual occupational monitoring program.

Table 9-61: Conceptual occupational 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.
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.
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	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	In mine during periods of very stable atmospheric conditions
	Grab sampling	Representative (audit) monitoring of work groups.

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 are not a regulated limit. An action level system requires that personnel take specified remedial action when monitoring results exceed the specified level. In some cases, the action would be a formal reporting and investigation procedure. It can also involve moving an individual from one task to another to reduce exposure. Table 9-62 provides an indication of action levels that may be set, and the remedial actions that would be required.

Table 9-62: Proposed radiation action levels

Radiation	Action Level	Actions
Gamma dose rates	5 µSv/h	Review occupancy, consider relocation if occupied, consider shielding if practicable.
Surface Contamination	4000 Bq/m^2	Immediate cleanup

Radiation	Action Level	Actions
Dust Concentrations	3 mg/m³	Identify source and suppress (e.g. water suppression, housekeeping and ventilation)
Personal electronic dosimeter	100 µSv in one week	Review tasks, review occupancy of high exposure situations, consider job rotation.
TLD - (¼ly result)	1 mSv	Investigate and identify source. Redesign workplace or tasks to reduce exposure. Shield if necessary.
RnDP Concentrations	3 µJ/m³	Limit occupancy to air conditioned cabins, require respiratory protection

Environmental Radiation Monitoring Programme

In addition to the occupational monitoring program, an environmental radiation monitoring program will be developed and implemented. The basis of the program will be the establishment of a number of environmental radiation monitoring locations (ERML's) taking into account current baseline monitoring locations. The aims of this program are to provide data for the assessment of doses to the public, to provide data for non-human biota impact assessment, 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. A conceptual plan is shown in Table 9-63.

Table 9-63: Proposed environmental radiation monitoring program

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 ERMLs
Dispersion of dust containing long-lived, alpha-emitting radionuclides	High volume samplers	Monitors will rotate between off-site ERMLs.
Dispersion of dust containing long-lived, alpha-emitting radionuclides	Dust deposition gauges	Establishment of permanent samplers at the nominated ERMLs.
Samples composited for one year then radiometrically analysed.	Groundwater sampling from monitoring bores	A network of monitoring bores will be sampled quarterly and analysed for radionuclides and other constituents.
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

Environmental Radiation Monitoring Network

A network of environmental radiation monitoring sites has been established as part of the broader environmental monitoring program.

