TORO ENERGY LIMITED

Environmental Review and Management Program

Radiation Baseline Report

FINAL Version 9.0

June, 2011

INDEX

1. Introduction

1.1 Executive summary

Toro Energy Limited (Toro) has conducted a technical review of radiological parameters associated with its proposed Wiluna Uranium Project (the Project) near Wiluna in Western Australia.

This technical report collates previous work and new work undertaken by Toro and provides:

- An overview of the international and national framework for radiation protection and dose assessment;
- An outline of the Toro's approach and systems for radiation protection;
- An overview of the naturally occurring background levels of radiation within the Project's footprint and adjacent areas, and the predicted impacts of the operations;
- An estimate of doses to workers and the public as a result of operations; and
- An assessment of doses to non-human biota.

The key findings of this review are:

- The Lake Way region is an area of naturally enhanced radiation levels due to the natural accumulation of uranium in the region. Levels are consistent with other mineralised regions in Australia and well within the range of natural variation observed around the world (UNSCEAR 2000);
- Worker doses, as a result of the operations, are calculated to be less than 5 millisieverts per year (mSv/y). Miners are expected to have the higher doses, while processing plant workers are expected to have less than 2 mSv/y, and all other workers less than 1 mSv/y (compared to the limit of 20 mSv/y);
- Public doses are expected to be less than 0.05 mSv/y (compared to the limit of 1 mSv/y) as a result of the operations. Doses to residents of Wiluna are calculated to be approximately 0.02 mS/y; and
- The risk of radiological harm to non human biota has been assessed as 'negligible'.

Overall, the impact of radiation from the proposed operations is assessed to be low.

1.2 Scope of this document

This document provides technical support for the Environmental Review and Management Program (ERMP) for Toro's proposed Wiluna Uranium Project in Western Australia.

The document addresses the following:

- The existing radiological environment;
- Assessment of the potential radiological source terms for the project;
- Estimation of the changes in environmental radiation levels as a result of the project;
- Assessment of potential exposures to workers and to members of the public living in the vicinity of the project;
- Description of the design and management controls that will ensure that all doses remain low and well controlled; and
- Assessment of exposures to non-human biota based on the approach outlined in International Commission on Radiological Protection (ICRP) publication 108 and using the ERICA tool.

Where appropriate and available, benchmarking information from other proposed or existing uranium mines is provided.

1.3 Historical data

Radiation assessments have been undertaken on the Lake Way and Centipede deposits during a period of almost 30 years by a number of different companies. Assessments have been both investigative (for impact assessments) and routine (radiation management during exploration or pre-mining activities). A summary of the radiation monitoring undertaken during these periods will be presented where appropriate in the discussion on existing background radiation.

Toro will primarily use the more recent monitoring results for the assessment with the earlier data used for support.

1.4 Principles of radiation protection

1.4.1 The International Commission on Radiological Protection

Toro bases its radiation protection philosophy and approach on the internationally-accepted recommendations of the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA) (ICRP 2007, IAEA 1996) which have been adopted in Australia, either through state-based legislation or through the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) series of radiation related Codes of Practices.

The ICRP is recognised as the pre-eminent international authority on radiation protection and has recommended a 'system of dose limitation' that has been widely adopted overseas and in Australia. The system has three key elements:

- Justification – a practice involving exposure to radiation should only be adopted if the benefits of the practice outweigh the risks associated with the radiation exposure;
- Optimisation – radiation doses received should be as low as reasonably achievable, taking into account economic and social factors (the ALARA principle); and
- Limitation – individuals should not receive radiation doses greater than the recommended limits.

Optimisation is generally considered to be the most effective means of radiological control.

1.4.2 Radiation dose limits

Radiation limits are expressed in terms of the 'effective dose' measured in Sieverts (Sv). Occupational doses in mining are in the range of millisieverts (mSv = one-thousandth of a Sievert) and the primary radiation protection limits are:

- Annual limit to a worker of 20mSv/y
- Annual limit to a member of the public of 1mSv/y

Occupational doses may be averaged over a five-year period when assessing compliance with the limits and exclude radiation from natural background sources. There is an absolute annual limit of 50mSv/y for workers.

1.4.3 Radiation standards

The primary national standards in Australia related to uranium production are:

- Recommendations for limiting exposure to ionising radiation (ARPANSA 1995/2002)
- The Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing 2005 (ARPANSA 2005)
- The Code of Practice for the Safe Transport of Radioactive Material 2008 (ARPANSA 2008)

These codes are adopted in all State and Territory jurisdictions in Australia and are consistent with the recommendations of the ICRP (1991, 2007) and the International Atomic Energy Agency (IAEA) 1996 Basic Safety Standard.

In Western Australia, a guideline for 'managing naturally occurring radioactive material (NORM) in mining and mineral processing' (known as the NORM guidelines) has been issued by Department of Mines and Petroleum. The documents provide guidance on the radiological protection for the mining and processing of uranium. Toro's approach to radiation protection is consistent with the NORM guidelines and specific aspects will be addressed in Toro's final Radiation Management Plan (RMP) and the Radioactive Waste Management Plan (RWMP).

1.5 Approach to radiation assessment

Assessment of the radiological impact of the proposed operation will focus on workers, members of the public and the environment. The member of the public assessment will consider critical groups at key receptor locations (Figure 1) as follows:

- Wiluna Township;
- Bondini Reserve;
- Nganganawili Community;
- Millbillillie Station;
- Lake Way Station;
- Apex Village;
- Toro's Construction Camp; and

- Toro's Operations Camp.

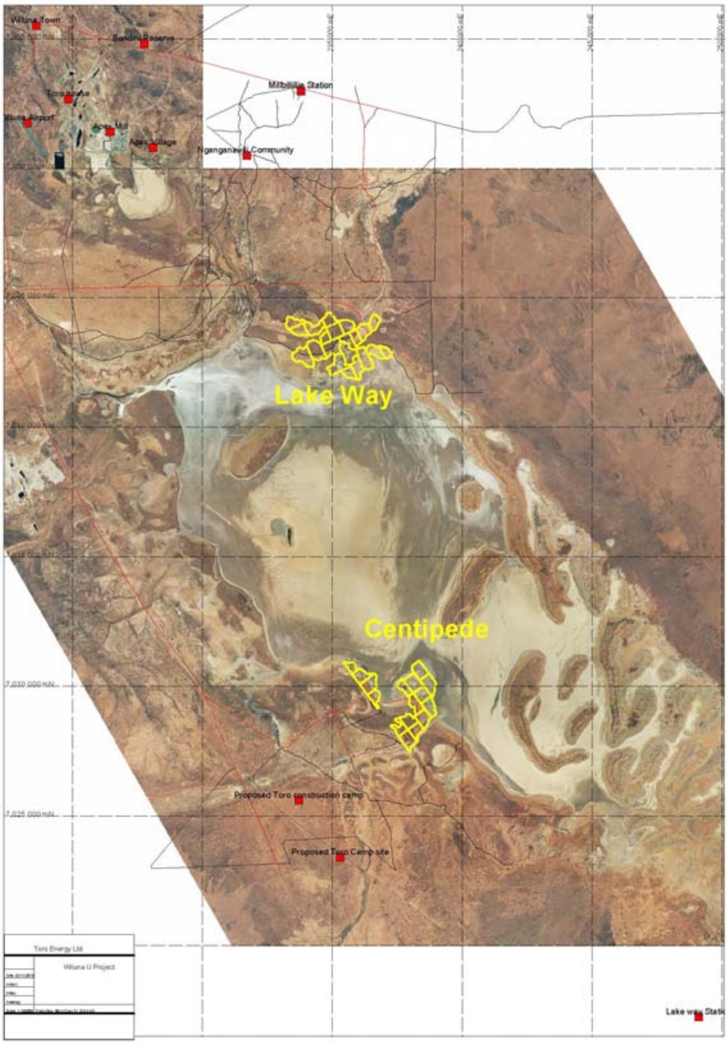

Figure 1: Location of critical groups

Radiological impact assessments incorporate an analysis of radiation exposure pathways (the ways that radiation enters the environment, or the ways that people may be exposed to radiation).

The main human radiation exposure pathways considered in this assessment are:

- irradiation by gamma radiation;
- inhalation of decay products of radon;
- inhalation of radionuclides in airborne dust; and
- ingestion of radionuclides.

To assess exposures from each of these pathways, the following radiological parameters are considered:

- gamma radiation;
- radon emanation from the soils;
- radon and radon decay products in air;
- radionuclides in dust;
- radionuclides in surface and ground water; and
- radionuclides in soils and flora and fauna.

2. Existing radiation environment

2.1 Introduction

This section provides a description of the existing radiation levels in the vicinity of the proposed mine and infrastructure facilities. This has been done by:

- assessing the recent baseline monitoring undertaken by Toro in 2009 and 2010; and
- considering radiation monitoring undertaken over a period of almost 30 years up until 2008.

A detailed assessment of the natural radiation background of the region is provided in this section and a general summary is as follows:

- Gamma radiation levels which are consistent with dose rates typically seen throughout Australia. Gamma concentrations peak in certain areas due to the natural accumulation of uranium.
- Highly variable atmospheric radon decay product concentrations depend upon atmospheric conditions, location and time of day.
- Elevated concentrations of airborne radionuclides.
- Radionuclide concentrations in flora, fauna, water and soil that are consistent with concentrations observed across Australia.

2.2 Previous radiation studies

Previous radiation studies undertaken in the Lake Way region include:

- Investigative studies for the 1981 Draft Environmental Impact Statement (DEIS 1981);
- Trial pit surveys (1985);
- Routine monitoring during exploration and site activities (2006/2007);
- Investigative baseline work (2009); and
- Recent investigative studies for the purpose of this ERMP (2010).

The types of radiation measurements undertaken in these studies are shown in Table 2. The earlier monitoring results are used for comparison purposes.

Table 2: Overview of previous monitoring

Radiation	Monitoring campaign				
	1981 DEIS	**1985**	**2006/7**	**2009**	**2010**
Gamma radiation	N	Y	Y	Y	Y
Ambient radon gas concentrations in air (real time or active)	N	N	N	N	Y
Ambient radon gas concentrations in air (passive)	N	N	N	Y	Y
Radon emanation	Y	N	N	N	Y
Radon decay product concentrations in air (spot and real time or continuous)	Y	N	N	N	Y
Radionuclides in soils	Y	N	Y	N	Y
Radionuclides in water	Y	N	Y	N	Y
Radionuclides in fauna	Y	N	N	N	Y
Radionuclides in flora	Y	N	N	N	Y
Radionuclides in dust	Y	N	Y	Y	Y

2.3 Gamma radiation

2.3.1 Introduction

Gamma radiation levels vary widely across Australia, with dose rates typically in the order of 0.1 microSieverts per hour (μSv/h). The levels of gamma radiation primarily depend on the levels of natural radionuclides in soil, including radionuclides from the U^{238}, Th^{232} and K^{40} decay chains.

Naturally occurring elevated concentrations of uranium or thorium result in higher levels of gamma radiation, as seen in the Lake Way region.

2.3.2 Gamma at Lake Way and Centipede

Gamma radiation levels in the broader region from 2006 are presented in Figure 2 and Figure 3. Blue dots refer to locations of actual measurements and contour lines refer to inferred contour gamma levels.

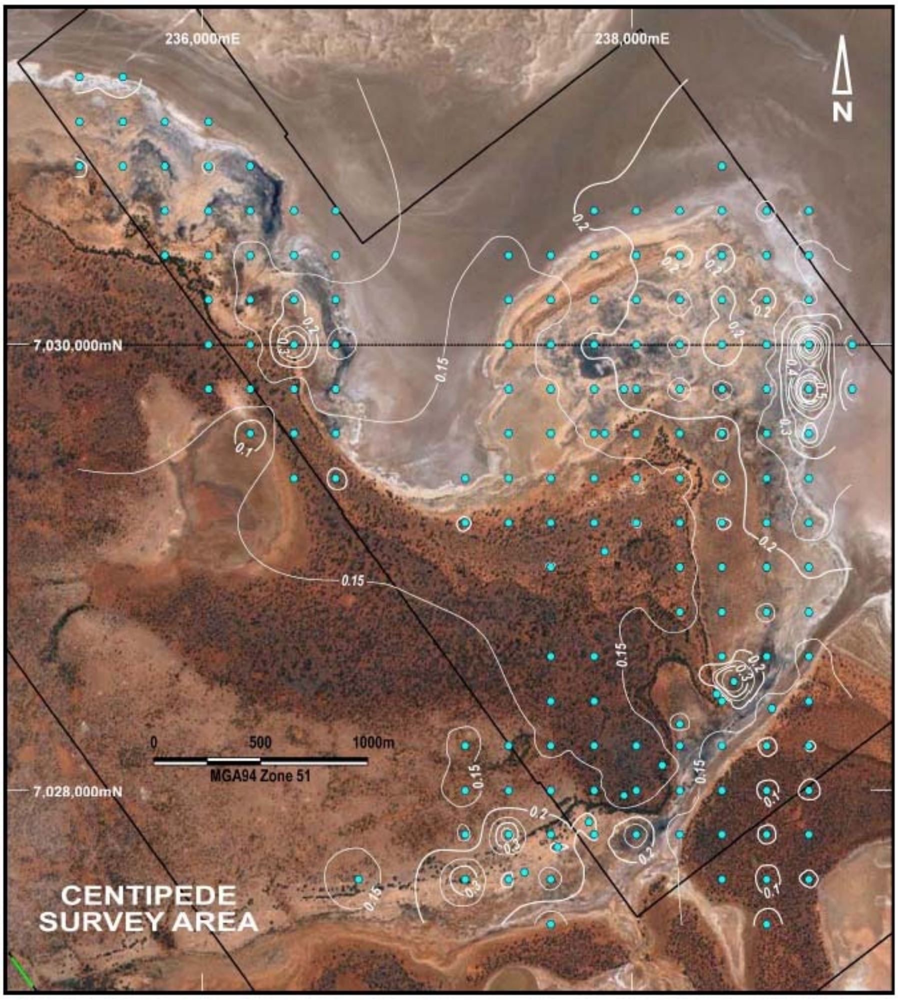

Figure 2: Centipede Gamma Survey

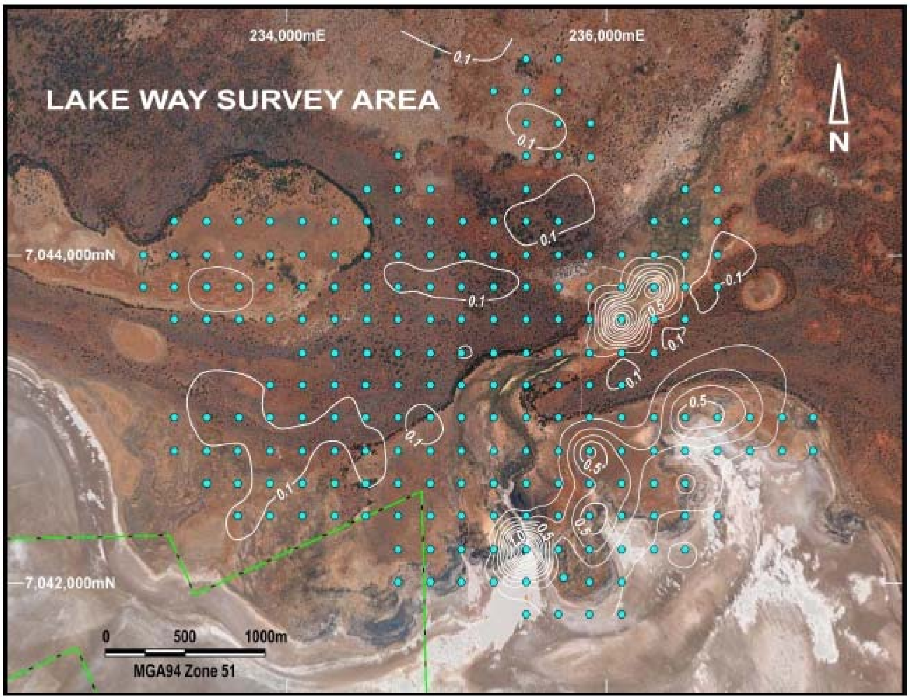

Figure 3: Lake Way Gamma Survey

Sampling undertaken in 2006 using hand-held meters shows gamma dose rates ranging from 0.07 - 0.86µSv/h, with an average of 0.17µSv/h. As expected, the higher dose rates were found in areas over the mineralised zone of the proposed mine. Gamma levels in the sand dunes were generally noted as about 0.1µSv/h, which are consistent with the natural background levels observed elsewhere in Australia.

During 2007, time integrating thermo luminescent dosimeters (TLDs) were placed in various locations for a period of three months, resulting in an average of 0.11µSv/h (range 0.10 - 0.16µSv/h). A second set of TLD monitors were deployed for a six-month period in 2008 giving a range of 0.10 - 0.30µSv/h. A third set of TLD monitors were deployed for another six-month period at the end of 2008 including the beginning of 2009, giving a range of 0.05 - 0.11µSv/h. The results, taken at different locations, show the regional variability in gamma radiation levels.

In 2010, Toro conducted an aerial radiometric survey of the region. The survey was conducted by an aircraft which flew along transects at low heights, measuring gamma radiation at regular intervals of approximately 100 metres with a highly sensitive detector. The detector measures the gamma from the naturally occurring decay chains of uranium 238, thorium 232 and potassium 40 at an inferred height of 1-metre from the ground, approximately every 100 meters.

Figure 4 and Figure 5 provide a graphical representation of the results of the aerial survey. Figure 4 shows the broader region including the two deposits which can be seen at Lake Way and Centipede. Figure 5 provides a more detailed view of the gamma radiation in the vicinity of the Centipede deposit where the processing plant and the camps are anticipated be located. The colours represent the measured gamma radiation levels with blue representing levels from 0 to 0.1µSv/h, yellow representing levels from 0.2 to 0.4µSv/h, and red representing levels from 0.5µSv/h and above.

A high level comparison between aerial results and hand-held monitor results was conducted. Care should be taken when comparing the results of hand-held and aerial monitoring as measuring techniques and measurement geometry are different. (For example, the aerial results average over a much wider area than the hand-held results). However, a broad comparison was made in which hand-held monitoring results (where available) were averaged over areas similar to the areas monitored by the aerial results. For particular ranges of results, the figures were averaged and compared (see Table 3).

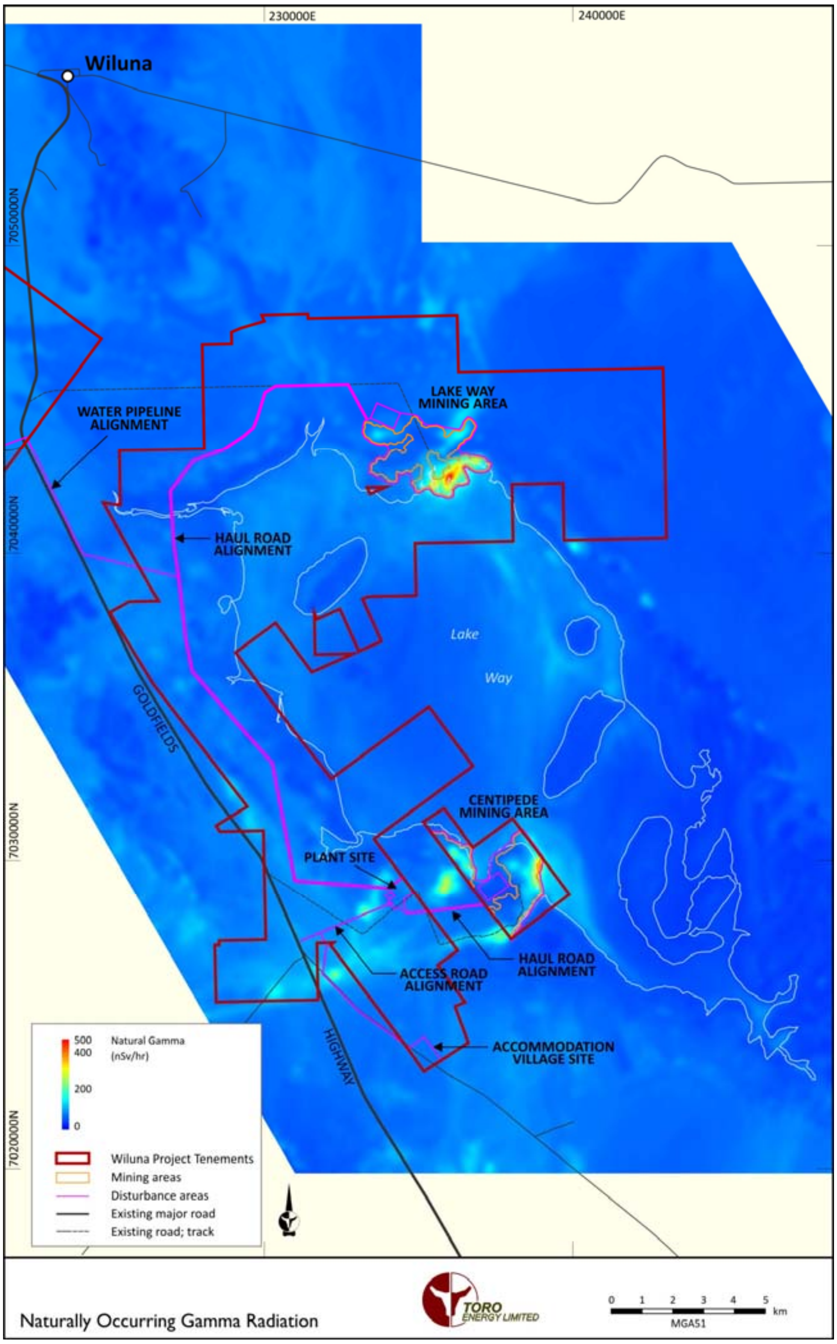

Figure 4: Aerial Gamma Survey of Region

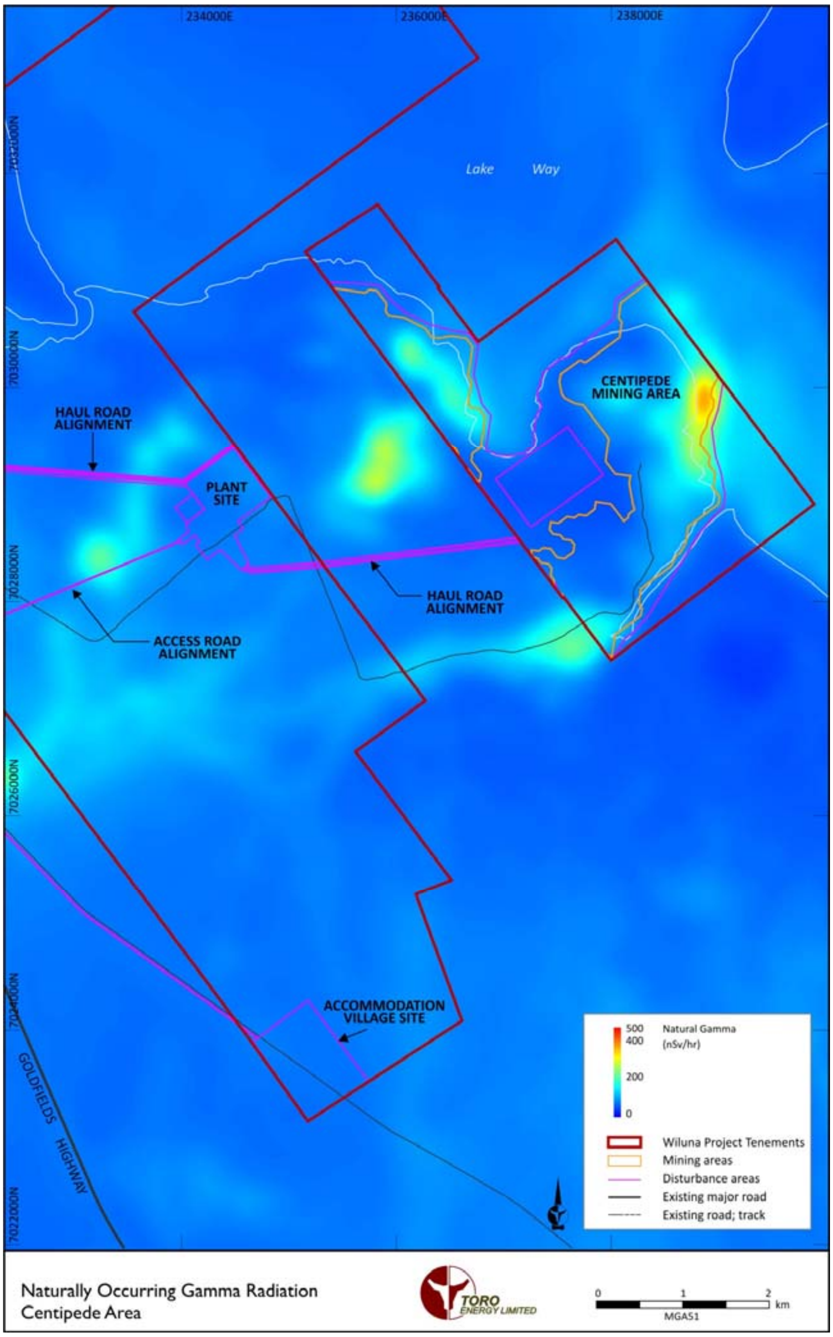

Figure 5: Aerial Gamma Survey of Centipede Region (showing location of plant and camps)

Table 3: Comparison of Aerial Gamma Levels and Handheld Monitoring (range referenced to aerial results)

Gamma Range (nSv/h)	Average Aerial Results (nSv/h)	Average Measured Results (nSv/h)
60 - 80	69	67
80 - 100	89	86
> 100	136	142

- Please note that the units in the table above are in nanoSieverts per hour (nSv/h). 1 nanoSievert per hour (nSv/h) = 0.001 microSieverts per hour (µSv/h).