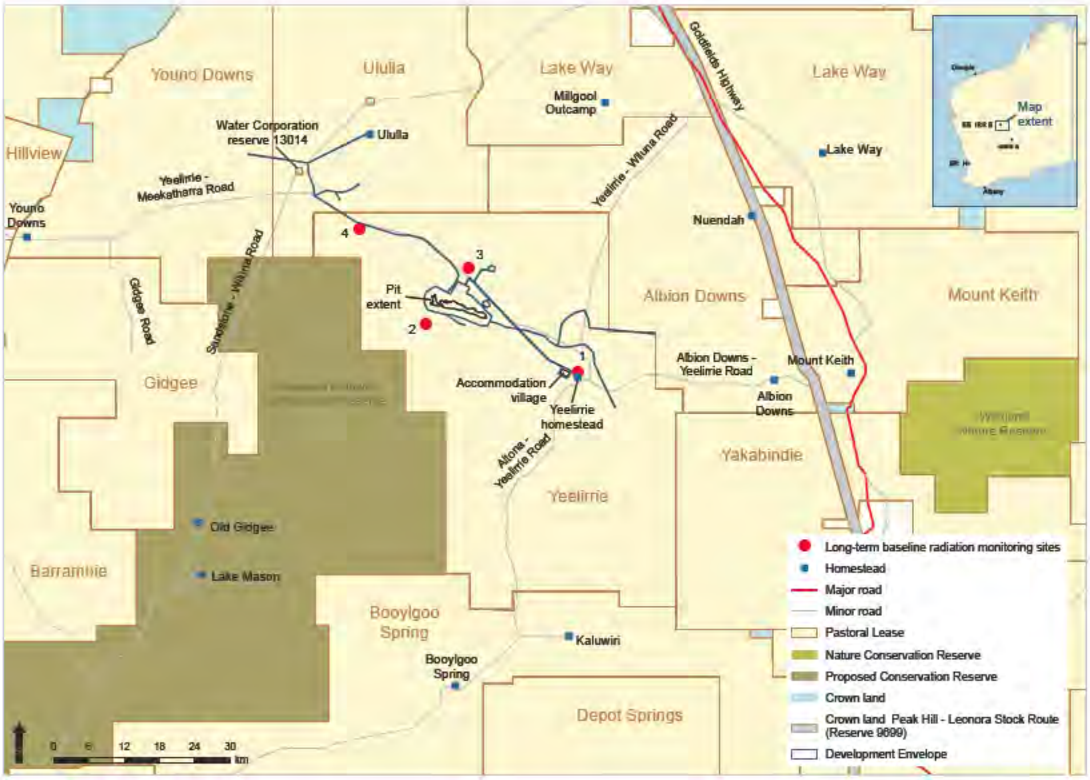

Figure 9-58: Location of longterm baseline environmental radiation monitoring sites

The four radiation monitoring sites have been installed and located based on their proximity to sensitive receptors and to provide even coverage around the orebody.

The locations of the four sites are shown on Figure 9-58. Each site consists of the following:

- Dust Deposition Gauge (set up to AS/NZS 3580.10.1:2003) - to be analysed annually for Total Solids, Insoluble Solids, Soluble Matter, Dust Weight, Gamma Spec and Mass Spec (10-12 metals);
- Environmental TLD badge - installed to measure long term average gamma doses over time; and
- Alpha-track radon gas detector (installed in protective canister to reduce exposure to heat) - installed to measure long term average radon concentration over time.

The dust deposition bottles, TLD badges and radon gas detectors will be collected and replaced on a monthly and quarterly basis (depending upon the requirements). TLD badges and the radon gas detectors will be sent to an approved laboratory for analysis on a quarterly basis.

Support Systems

The support system for the monitoring programs will 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 new equipment; and
- regular external audits of the monitoring program and system.

9.6.6.6 Radioactive Waste Management

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 670 ppm which may be blended with higher grade ore and processed or may be returned to the open pit 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.

All radioactive waste produced by the project is naturally occurring radioactive material (NORM) waste and therefore classified as low level radioactive waste. The Project would not produce any intermediate level radioactive waste streams.

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 open pit mine as part of the closure program and then capped with unmineralised waste material to minimise radiation at the surface of the rehabilitated open pit.

Tailings Management

Tailings will be disposed of into the mined out voids. 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 closure plan for the TSF is included in the Mine Closure Plan (Appendix O1).

Radionuclide assessments of tailings have been conducted and are summarised in Table 9-64. 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.

Tailings handling will be similar to other uranium mines. Tailings will be pumped from the processing plant to an empty mine cell and deposited in thin layers. The tailings discharge points will be rotated around the cell with a cycle time of several weeks, which will allow some drying but will retain the tailings in a damp state to reduce dust generation. Excess liquor will collect near the centre of the facility and will be reused in the plant or pumped to lined evaporation ponds.

The philosophy of maintaining a moist beach surface during operation is leading practice for radon emanation control from tailings storage facilities, with trials conducted at Ranger Mine showed that the radon emanation from tailings kept below the air entry point were similar to submerged tailings (Cameco, 2015, Appendix D).

Table 9-64: Radionuclide analysis of tailings

Tailings Material	Radionuclide Concentration							
	U^{238}	U^{234}	Th^{230}	Ra^{226}	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	90
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}).