2.3.3 Comparison of gamma radiation levels from other areas

The background levels from the Lake Way and Centipede areas show localised elevated gamma radiation levels above mineralised areas which would be expected. Table 4 provides an example of gamma dose rates at other locations across Australia.

Table 4: Typical gamma radiation levels across Australia

Region	Gamma levels (µSv/h)	Source
Central South Australia	0.1	BHP Billiton 2009
Australian average	0.07	Inferred from ARPANSA 2005
Rehabilitated Kalgoorlie Research Plant	0.07 – 0.18	DMP 2010
Typical for Australia	0.02 – 0.1	Mudd 2002
Honeymoon Uranium Mine (South Australia)	0.1	Honeymoon EIS 2006

2.3.4 Summary of gamma

Naturally occurring gamma radiation dose rates directly above the Lake Way and Centipede ore-bodies show that gamma dose rates range up to 0.9µSv/h. Away from the mineralised areas, gamma dose rates are in the range of up to 0.1µSv/h which is consistent with levels found elsewhere in Australia.

2.4 Radionuclide levels in airborne dust

2.4.1 Introduction

Sampling of radionuclides in airborne dust can be performed using active dust sampling and passive dust sampling.

2.4.1.1 Active Dust Sampling

Active dust sampling involves drawing ambient air through filter papers and analysing the material that is deposited on the filter paper. Generally high volume air sampling is used for environmental dust because the concentration of dust in air is usually very low and low volume dust sampling dose not collect sufficient samples for accurate analysis. High volume dust sampling requires a reliable power supply, so lower volume samplers, which are not reliant on fixed power supplies, are also used for dust sampling. The disadvantage of lower volume samplers is that the volume of air sampled is much smaller and therefore quantities of materials collected are much less.

2.4.1.2 Passive Dust Sampling

Passive dust sampling is a method for collecting dust that settles from the air or windblown dust that impacts the collection media. The standard sampling method includes a collection mechanism, usually an elevated jar and funnel. Material from the atmosphere deposits in the jar and after a predetermined time (usually months) the collected material is analysed for radionuclides and other materials. The results provide an indication of airborne particulates that are settling out of the atmosphere and depositing in the environment.

There is generally no direct relationship between active dust monitoring results and passive dust monitoring results. However, both methods provide different information that gives a broader picture of atmospheric dust.

2.4.2 Dust Monitoring Results

In 2010, Toro conducted a program of active and passive dust sampling to characterise the naturally occurring dust levels and radionuclide concentrations in airborne particulates. A previous program of active and passive dust sampling was conducted in 2006. Figure 6 shows the location of all dust samples (including passive dust monitors, low volume samplers and high volume samplers).

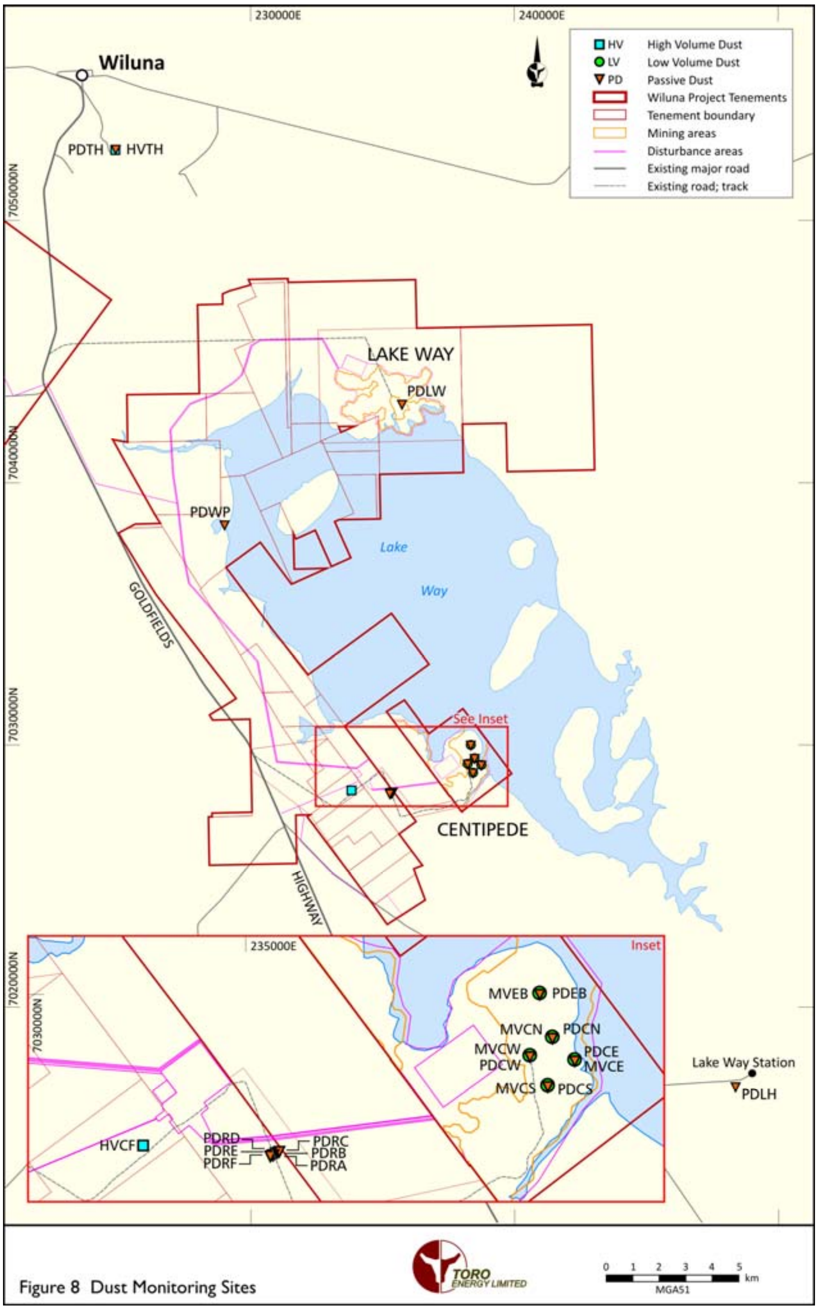

Figure 6: Location of dust monitoring sites

High volume air sampling could not be conducted during the 2010 sampling period due to power supply limitations. Consequently, active airborne dust sampling has been predominantly based on low volume dust sampling (microvols), which can be used to provide both mass concentration and total alpha concentration in the sampled air. However, sampling was conducted during August, September and October of 2010 and summarised results are in Table 5.

Table 5: Summary of low volume dust sampling 2010 – (averaged over complete sampling period)

Location	**Average dust concentration ($\mu g/m^3$)**	**Average activity concentration ($\mu\alpha dps/m^3$)**
~100m east of mining area	7	45
~100m north of mining area	12	33
~100m south of mining area	6	43
~100m west of mining area	34	75
South of East Bore	4	26

(Note that the unit $\mu\alpha dps/m^3$ refers to micro alpha disintegrations per second per cubic metre and is a measure of the gross alpha radiation activity in the air.)

The high volume sampling was conducted in September, October and November of 2010 and results are detailed below in Table 6.

Table 6: Active (high volume) Dust Sampling 2010

Location	**Run Time**	**Radionuclide Concentration ($\mu Bq/m^3$)**				
		U^{238}	**Th^{230}**	**Ra^{226}**	**Pb^{210}**	**Th^{228}**
Centipede Site	14/9/2010 – 27/10/2010	23	<150	11.8	690	4
Toro Wiluna House	28/10/2010 – 26/11/2010	13	<170	7.5	670	6

Note that the limit of detection for Th^{230} is due the small amounts of sample collected and the analytical techniques. It would be expected that the actual concentrations of Th^{230}

would be similar to the other long-lived alpha emitters (uranium or radium) as there is no mechanism to cause the thorium to concentrate in the dust naturally.

Passive dust sampling measures dusts that deposit from the air and the results can be seen in Table 7.

Table 7: Passive dust sampling - June 2010

Location	U (as U^{238}) Bq/m²/month	Th (as Th^{232}) Bq/m²/month	Gross Alpha Bq/m²/month	Gross Beta Bq/m²/month	Ra226 Bq/m²/month
~100m east of mining area	0.1	< 0.1	0.5	1.3	<1
~100m north of mining area	0.1	< 0.1	0.9	0.6	<1
~100m south of mining area	0.1	< 0.1	0.4	1.8	<1
~100m west of mining area	0.1	< 0.1	1.1	1.2	<1
South of East Bore	0.1	< 0.1	0.5	1.2	<1

2.4.3 Other dust monitoring results

During 2007 and 2008 Nova Energy Limited (Nova) conducted real-time dust monitoring (of PM_{10^*} dust) in the region using a Tapered Element Oscillating Microbalance (TEOM). Summarised results are provided in Table 8. (*Particulate matter less than 10 microns).

Table 8: Monthly dust measurements (TEOM-PM_{10})

Dates	Dust concentration µg/m³	
	Average	Max
Sept 2007	10.4	112
Oct 2007	12.8	346
Nov 2007	12.4	448
Dec 2007	12.8	351
Jan 2008	21.2	1367
Feb 2008	11.9	186
Mar 2008	17.6	728

2.4.4 Comparison with other results

Pre-operational airborne dust concentrations from two other mines are provided in Table 9.

Table 9: Dust Concentration results from other uranium operations in Australia

Operation	Concentrations	Source
Olympic Dam	20µg/m^3	WMC 1982
Honeymoon	15µg/m^3	Honeymoon EIS

UNSCEAR 2000 states world averages are as follows according to the available world data (ranges in brackets):

- U^{238} 1 (0.02 – 18) µBq/m^3
- Th^{230} 0.5 (0.02 – 1.7) µBq/m^3
- Ra^{226} 1 (0.8 – 32) µBq/m^3
- Pb^{210} 500 (<40 – 2250) µBq/m^3
- Po^{210} 0 (10 – 80) µBq/m^3

(The UNSCEAR values are based on an assumed mass concentration of dust in the air and an average concentration of radionuclides in the soil).

2.4.5 Summary of airborne dust results

Results of limited high volume sampling show that radionuclides in air in the region are elevated compared to world averages. This is to be expected given the presence of the shallow uranium ore in the area.

2.5 Environmental radon concentrations in air

2.5.1 Introduction

Radon is a naturally occurring inert gas that is ubiquitous in the atmosphere and has a half-life of 3.8 days. It is produced from the decay of Radium226 (Ra^{226}) which is naturally present in soils, rocks and water and makes its way into the atmosphere through diffusion. Where there are areas of naturally higher Ra^{226} concentrations, such as granite geological features or near surface higher concentrations of uranium, there are correspondingly higher concentrations of radon.

Average concentrations of radon in the atmosphere vary depending upon a wide range of factors including temperature, moisture, weather and the geology of the region. Typically concentrations can vary between 1 and 100 Bq/m^3 peaking at up to $1000Bq/m^3$ and the worldwide average is reported as $10Bq/m^3$ (UNSCEAR 2000).

The concentration of radon in the air depends on the amount of radon being released into the air from the surface (emanation rate), and the amount of atmospheric mixing. The emanation rate is determined by the radium content of the soil which determines the amount of radon being produced, and the porosity of the soil which determines the amount of radon that can diffuse into the atmosphere before decaying. The effective soil porosity can be altered by the moisture content and so this may also influence radon emanation. Radon has a half-life of 3.8 days, and so it can travel hundreds of kilometres before decaying. Atmospheric radon can therefore be influenced by emanation over a wide area.

Under normal daytime conditions, the atmosphere is generally well-mixed. However, on calm nights, temperature inversions may form close to the ground, and any radon emanating from the soil may be contained near the surface. In these conditions the radon concentration can increase rapidly to levels more than one-hundred times the normal daytime concentration.

2.5.2 Radon concentrations in the Lake Way region

Radon concentrations have been monitored in the Lake Way region on occasion since the early 1980's. The main methods used for measuring radon are as follows:

- Grab Sampling
  - Grab sampling such as Lucas Cells, the two filter tube method or 'radon sniffers' provide an instantaneous measurement of radon.
- Continuous Monitoring
  - Active powered monitoring devices can either measure radon concentrations in real-time, or averaged over an extended period. Real-time monitors provide information on the natural variation that can occur in radon concentrations due to atmospheric conditions.
  - Passive track etch devices provide a measure of the long term average radon concentrations.

An example of results from both grab and continuous sampling can be seen in Figure 7, which shows monitoring results from 1979.

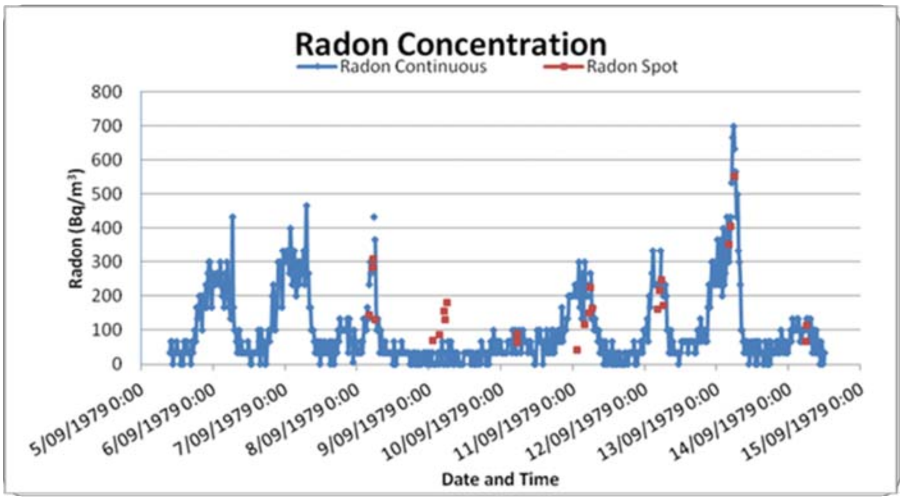

Figure 7: Example of Radon concentration variation with time (Lake Way Joint Venture Appendix 4 – Radon Emanations, Australian Atomic Energy Commission Report (AAEC 1979)

Previous radon concentration monitoring in the Lake Way region has been undertaken and is summarised in Table 10. See also Appendix F for more detail on historical data.

Table 10: Summary of radon concentration measurements in the Lake Way region

Date	Location	Sampling period	Average Radon Concentration (Bq/m^3)	Comment
Sept 1979	Mine Site	0000 - 0800	180	Real time sampling by Australian Atomic Energy Commission in 1979 Note that resolution of monitoring equipment was limited. (Note that time scales as reported by AAEC)
		0800 - 1700	45	
		1700 - 2400	97	
		24 hour average	101	
	Near Mine Site	24 hour average	75	
	Off Mine Site	24 hour average	101	
Aug 2007 – Mar 2009	Regional	Total Average	21	Average of all track etch detectors
	Mine Site		38	

The AAEC (1979) monitoring concluded that radon concentrations in the Lake Way region were naturally high due to two main factors:

- Higher radon emanation due to the area being a “broadly distributed source of radon” due to the near surface uranium deposits; and
- The relatively stable atmospheric conditions that occur (particularly at night) causing radon concentrations to build up.

Toro conducted additional monitoring in 2010 to provide further detail on the naturally occurring background radon concentrations in the region. Details of this work are in Appendix G.

The 2010 results show that radon concentrations vary diurnally as observed in the earlier AAEC results. Under stable atmospheric conditions (at night), hourly average radon concentrations can increase by up to an order of magnitude (see Figure 8) and peak readings can be more than two orders of magnitude higher than the lowest figures.

The average radon concentration for the sampling period (in November 2010) was 27Bq/m^3. This is low compared to the AAEC results but consistent with the track etch results.

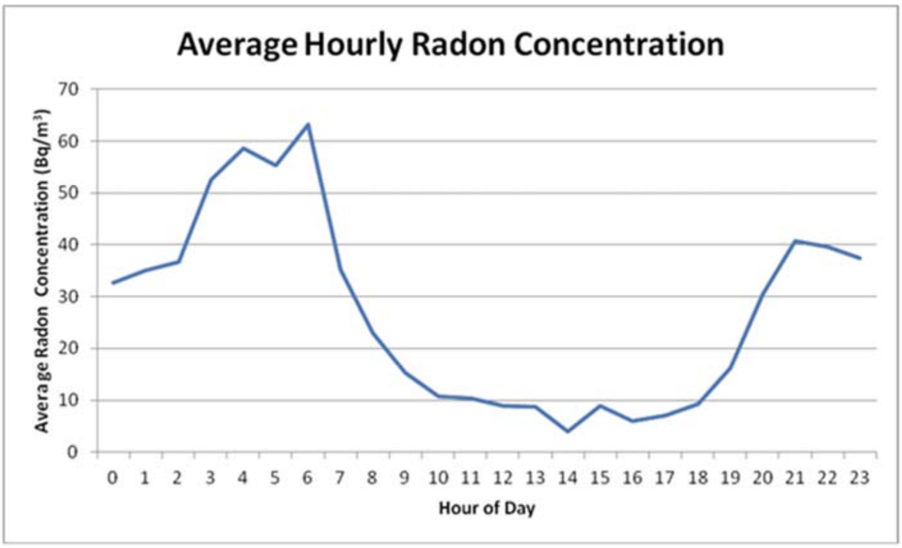

Figure 8: Average hourly radon concentrations during November 2010 sampling period at Lake Way

2.5.3 Comparison of radon levels elsewhere

The results of the 2010 radon monitoring are consistent with results from radon monitoring at other uranium mines in Australia as shown in Table 11.

Table 11: Radon concentrations in Australian uranium mining regions

Location	Reported Radon Concentrations Bq/m^3	Year of report
Lake Way	27	This report
Beverly	36	2003
Honeymoon	28	2003
Olympic Dam	20	2008

2.5.4 Radon Emanation

Radon emanation provides an indication of the source of radon into the atmosphere. In 1979, the AAEC conducted test work in the region and the results are in Table 12 with more details in Appendix F.

Table 12: Radon Emanation

Location	Radon Emanation Rate (Bq/m^2s)
Regional (>3km from mine area)	0.04
Outer region of mine (2-3km from mine area)	0.14
Inner mine area (within 2km of mine	0.30

Radon emissions from the proposed operations were also predicted in the AAEC work as outlined in Appendix F. The results of this work are discussed in Section 3 and are compared to more recent estimates of radon emissions.

In 2010, Toro undertook additional sampling to determine the amount of radon emanating from different materials in the region, including soils and ores. Results are in Table 13.

Table 13: Radon Emanation Test-work

Material	Measured Emanation Rate ($Bq/m^2.s$)	Calculated Uranium Grade (ppm)
Unmineralised Calcrete	0.1	40
Unmineralised Soil	0.1	30
Clay	0.3	544
Ore Sample 1	0.2	268
Ore Sample 2	0.6	745

2.5.5 Summary of Radon Concentrations

The Lake Way and Centipede region is an area of enhanced radon emanation due to the near surface uranium deposit. Stable atmospheric conditions (particularly at night) lead to a build up of radon concentrations, with peak levels up to two to three orders of magnitude higher than the average range encountered during the day.

Radon concentrations from the region ($27Bq/m^3$) are similar to levels measured at other uranium mines and higher than the UNSCEAR 2000 world average of $10Bq/m^3$.

2.6 Radon Decay Product Concentrations

2.6.1 Introduction

Radon decay products (RDP) are formed from the decay of radon.

The effective dose from radon itself is very small and radon primarily acts as a transport mechanism for the RDPs. Radon emanates from material and, being a gas, can move with the air if it reaches air. It is radioactive turning into the short-lived isotopes (see Figure 9) which are solid particles that, if inhaled, can deliver radiation dose to the lungs.

	Rn^{222}	½ life
α decay	↓	3.8 Days
	Po^{218}	
α decay	↓	3.10 minutes
	Pb^{214}	
β decay	↓	26.8 minutes
	Bi^{214}	
β γ decay	↓	19.9 minutes
	Po^{214}	
α decay	↓	0.16ms
	Pb^{210}	22.3 years

Figure 9: RDP Decay Chain

RDP concentrations in the Lake Way region have been measured using two different methods. Grab samples have been taken as part of the existing radiation monitoring program and also during regular monitoring. More recently, active real-time RDP monitors have been used to determine the RDP concentrations.

RDP concentrations depend on the radon concentrations. Using real-time monitoring equipment, Figure 10 shows the typical correlation between radon and RDP levels. RDP (like radon concentrations) are also directly affected by atmospheric conditions.

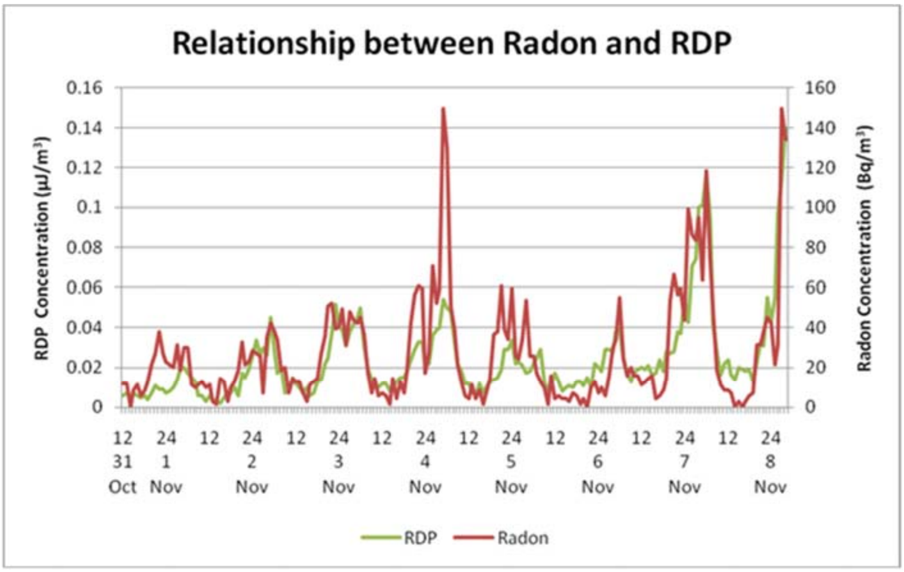

Figure 10: Typical Relationship between RDP and Radon (Centipede Site November 2010)

2.6.2 Earlier RDP Measurements

RDP concentration monitoring in the Lake Way region was undertaken in 1979 and is summarised in Table 15 (see also Appendix F for further detail on historical data).

Table 15: Summary of RDP concentration measurements (historical)

Date	Location	Sampling Period	Average RDP Concentration (µJ/m³)
Sept 1979	Mine Site	0000 - 0800	0.347
		0800 - 1700	0.033
		1700 - 2400	0.119
		24-hour average	0.148
	Off mine site (north)	24-hour average	0.029
	Off mine site (east)	24-hour average	0.054

2.6.3 Recent RDP Measurements

Toro Energy has been using real-time monitoring equipment to characterise RDP concentrations at the Centipede deposit. The sampling program used an environmental radon decay monitor (ERDM) (provided by Radiation Detection Systems) real-time monitor which takes hourly samples. Results can be seen in Appendix G.

The results show diurnal variation due to the effects of the stable atmospheric conditions at night with RDP concentrations peaking at almost ten times the average daily concentrations. Figure 11 is a plot of the typical results at August 2010 which shows the regular diurnal variation that occurs and the magnitude of that variation. Figure 12 shows average RDP concentrations by month. Averages are provided for whole of month, during day time only and during night time only. The results show that on average RDP concentrations are approximately 0.02 – 0.03µJ/m³.

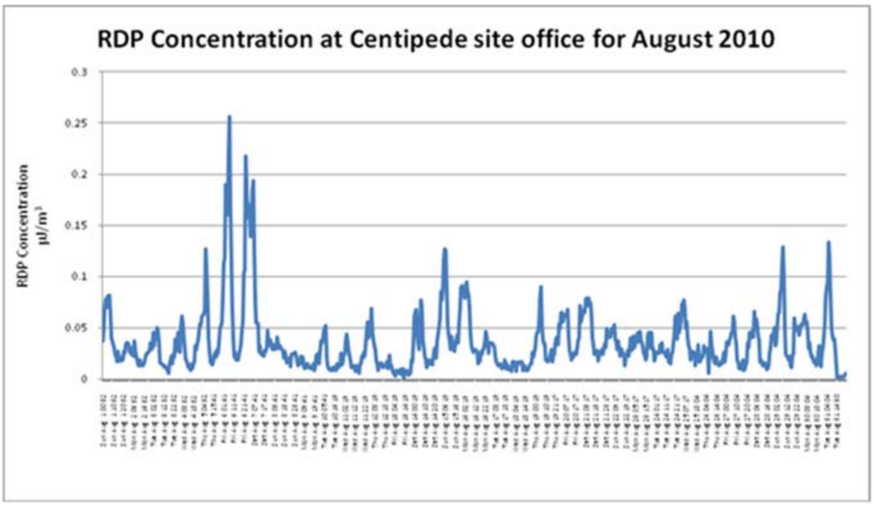

Figure 11: Real Time RDP Concentrations (Centipede site for August 2010)

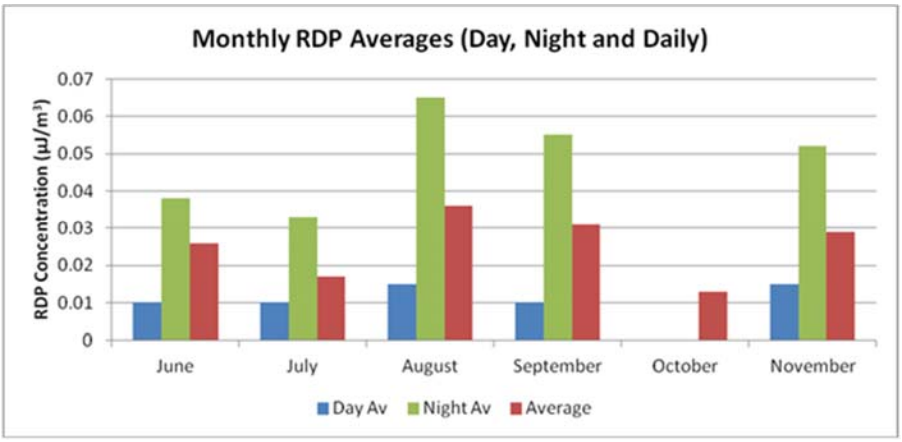

Figure 12: Monthly Average RDP Concentrations (including day and night time averages)

2.6.4 Summary of RDP Concentrations

Real-time RDP monitoring was undertaken during the colder months of the year, when stable atmospheric conditions are common. These conditions usually result in elevated concentrations of radon and RDP and therefore, could be considered worst case RDP conditions. RDP concentrations in the region are naturally elevated due to the uranium-rich nature of the region. Typical average concentrations are 0.02 - 0.03µJ/m^3 and can peak at up to 10 times this level during night time inversion conditions.