During March 2010, BHP Billiton conducted drying tests on tailings samples to investigate the drying behaviour of the tailings, and in particular the 'air entry point', which indicates the moisture content at which the tailings begin to de-saturate. This is important for determining the moisture content at which the tailings should be kept to minimise radon emanation.

The results of this work will be used during operations to minimise radon emanation.

Waste Water Management

Water that has come in contact with mineralised material, such as stormwater runoff from the ore stockpile or from 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. Spillage will be collected and returned to the processing vessels or to the tailings management system.

Waste water from washdown areas and cleanup water would also be captured for treatment and evaporation.

Contaminated Material Waste Control

Material including contaminated equipment and wastes from operational areas 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 TSF during mining; or
- disposal into the mine pit at the end of operations.
- In all cases records of the disposal, including type of material, quantities and locations will be kept.

Rehabilitation and Decommissioning

A Mine Closure Plan has been developed for the Project and will be submitted to DMP for approval before commencement of operations (Section 9.12 and Appendix O1). 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 well below the member of public dose limit.

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 the open pit in an approved manner.

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.

Assessment of radon exhalation from the TSF post closure

In the Mine Closure Plan (Appendix O1), Cameco proposes to cover the completed tailings cells with at least 1 m of capillary break material and at least 2 m of growth medium. The capillary break will be constructed from compacted coarse material, likely to be calcrete and local loamy material while the growth medium will be local soils and previously stored mine overburden.

The completed cover provides an effective barrier to radon by increasing the diffusion time of radon through the cover material to the surface and then into the atmosphere. A longer diffusion time increases the chance that the radon decays within the cover material itself.

The rate of radon movement through the cover is proportional to the diffusion characteristics of the cover material and the depth of material. Canadian work (Chambers 2009) has been used to determine the rates of radon penetration through various depths of various materials. This work shows that one metre of soil reduces radon emission rates to 25% of their input rate. One metre of compacted soil is estimated to reduce radon emission rates to 16% of the original input (average of soil and compacted moist soil values). Therefore, for the proposed Yeelirrie tailings cell cover, the radon emission rates would be reduced to 1% of the radon input into the cover material. (Note that 1% is obtained by multiplying the reduction rate of each layer.)

Cameco will commit to undertaking test work during operations to accurately determine the attenuation rate of various covers.

A conservative radon emission rate of 50 Bq/m^2/s per % uranium for tailings has been used to estimate the radon emission. For an average ore grade of 1,600 ppm uranium, the radon emission rate is therefore calculated to be 8 Bq/m^2/s. Applying the reduction factor gives a covered tailings radon emission rate of 0.08 Bq/m^2/s.

Appendix O1 identifies that erosion of the in-pit TSF cover may occur at rates that exceed the natural background rates. The modelling indicates that the natural erosion rates in the region over 10,000 years are less than 0.5m over approximately 80 to 85% of the former TSF area, with the potential for gullying up to depths of 1.5m for the remain area.

Based on an initial cover of 1m of capillary break (compacted soil) and 2m of soil, the radon emission rate was reduced to less than 1% of the un covered emission rate and calculated to be approximately 0.08Bq/m^2/s (see section 9.6.6.7 of this document).

If it is assumed that 0.5m of the soil cover is eroded over all of the TSF, then the total emission rate is reduced to approximately 2% of the uncovered emission rate. To account for gullying, if it is assumed that 20% of the cover has gullies that are 1.5m deep (compared to the original depth of cover), then the total emanation rate can be calculated to be reduced to 4% of the uncovered emission rate. This gives an areas emission rate of approximately 0.3Bq/m^2/s. As noted during earlier site assessment work by the AAEC (AAEC 1978), naturally occurring radon emission rates were measured to be 3.7 Bq/m^2/s (atop the orebody) and 0.37 Bq/m^2/s (away from orebody).

During earlier site assessment work by the AAEC (AAEC 1978), naturally occurring radon emission rates were measured to be 3.7 $Bq/m^2/s$ (atop the orebody) and 0.37 $Bq/m^2/s$ (away from orebody).