2.7 Radionuclides Concentrations in Water

2.7.1 Introduction

The Lake Way region is a natural deposition basin for surface and groundwater for an area of over several thousand square kilometres (RPS Aquaterra 2010). Water flow in the region is generally episodic dependent upon sufficient rainfall leading to water flows and the filling (or potential filling) of the dominant water bearing feature of the region. Groundwater and opportunistic surface water sampling has been conducted in the region to determine the pre-existing radionuclide concentrations.

It should be noted that the existing groundwater near the ore bodies is unsuitable for human or stock consumption due to salinity levels. Therefore, it is unlikely that any of the water would be consumed, and there is no pathway for potential exposure.

2.7.2 Radionuclides in Groundwater

Radiological monitoring of groundwater occurred in 1981, 2009 and 2010 and is summarised in Table 16.

Table 16: Radionuclides in Groundwater

Date	Location	Ra^{226} (Bq/L)		U^{238} (Bq/L)	
		Range	Average	Range	Average
1981	Ore Zone	0.2 – 6.3	1.7	0.35 – 1.36	7.81
2009	Production Bores	5.6-7.7	6.4		
2009	Production Bores			0.62 – 42.16	2.36
2009	Regional Bores			0.06 – 1.18	
2010	Production Bores			0.25 – 1.86	0.87
2010	Production Bores			0.11 – 1.45	0.77

2.7.3 Radionuclides in Surface Water

The presence of natural surface water in the region is dependent upon rainfall and water flows into the lake system. Permanent water holes rarely exist naturally in the region, although after rains, standing surface water is present.

In 2010, surface water sampling was conducted around the margins of Lake Way. Five samples were collected and sent for metals analysis. Four samples were from remote areas of the main ore bodies, while one sample was from an area impacted by the trial mining.

The results from the remote areas show U^{238} concentrations ranging between <0.01 Bq/L and 0.07 Bq/L (average of 0.05 Bq/L). For the project impacted sample, the U^{238} concentration was 2.3 Bq/L.

In December 2010, a rainwater sample was collected from the lakebed near the Centipede deposit following a rainfall event and sent for analysis of the long-lived radionuclides. The results were as follows;

U238	1.18 Bq/L (equivalent to 83 ug/L)
Th230	0.05 Bq/L
Ra226	0.45 Bq/l
Po210	0.28 Bq/l
Pb210	0.59 Bq/l

2.8 Radionuclide Levels in Soils

2.8.1 Introduction

Monitoring of radionuclides in soils in the region has been undertaken on a number of occasions. Two radionuclides in soil sampling programm were undertaken in 2010, and earlier sampling was undertaken for the 1981 DEIS and in 2007.

Radionuclide concentrations in the region soils in the mineralised areas are elevated in comparison to concentrations outside of the mineralised areas. In general, radionuclide levels across the region are also elevated in comparison to world averages (UNSCEAR 2000) as lake systems are areas of natural deposition.

2.8.2 Historical Monitoring Results

Radionuclide in soil monitoring from 1981 and 2007 have been summarised in Table 18. The results show the impact of the mineralisation with Ra^{226} concentrations being three to four times higher, on average, from soils within the mineralised area. Uranium concentrations are also elevated in the mineralised area, although uranium was only analysed in the 1981 results.

Table 18: Historical Radionuclide in Soil Analyses

Date	General Area	Ra^{226} Concentration (Bq/kg)		Uranium Concentration (ppm)	
		Range	Average	Range	Average
1981	On mineralised zone	200 – 230	210	24 - 45	33
	Off mineralised zone	40 - 130	60	0.7 – 6.1	2.1
2007	On mineralised zone	30 -400	190		
	Off mineralised zone	20 - 90	40		

Note: Minimum detectable level for Ra^{226} was 40 in 1981 and 20 in 2007.

No uranium analyses were undertaken in 2007.

2.8.3 Recent Radionuclide in Soil Monitoring

In 2010, two soil sampling programs were undertaken. The first was a larger regional study which looked at a range of soil characteristics. This program included limited radionuclide analysis of 12 samples (10 from soils away from ore bodies and two from soils atop the ore bodies). To complement this program, a second program took an additional five samples which were analysed for the full suite of long-lived radionuclides from the U^{238} decay chain (being, U^{238}, Th^{230}, Ra^{226}, Pb^{210} and Po^{210}). Soil sampling locations are shown in Figure 13 for the former sampling and Figure 14 for the latter.

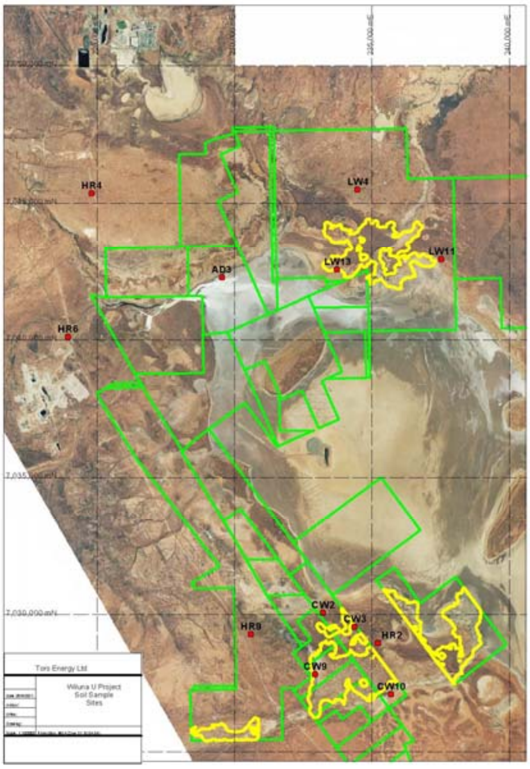

Figure 13: Soils Sampling Locations Regional Survey

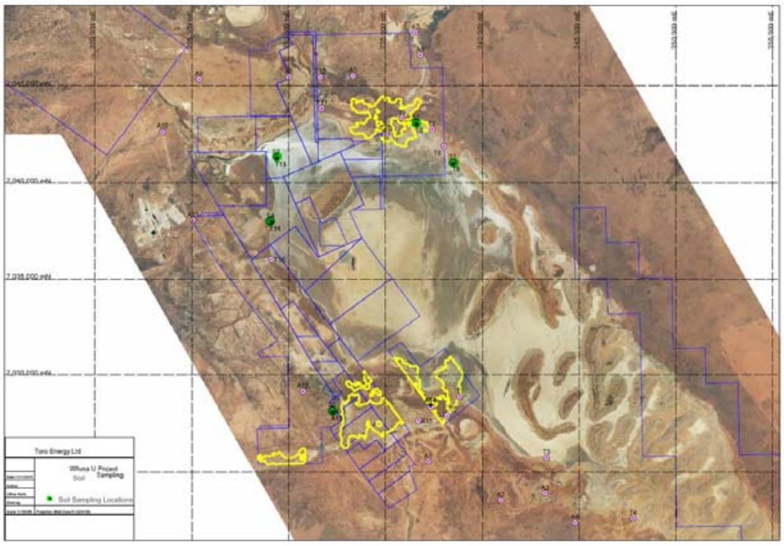

Figure 14: Soils Sampling Locations Full Radionuclide Suite

These radionuclide results are summarised in Table 19 and are consistent with the earlier results.

The measured U^{238} and Ra^{226} concentrations are generally higher than the world median for soils (which UNSCEAR 2000, Annex B, reports as 35 (range 16 - 110) and 35 (range 17 - 60) Bq/kg, respectively). This is expected as the region has generally enhanced concentrations of uranium.

Table 19: Radionuclide concentrations in different soil types

Sources of Soil	Radionuclide Concentration (Bq/kg)						No.
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}	Ac^{227}	
Samples from radionuclide survey (not on orebodies)							
Average	50	30	60	90	90	n/a	4
Range	30 – 80	10 – 40	40 – 100	40 – 160	40 -190	n/a	
Samples from regional soils survey (not on orebodies)							
Average	41	55	46	n/a	n/a	2.5	10
Range	24 - 110	50 - 90	24 - 105	n/a	n/a	1 - 7	
Samples from both surveys (atop ore bodies)							
Range	21 - 530	< 50 - 330	65 - 750	790	730	2 - 6	3

Note: 'on ore body' samples for the two programs have been combined because of the low numbers of samples.

2.8.4 Summary

The radionuclide concentrations in soil in the region are generally elevated in relation to the world average. Concentrations on the mineralised zone are up to an order of magnitude higher than concentrations in the broader region. This is due to the area being a natural uranium rich region.

2.9 Biota

2.9.1 Radionuclides in Flora

A baseline study of radionuclide concentrations in flora was conducted during 2010. Thirty samples were collected and analysed, with half the samples being long-lived Acacia Aneura (Mulga) and half the samples being the short-lived Tecticornia. Samples were analysed for U^{238}, Th^{230}, Ra^{226}, Po^{210} and Pb^{210}. In addition, Ra^{228} and Th^{228} were analysed (from the Th^{232} decay chain) to provide an indication of the total radionuclide content of the flora sampled. Uranium metal was analysed using mass spectrometry.

Sample locations can be seen in Figure 15 and results are summarised in Table 20.

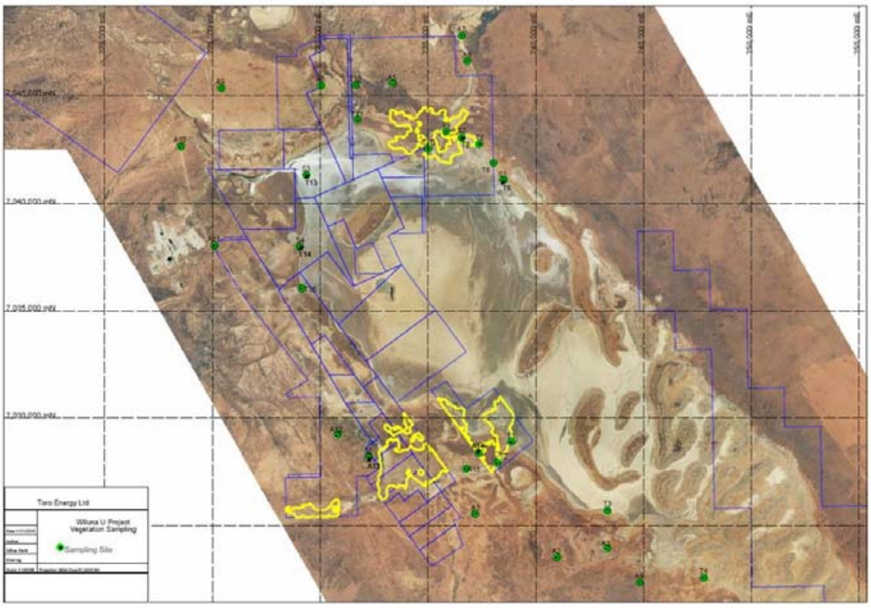

Figure 15: Flora sampling location

Table 20: Summarised Flora Analyses

Samples (number of samples)	Radionuclides (Bq/kg) (Average and Range)					
	U^{238}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}	Ra^{228}
Acacia (15)	9 (3 - 18)	1.0 (0.4 – 1.8)	2.5 (1.5 – 5)	95 (22 – 170)	52 (24 - 72)	2.1 (1 – 3)
Tecticornia (14)	10 (3 - 21)	8 (0.8 – 15)	4.6 (0.9 – 22)	30 (12 – 55)	31 (29 – 32)	2.2 (0.8 – 4)
From ore area (7)	12 (5 – 21)	7.7 (0.4 – 15)	6.7 (2.1 – 22)	31 (13 – 70)	28 (24 – 32)	2.2 (0.8 – 3)
Away from ore area (22)	9 (3 – 18)	1.2 (0.8 – 1.8)	2.5 (0.9 – 7)	74 (12-170)	54 (29 – 72)	2.1 (0.9 – 4)
Location A11 Acacia (1)	<41	-	5	750	-	<6

2010 Sampling Results

In undertaking the analysis of the results, the following was applied:

- When a sample recorded concentrations less than a minimum detectable level, the level of detection was used for the summary statistics (for example, if the level recorded was < 3, then 3 was used for the statistical analysis).
- One Acacia sample (approximately 10 kilometres west of Lake Way – site A11) had reported radionuclide concentrations which were up to 10 times higher than other 'non' ore Acacia samples. For the purpose of this assessment, the results for this sample have been removed and reported separately.