9.6.6.7 Summary of Management Measures

General - Avoid and Minimise

- Cameco will develop a Radiation Management Plan and obtain approval to implement the Plan prior to commencement of the Project. Incident response planning will be included as part of the overall site Emergency Response Plan.
- Qualified radiation protection personnel would be employed to implement the management plan.
- Operations will be divided into 'clean' and 'potentially contaminated' areas. Access to controlled areas will ensure that only those who have been properly trained in radiological protection measures are admitted.
- Movement of vehicles from the potentially contaminated areas will be via a washdown bay to remove all mineralised material. Generally vehicles that are likely to be regularly in contact with higher grade uranium mineralisation will be kept within the contaminated area.
- All personnel will be appropriately trained.
- A specific radiation safety work permit system will be implemented.
- A data management system will be used to store and manage all information relating to radiation management and monitoring.
- The time spent in high dose areas by individual workers will be limited, through careful rostering and scheduling of those workers operating ore recovery equipment, backed up by detailed monitoring.
- Radiation monitoring results will be reviewed on an ongoing basis to determine the adequacy and effectiveness of engineering and management controls and reduce radiation exposures of people and the environment.
- As part of the operational ALARA program, a series of action levels would be established to ensure that radiation exposures remain controlled.

Mining

- All heavy equipment operating in the pit will have air-conditioned cabs with effective air filtration systems.
- Dust management measures will be implemented in accordance with the Dust Management Plan.

Process Plant

- Crushers and conveyor systems will be fitted with appropriate dust control measures, including dust extraction at dust generating sources.
- The process plant uses wet processing which minimises dust generation.
- All operational areas in the plant will be bunded. Spillage will be collected and returned to the processing vessels or to the tailings storage facility.

Mineralised Waste Management

- Stockpile areas will be compacted to minimise infiltration and bunded to capture potentially contaminated surface water, which will be transferred to the process plant.
- Dust management measures will be implemented in accordance with the Dust Management Plan.

Tailings Management

- Tailings will be pumped from the processing plant to the TMF in a slurry form. Tailings will be kept moist during operations to prevent dust lift off.

Waste Water Management

- Water that has come in contact with mineralised material, such as stormwater runoff from the ore stockpile or from the mineralised overburden stockpile will be captured and transferred to the process plant.
- Runoff will drain to sedimentation and evaporation ponds which will be designed to retain runoff from a 1-in-100 year 72-hour storm event. The surface water retention bund will be capable of retaining runoff within the mine area from a 1-in-1,000 year ARI event.
- Waste water from washdown areas and cleanup water would also be captured for treatment and evaporation.

General Waste

- A system of separate collection of potentially contaminated wastes from operational areas will be instituted.
- 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.

Transport

- The dried UOC product would be top-loaded into 205-litre steel drums and sealed with lids and ring-clamps. The drum-filling station would be located in an airlock that maintained negative pressure to prevent uranium entering the work areas. The outside of the drums would be subsequently washed to remove any residual product from the lids and surfaces before labelling and loading into shipping containers for transport and export.
- All consignments would have extensive safety, operational, emergency response and security arrangements in place.

Closure and Rehabilitation

- All mineralised material will be backfilled to the pit with an engineered cover (refer to Section 9.12).
- The post-closure landform will be monitored in accordance with the Mine Closure Plan (Appendix O1) to ensure that it meets surface contamination criteria.

Management Measures

- Comply with Australian standards, codes of practice and guidelines regarding human and ecological radiation exposure.

9.6.7 Commitments

- Develop and implement a Radiation Management Plan.
- Develop and implement a Transport Radiation Management Plan including an Emergency Response Plan.

9.6.8 Outcomes

Taking into account the Project design and proposed management measures to be implemented, Cameco believes that the Proposal will meet the EPA's objective with regards to Human Health (Radiation).