The average Ra^{226} concentration in Tecticornia is twice the concentration in Acacia, mainly due to the higher concentrations that are present in the samples from on the ore body.

Pb^{210} concentrations in the Acacia are three times that of the Tecticornia and there does not appear to be an effect of plant location in relation to the ore body as the Pb^{210} concentrations are on average higher in samples off the ore body. A similar trend can be seen for Po^{210}, although low sample numbers for Acacia on ore may be biasing the data.

Elevated Pb^{210} and Po^{210} concentrations are observed naturally due to the radon decay products.

Th^{230} concentrations in Tecticornia are on average higher than those in Acacia with higher average concentrations noted for samples on the ore body.

U^{238} concentrations were all less than the minimum detectable level for Acacia, with this concentration varying depending on the actual sample. Concentrations in Tecticornia were also generally below the minimum detectable level, although three of the six samples from the mineralised area recorded concentrations up to 20Bq/kg. The work shows that in general, uranium concentrations appear to be consistent across the region.

Earlier Sampling

Earlier vegetation sampling was conducted for the 1981 DEIS. A range of species were tested and Ra^{226} concentrations were below the detectable level (<40Bq/kg). Uranium concentrations varied from a maximum level of approximately 10ppm (125Bq/kg) in foliage at one location on the lake margin to 0.1 - 0.2ppm (1.25 to 2.5Bq/kg) at sites remote from the lake shore.

Detection levels for the earlier samples for Ra^{266} are higher than the more recent results reflecting differences in the analysis techniques. Overall, the results from the earlier and more recent sampling are relatively consistent, excluding the lake margin uranium sample.

2.9.2 Radionuclides in Fauna

Fauna samples from previous surveys in the Lake Way region have been reviewed and opportunistic sampling has occurred.

For the 1981 DEIS, samples were obtained and a summary of the results is listed in Table 21. In 2010, a Bungarra (monitor) was accidentally killed by a vehicle on site and was collected and sent for analysis.

Table 21: Fauna Sample Analyses

Animal	Body Part	Year	U^{238} Bq/kg	Th^{230} Bq/kg	Ra^{226} Bq/kg	Po^{210} Bq/kg	Pb^{210} Bq/kg
Sheep (3 animals)	Flesh	1981	0.62		0.75		
	Kidney	1981	1.5		1.8		
	Liver	1981	1.0		0.75		
Kangaroo (3 animals)	Flesh	1981	0.62		0.6		
	Kidney	1981	0.62		0.6		
	Liver	1981	1.1		0.6		
Bungarra (1 animal)	Tail	2010	< 90	1.9	28	7.1	120
	Liver	2010	< 50	2.8	55	80	55
	Bone	2010	< 70	1.8	25	12.1	<80
	Skin	2010	< 40	6.4	10.2	10.2	<40

(Note that results are reported as dry weight with uncertainty removed.)

3. Radiological impacts of the Project

3.1 Introduction

The overall radiological impacts of the operations at Lake Way and Centipede are related to workers, members of the public and the environment. This section outlines the basis for quantifying those impacts.

For workers, impacts are based on calculation of a radiation dose from a range of inputs including; theoretical assessment, exposures from other similar mines or operations and review and interpretation of occupational monitoring results to date. The dose assessments are provided in Section 4 of this document.

For the environment and members of the public, impact is based on quantifying radioactive material releases from the project that impact outside the Project Area. These impacts are described in Section 5 and 6 of this document.

To quantify the radiological impacts of the operation outside the project area, the potential sources of radiological emissions from the operation are determined and modelled. These are known as 'source terms', and are then used as input to dispersion models. The dispersion models provide estimates of concentrations at various distances from the operation as a result of the emissions.

This section will provide an overview of the source terms and the outputs of the dispersion models which can then be used as the basis for human and environmental radiation exposure assessments.

Note that the air dispersion modelling has been conducted at year four and year eight of operation. The reason for this is that the mining transfer from the Centipede deposit to the Lake Way deposit over this period and the modelling covers both of these situations.

3.2 Airborne sources of radiation

3.2.1 Radionuclides in Airborne Dust

There are a number of radiological dust sources that result from the mining and processing of uranium ores.

The following sources of dust from the mining operations have been identified:

- dust from mining of ore;
- dust from ore stockpiles; and
- ore transfer processes crushing, road haulage and conveyors systems.

Processing ore generates dust from the following sources:

- fugitive dust from tailings deposits;
- transport systems in mill area (conveyors etc); and
- uranium oxide drier and packaging area.

The estimates for the key sources of PM_{10} dust emissions are detailed in Table 22. Note that modelling was conducted for emissions at year four which represents mining from the Centipede deposit, and year eight which represents mining from the Lake Way deposit. Table 22 provides results from the highest modelled emission year (year eight).

Table 22: Average Annual PM_{10} Dust Emission (Source Term) Estimates used in Atmospheric Modelling (Toro Air Quality Assessment 2011)

Source	Emissions (g/s)	Specific activity (Bq/g) per radionuclide	Activity Emissions (Bq/s) per radionuclide
Mining	13.6	7.4	101
Vehicle movement	19.4	0.0	0
Mine wind erosion	3.1	7.4	22.99
Rehabilitation wind erosion	3.0	0.0	0.0
Waste rock stockpiles	2.3	0.0	0.0
Tailings	4.8	7.4	35.5

Note: Assumes mine average ore grade of 600ppm.

Assumes that tailings radionuclide content is identical to ore minus the uranium isotopes.

The estimated radionuclide content of the different dust emissions can be seen in Table 23.

Table 23: Relative Radionuclide Content of Airborne Dust Sources

Location	Relative Radionuclide Content (Bq/α dps)				
	Each of U^{238}/U^{234}	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
Mining	0.2	0.2	0.2	0.2	0.2
Tailings	0.0	0.33	0.33	0.2	0.33
Processing	0.2	0.2	0.2	0.2	0.2
Uranium Oxide	0.5	0.0	0.0	0.0	0.0

(Note that units are Bq per alpha disintegration per second.)

The efficiency of the uranium oxide dryer and packaging area air scrubbing systems is expected to be approximately 99 per cent, which is similar to levels at other equivalent facilities and therefore, emissions should be minimal.

The air dispersion model CALMET/CALPUFF was used to undertake the air quality assessment. The estimated dust emissions (in grams per second) from the various sources are input into the air dispersion model. The outputs of the model are contour plots which show the projected annual average airborne dust concentrations and dust deposition at year four and year eight at various locations in the region of the operations (Figure 14 shows average dust concentration at year four, and Figure 15 shows average dust concentration at year eight).

To determine the radiological impact, the modelled mass concentrations (mg/m^3) are converted into activity concentrations (Bq/m^3). This is done by determining the amount of radioactivity per gram of material using the specific activities outlined in Table 22 and 23.

The average ore grade for the whole of mining is approximately 600ppm. However, the dust dispersion modelling also includes other dusts such as road dust and dust from overburden removal. For the purposes of radiological assessment, a weighted average uranium in dust concentration of 200ppm was used.

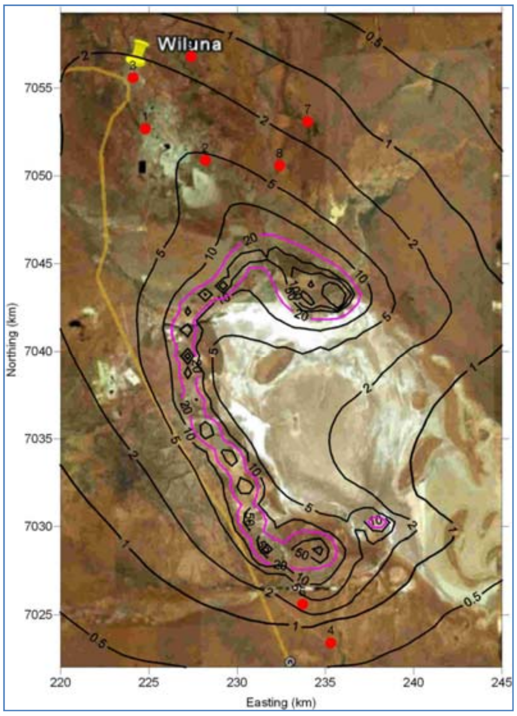

Figure 16: Modelled Annual Average Particulate Concentration (µg/m³) at year four of operation

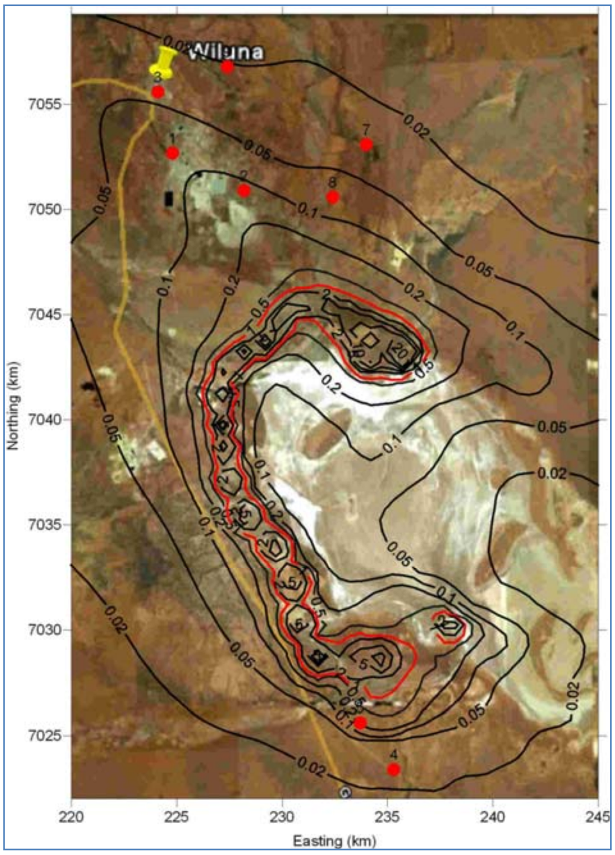

Figure 17: Modelled Annual Average Particulate Concentration (µg/m3) at year eight of operation

(Note: The figures include the impact of non-mineralised dust from roads.)

Figures 16 and 17 show the location of the key receptors and Table 23a provides the modelled dust concentration at each of these locations.

Table 23a: Modelled Dust Concentrations at Key Receptors

Location	Site No.	Annual Average TSP (Year 4) ($\mu g/m^3$)	Average Annual TSP (Year 8) ($\mu g/m^3$)
Toro House	1	0.2	2.6
Apex Village	2	0.2	4.1
Wiluna Town	3	0.1	1.9
Toro Camp Site	4	1.1	0.6
Toro Construction Camp	5	0.6	2.0
Lake Way Station	6	0.1	0.2
Millbillillie Station	7	0.1	1.3
Nganganawili Community	8	0.2	2.7
Bondini Reserve	9	0.1	1.2

3.2.2 Radon

As noted earlier, radon does not provide a significant source of radiation exposure. However, its gaseous nature means that it is able to diffuse from materials, disperse into the atmosphere and move, therefore making it a transport mechanism for the more hazardous radon decay products.

Radon gas is released during mining and processing as follows:

- mining of ore;
- stockpiles;
- ore processing; and
- tailings management and disposal.

Radon emanation from the main sources is presented in Table 24. (See Appendix C for more detail).

The approach to define radon emanation estimates was based on worst case estimates.

Commented [EM1]: Rework

Table 24: Estimated radon emanation rates

Site	Activity	Year 4			Year 8		
		Area (ha)	Emanation (Bq/m^2s)	Emission (kBq/s)	Area (ha)	Emanation (Bq/m^2s)	Emission (kBq/s)
Centipede	Mine Pit	159	3.6	5724	0	0	0
	Waste Stockpile	40	1.2	480	40	1.2	480
	Tailings Dry Beach area	32.2	3.6	1,159	69.65	3.6	2,507
	Tailings Water Covered	45	0.05	22.5	99.5	0.05	49.7
Lake Way	Mine Pit	0	0	0	206	3.6	7,416
	Waste Stockpile	0	0	0	40	1.2	480
Plant	Ore Stockpile	3.65	3.6	131	3.65	3.6	131
	Process-ing Plant	-	-	4			4
TOTAL				7,557			11,104

Another potential source of radon is groundwater which is to be pumped from the pits prior to and during mining. This was recognised by the AAEC and its work assumed that all radon contained in the groundwater would be released into the atmosphere during the pumping process. Using this approach, a radon in water concentration of 3.5kBq/L and an assumed pit dewatering rate of 5.5 ML/d (RPS Aquaterra 2010), it can be calculated that the estimated emanation of radon from this source is 200kBq/s.

There is uncertainty over the amount of radon that is released from groundwater. If it is assumed that all the radon is released (worst case), it would be less than 5 per cent of the overall estimated radon emissions. Given the uncertainty, and the corresponding low level, it was not included as a source term in the modelling.

Appendix C provides further details on the radon source terms.

The radon emissions have been used as inputs to the air dispersion model and the modelled radon contour plots can be seen in Figures 18 and 19 and show that the effect of the shift in mining operation location.

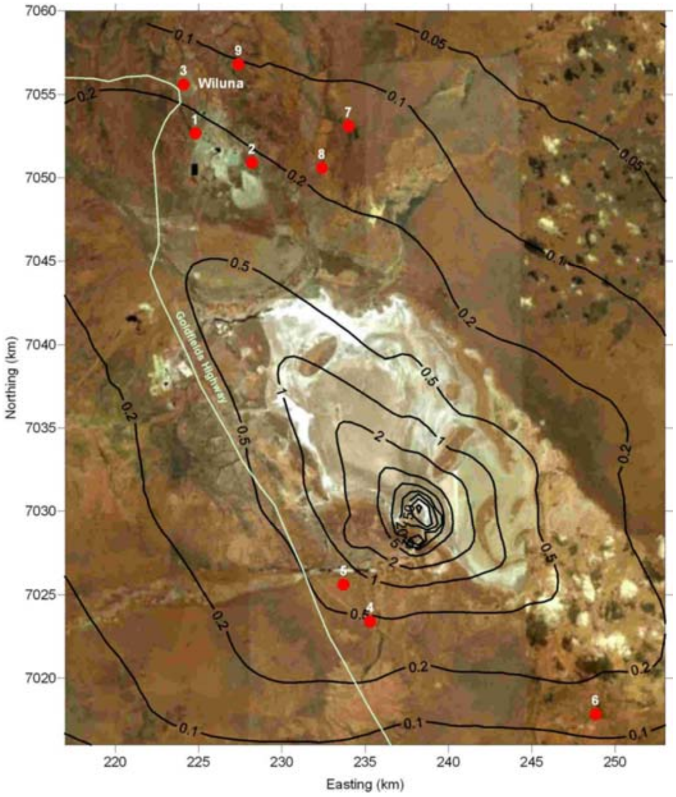

Figure 18: Modelled Annual Average Ground Level Radon Concentration (Bq/m^3) at year four of operations

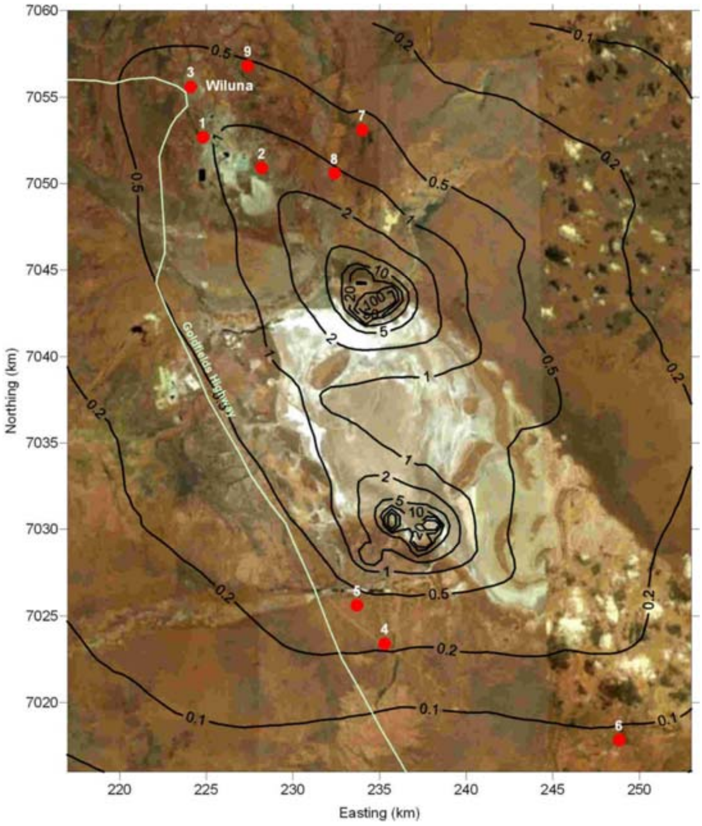

Figure 19: Modelled Annual Average Ground Level Radon Concentration (Bq/m^3) at year eight of operations

The plots show the average annual radon concentration as a result of the operations. These can be compared to the natural background radon concentration average, previously noted as 27Bq/m^3.

The average radon concentration increases at the sensitive receptors locations can be seen in Table 25.

Table 25: Average Radon Concentration at Sensitive Receptor Locations

Key Receptor Locations	Modelled Radon Concentrations (Bq/m^3)	
	Year 4	Year 8
Wiluna Township	0.13 (0.5)	0.60 (2.2)
Bondini Reserve	0.10 (0.4)	0.43 (1.6)
Nganganawili Community	0.16 (0.6)	0.92 (3.4)
Millbillillie Station	0.14 (0.5)	0.59 (2.2)
Lake Way Station	0.14 (0.5)	0.09 (0.3)
Apex Village	0.19 (0.7)	1.23 (4.6)
Toro Energy Construction Camp	0.94 (3.5)	0.40 (1.5)
Toro Energy Operations Camp	0.46 (1.7)	0.22 (0.8)

Note – figures in brackets are percentage increases above natural background of 27 Bq/m^3

The recent additional test-work undertaken by Toro indicates that the measured radon emanation rates are less than the estimates used in the air quality modelling (Toro Air Quality Assessment 2011). This has resulted in an overestimate of the potential doses from exposure to radon and its decay products. However, for the impact assessment, the earlier AAEC figures are used.

3.2.3 Radon Decay Products (RDP)

The RDP impact is determined from the radon impact modelling. To do this requires an understanding of the relationship (that is the equilibrium factor (E)) between radon and its decay products.

Appendix G provides an analysis of recent radon and RDP monitoring data and has been used to determine an equilibrium factor. The earlier work concluded that the equilibrium factor was 0.2. The more recent work shows that the equilibrium factor varies according to the time of day, but on average it is less than 0.1.

A low E indicates relatively 'fresh' radon (that is, the RDPs have yet to fully grow into equilibrium with the parent radon). A conservative value of 0.2 for E is, therefore, reasonable to apply to the modelled radon concentrations in order to determine long-term average project impact RDP concentrations at key receptor locations. These can be seen in Table 26.

Table 26: Modelled RDP Concentration at year four and year eight

Key Receptor Locations	Modelled RDP Concentrations (nJ/m^3)	
	Year 4	**Year 8**
Wiluna Township	0.5	2.1
Bondini Reserve	0.4	1.5
Nganganawili Community	0.6	3.3
Millbillillie Station	0.5	2.1
Lake Way Station	0.5	0.3
Apex Village	0.7	4.4
Toro Energy Construction Camp	3.3	1.4
Toro Energy Operations Camp	1.6	0.8

3.3 Radionuclides in Soil

The radionuclide concentrations in soils may be affected by the addition of radioactive material to the soil. The main ways that this could occur are through spills or through long term dust deposition.

Operational procedures will require that all spills be cleaned up and therefore would not contribute to long-term changes in soil concentrations. Consequently, spills have not been considered in this assessment. However, spill management is an important factor in the radiation management plan.

Over time, dust deposited from emissions from the project would accumulate in the local soil, leading to increases in the pre-existing radionuclide concentrations. The impact of long-term dust deposition from the project on soils can be estimated from the air quality model which provides the modelled deposition contours in units of mg/m^2 per month. Figure 20 shows the annual modelled particulate deposition for year eight of operations.

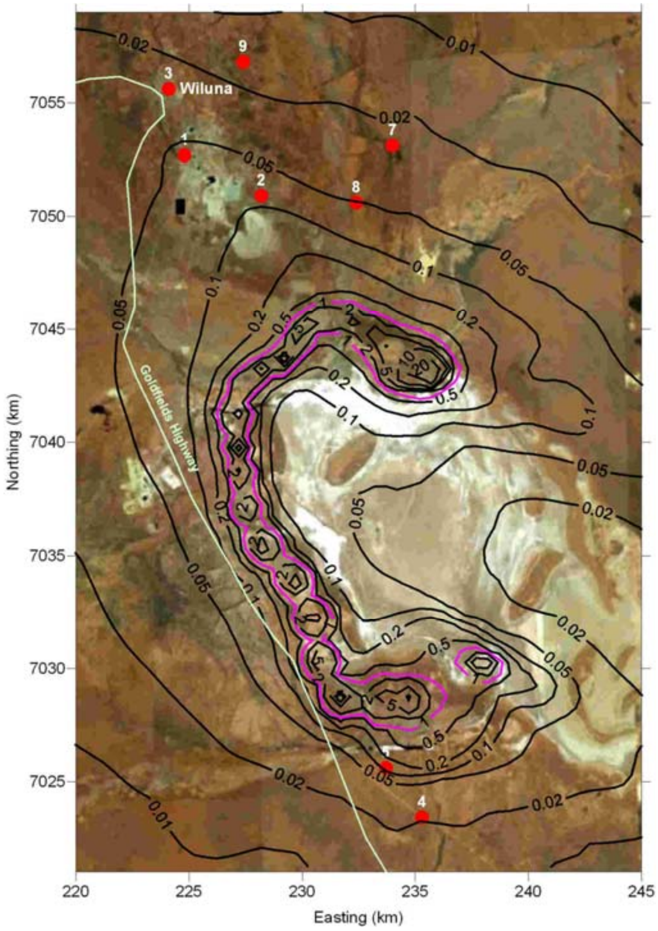

Figure 20: Modeled Average Particulate Deposition (g/m2month) for year eight of operation

Assuming a worst case situation where all dust from the operation is ore dust at a uranium grade of 600ppm, the quantity of radionuclides depositing in the soil at the key receptor sites can be determined. The modelling was based on dust fallout from the operations mixing in the top 10 centimetres of soil and shows that after 15 years of operation, the uranium levels in soils at the key receptor locations are expected to increase by the amounts shown in Table 27.

Table 27: Increase in Uranium in Soil

Key Receptor Locations	Calculated % Increase in Uranium Concentrations in Soil after 15 years	
	Based on Year 4 Emissions	**Based on Year 8 Emissions**
Wiluna Township	0.1	1.0
Bondini Reserve	0.1	0.7
Nganganawili Community	0.1	1.7
Millbillillie Station	0.1	1.0
Lake Way Station	0.1	0.1
Apex Village	0.1	3.0
Toro Energy Construction Camp	1.3	0.7
Toro Energy Operations Camp	0.1	1.0

Note that calculated percentage increases are based on modelled dust deposition, an assumed average project dust uranium concentration of 600ppm and a pre-existing natural average uranium in soil concentration of 40Bq/kg (equivalent to 3.2 ppm).

Increases in uranium concentrations would be well within the natural range of uranium concentrations in soil which was measured to be 0.7 - 6.1ppm.

3.4 Gamma

The main sources of gamma radiation from the proposed operation are:

- stockpiles;
- tailings;
- uranium; and
- process materials.

All materials (apart from the final uranium oxide product which is discussed later) are to be contained within the general project area, therefore gamma radiation from the project is not expected to be detectable beyond the project boundary.

For sources of gamma radiation within the project area, the gamma radiation levels would decrease with distance from the sources, with gamma dose rates expected to approach background levels at 20 to50 metres from the sources.

For example, for a stockpile of ore, gamma radiation would firstly be attenuated within the stockpile itself, resulting in only a portion of the total gamma being emitted beyond the volume of the material. Secondly, the intensity of the gamma radiation at any point from the stockpile depends upon the exposure geometry and can be calculated. Using the Wise (http://www.wise-uranium.org/calc.html) radiation calculators, for a uranium ore stockpile of 0.06% uranium and an exposure of surface area of 500 square meters, the dose at 100 metres is 0.02µSv/h.

While environmental levels of gamma radiation are expected to be negligible, occupational exposures may be more significant and have been assessed.

3.5 Emissions to Water

3.5.1 Emissions to Groundwater

Radionuclides in water can lead to radiation exposure to the environment or to humans when consumed.

Due to its relatively high salinity levels, the Lake Way region groundwater is unsuitable for human or stock consumption. Therefore, human and animal exposure to radionuclides in the groundwater is highly unlikely.

Additional radionuclides may enter the groundwater from various sources including seepage from tailings storage facilities, seepage from the pit and water infiltration through the stockpiles into groundwater.

There are two mechanisms that need to be considered when determining the radiological impact of seepage on the groundwater. The first is to determine the likelihood of seepage and understand if radionuclides might migrate in any seepage. The second is to determine the level of impact if the radionuclides enter the natural groundwater.

Groundwater modelling (RPS Aquaterra 2010) indicates that movement of groundwater from the mine area is limited due to the broader area being a natural drainage basin.

During mining, in addition to natural flows, there would be an induced groundwater flow towards the mine as a result of active dewatering.

Initial metallurgical test-work has shown that the radionuclides other than uranium have relatively low solubility (compared to uranium). Table 28 provides an indication of the percentage of radionuclides coming into the process that report to both the solid and liquid tailings following leaching.

Table 28: Solubility of Radionuclides (Note that remaining radionuclides report to final product)

	Distribution of Radionuclides In Tailings	
Element	**% to Liquid**	**% to Solids**
U^{238}	4.5	29.4
Th^{230}	0.1	83.6
Ra^{226}	0.0	70.4
Pb^{210}	0.0	87.2
Ac^{227}	0.0	98

3.5.2 Emissions to Surface Water

Deposition of radionuclides in dust into surface water systems can be predicted from the air quality modelling (and it should be noted that the deposition only occurs during operations). Based on a weighted average uranium in dust concentration of 200 ppm, the quantity of uranium depositing per square metre (at the 0.1 g/m2/month contour) is 0.25Bq per month.

3.5.3 Impacts on Drinking Water

The drinking water supplies for the region are subterranean and are from an area at least 20 kilometres northwest of the mine. At this distance, there would be no impact from potential seepage from the mine or tailings. This is due to the direction of the groundwater flow and the low solubility of radionuclides in the tailings.

3.6 Other Sources

3.6.1 Radionuclides in Process Materials

Process materials are potential sources of radiation emissions. An understanding of the radionuclide composition of the various materials in process streams provides information to determine radiation protection requirements. Anticipated radionuclide concentrations in process streams from the Lake Way and Centipede deposits have been determined and results are presented in Table 29. Note that this is based on initial test work and shows that the majority of the radionuclides (apart from the uranium) remain as solids.

Table 29: Indicitave Radionuclide Analyses of Lake Way and Centipede Material

Material	U^{238}/U^{234} Bq/g	Th230 Bq/g	Ra^{226} Bq/g	Pb^{210} Bq/g	Ac^{227} Bq/g
Ore	5.6	6.1	5.4	4.7	0.2
Pregnant Liquor Solution (PLS)	3.0	0.1	0.006	0.006	0.0008
Tailings (liquid)	0.1	0.005	0.0003	0.0003	0.00004
Tailings (solids)	1.7	5.1	3.8	4.1	0.2
Final Product	~10,000	n/a	n/a	n/a	n/a

Gamma radiation is expected to be present during operations. The processing plant is expected to include have a number of in-stream density gauges, which are process control devices usually containing a large gamma radiation source. There are strict controls for their use and exposure from them is expected to be negligible.

3.6.2 Emissions During Transport

The primary transport associated with the project includes the movement of ore from the mine to the processing plant and the transport of final uranium ore concentrate (UOC) product to the final export destination.

Ore

Ore will be transported from the Lake Way and Centipede deposits to the processing plant located near the Centipede deposit. Side dumping trucks will transport the material along dedicated haul roads. The conveyed ore will be damp and loads will be covered to minimise dust emissions during transportation. Any dust generated during transport will be non-radioactive road dust.

UOC

The transport of UOC is a closely regulated activity with strict requirements for packaging, labelling, emergency response and management. Uranium product will be contained in sealed drums within a locked container. This will result in no emissions during material transport. Low levels of gamma radiation (1 to 5 uSv/h at 1-metre from a container) would be detected close to the containers. Gamma radiation levels are reported indirectly on container labels.

4 Occupational Dose Estimates

4.1 Introduction

This section considers the results of the impact assessment (section 3) and estimates occupational doses for workers.

4.2 Methods for Estimating Dose

Three primary exposure groups have been identified and assessed as follows:

- miners;
- plant operators; and
- product packers.

A secondary exposure group consists of transport workers and administrative workers have been made.

The dose assessment takes into account exposure pathways and exposure estimates are based on the following: consideration of the emissions modelling;

- calculation from first principles; and
- comparison with actual doses from similar operations.

4.3 Exposure for Miners

Mining at Lake Way and Centipede will involve a relatively small workforce, operating 24/7 on a continuous 12-hour shift roster. A dedicated surface mining machine will be used in the pit and an excavator and/or front-end loader will load the material onto trucks to transport the material to the processing plant. A typical mining shift will involve equipment operators as shown in Table 30.

Table 30: Mining Shift Numbers (estimated)

Equipment	Operators/shift
Scrapers/Surface Miners	2
Trucks	4
Excavators	2
Dozers	2
Others	10

Other service workers will be involved in the mining operations, including supervisors, geologists and environmental and safety officers. No drilling and blasting activities are anticipated.

The full-time miners will be predominantly equipment operators and estimates of exposure to these full-time workers will provide the maximum exposures to be received by all mine workers.

4.3.1 Gamma Radiation

Estimates of gamma radiation exposure have been based on two sources; information from other operational uranium mines and estimates from first principles.

Table 31 provides a summary of the annual gamma doses from other open-cut uranium mines. Results show that generally, annual gamma doses are a few mSv per year.

Table 31: Gamma Doses from other open-cut mines

Mine	Average Gamma (mSv)	Maximum Gamma (mSv)
Ranger	1.0	4.0
Rossing	0.6	
McLean Lake	0.5	

Thompson and Wilson (1980) quote a theoretical gamma dose rate of 65µSv/h per one per cent of uranium from an extended plane of exposed uranium ore. The figure provides an estimate of maximum gamma exposure without taking the practicalities into account. For example, most mine workers would be equipment operators and therefore receive shielding from the mining equipment, and not all uranium would be exposed, therefore reducing gamma radiation exposure.

The average ore grade of the Lake Way and Centipede deposits is 600ppm uranium. However, the average grade of all material mined is expected to be approximately 300ppm. For a full year (assume 2,000h/y), the theoretical maximum exposure would be 3.9mSv/y. This figure does not take into account the shielding afforded by the mining equipment.

Based on gamma radiation levels observed in other open-cut uranium mines, it is estimated that miners would on average receive 1mSv/y from gamma radiation, with a possible maximum annual dose of 4mSv/y.

4.3.2 Dust Exposures

Estimation of exposures from the inhalation of uranium ore dust can be made based on predicted airborne dust concentrations. Mining at Lake Way and Centipede is expected to generate low levels of dust. This is because the mined material would generally be damp, and dust suppression techniques will minimise airborne dust levels. During excavation of the test pits, low levels of dust was observed, confirming the initial predictions (see Plate 1).

Plate 1: Low level dusting during excavation

Estimates of airborne dust concentration in the pit are based on assumed dust levels.

In terms of dust concentrations, if it is assumed that a dust concentration of $1mg/m^3$ exists in the pit during mining, then an assessment of dose can be made (note that $1mg/m^3$ for full-time exposure will be considered dusty and dust control, such as watering, would be implemented).

The average uranium grade of the material being mined is expected to be 300 ppm uranium. Therefore, for an average ore grade of 300ppm, a dust cloud of 1mg/m^3 would equate to an activity concentration of 3.7mBq/m^3 (for each of the U-series radionuclides or 18.6αdps/m^3 for the mixture of the long-lived alpha emitting radionuclides in the dust).

Exposure for 2,000h/y and a dust dose conversion factor of 7.2µSv/αdps (ARPANSA 2005) gives an annual dose of 320µSv/y. Calculation is:

Annual Dose = 18.6 m αdps/m^3 x 1.2 m^3/h x 2000 h/y x 7.2 µSv/ αdps

It is expected that this is the possible maximum dose and average doses would be lower than this by a factor of two due to the high moisture content of the material and dust control measures.

4.3.3 Radon Decay Product (RDP)

The RDP doses to miners have been determined by modelling the mine as an open pit and estimating the release rate of radon into the mine. The ventilation rate of the open pit is predicted by atmospheric modelling.

The release rate of radon into the Centipede pit and the Lake Way pit have been determined from the estimated emanation rates of radon.

The ventilation rates have been determined using the model developed by Thompson (1994). This model shows that the ventilation rate for a pit is proportional to the wind speed on the surface.

The Centipede pit would be mainly producing in the first half of the life of the operation, with the Lake Way pit producing in the second half. The radon emanation from ore from both mines has been estimated to be 3.6Bq/m^2/s from areas of 159 and 206 Ha, respectively (see Table 24). The depths of the pits are anticipated to both be approximately 15 metres.

For the purposes of this assessment, the doses have been estimated on worst case scenarios, that is, at the point of maximum pit size. In this scenario it is also assumed that all radon emanation is from the pit floor and that the walls do not have any ore and therefore, do not produce radon. This is a reasonable assumption as the surface area of the walls are small compared to the surface area of the base of the pit (walls are approximately 5 per cent of the surface area).

Baseline monitoring shows that during still night conditions, radon and RDP concentrations rise. Therefore, doses have been estimated for two exposure situation as follows:

- normal ventilation conditions, where radon and RDP are dispersed
- stable ventilation conditions, mainly at night, when there is minimal air movement.

4.3.3.1 Normal Ventilation Conditions

The quantity of radon entering each pit is calculated from the emanation rate and the pit surface areas and is as follows:

- Centipede 5.7MBq/s
- Lake Way 7.4MBq/s

The ventilation rates for each of the pits can be expressed as the number of air changes that occur each hour and can be calculated using the formula of Thompson (1994) as follows;

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

Where T is residence time of the air in the pit, Ur is the wind velocity in meters per hour, L is the length or the pit and W is the width of the pit, x is the angle of the wind to the long axis. (In this calculation, cos(x) is assumed to be one as the pits are being modelled as squares).

For an average wind speed in the region of 2m/s, the calculated residence time for both pits is 0.07h (which is approximately 14 air changes in the pit per hour).

From here, the radon equilibrium concentration can be calculated from the following equation:

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

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.

The radon concentrations in each pit are calculated to be approximately 60Bq/m^3 under normal ventilation conditions. Based on a conservative equilibrium factor of 0.5, this equates to an annual RDP dose (for 2,000h) of 1.5mSv/y for a miner working for a full year during normal ventilation conditions.

4.3.3.2 Stable Ventilation Conditions

A simple model was used to estimate the RDP dose under still ventilation conditions. Appendix G, Table 2 shows that RDP concentrations at night can be on average four times higher than the concentrations during the day. While the data is limited to the second half of the year, this ratio can provide the basis of estimating doses under night time conditions.

Therefore, the annual dose (for 2,000h) for a miner working under still ventilation conditions is 6mSv/y.

4.3.3.3 Miners' Doses

The workforce would normally operate under a rotational shift, alternating day and night shifts. Under these arrangements, the estimated dose to a miner would be a combination of the still and normal ventilation conditions. Assuming that miners work half their time on day shift (nominally 'normal' ventilation conditions) and half their time on night shift (nominally 'stable' ventilation conditions), the estimated average RDP dose wouldbe 3.8mSv/y.

4.3.3.4 Radon Modelling

Air quality modelling provides a second assessment process. Annual average radon concentrations are shown as contours (as seen in Figure 16 and Figure 17). Although there is uncertainty in modelling results close to source terms, the modelled radon concentrations (100Bq/m^3) in the region of the pits is consistent with previous calculations.

4.3.4 Total Dose Estimates (Miners)

Table 32 provides a summary of the estimated doses to miners.

Table 32: Miners' Dose Estimates

Workers	Gamma dose (mSv/y)	Dust Dose (mSv/y)	RDP Dose (mSv/y)	Total Dose (mSv/y)
Miners (average)	1.0	0.3	3.8	5.1

4.4 Exposures in the Processing Plant

The processing plant would be located on the south eastern edge of Lake Way near the Centipede deposit, with ore being trucked to the site for treatment. There may be up to 40 employees working rotation on day and night shifts. Employees would generally work on various parts of the plant and are considered one homogenous workgroup for the purposes of dose assessment. Doses to workers in the uranium packaging area have been calculated separately.

Estimates of doses are based on exposures at other uranium processing facilities. Table 33 shows doses from the Olympic Dam processing plant (BHP Billiton 2009) and as can be seen, annual average doses are low.

Radiation doses at Beverly uranium mine, which uses a similar packing method and produces a similar product to Toro, are low with average production workers doses less that 1mSv/y (Kutty 2010).

Table 33: Processing Plant Doses

Processing Plant	Average (mSv/y)
Olympic Dam (concentrator)	1 – 2
Olympic Dam (hydrometallurgical plant)	1 - 2
Olympic Dam (product packers)	2

4.4.1 Gamma

Estimates of gamma doses for processing plant workers are based on doses from uranium processing facilities elsewhere. Average gamma doses for plant workers at Olympic Dam (BHP Billiton 2009) are 1 to 2mSv/y, with a maximum of 2mSv/y. It is expected that doses in the processing plant would be similar to these levels.

4.4.2 Airborne Dust

Dust levels in the plant are expected to be low due to the process material being mainly wet or damp. Sources of dust include dry spills and transfers of raw materials. However, operational controls would ensure that spills are cleaned up promptlybefore they became a source of dust after drying. Doses from airborne dust are also expected to be low due to the relatively low grade of the material being processed. Where concentrated uranium bearing material was present, such as in the uranium extraction and packing area, additional engineered dust controls will be employed.

Estimates are based on the assumption that the predominant dust in the processing facility is ore dust and the average dust concentrations is assumed to be 1mg/m^3 (identical to the dust conditions in the mine). However, the dust in the plant is assumed to be at the processing ore grade of 600 ppm uranium. Using the method outlined in the mining section, the estimated average dust dose is 0.64mSv/y.

4.4.3 Radon Decay Product (RDP)

RDP doses to processing plant workers from project originated RDPs are expected to be low.

The radon contour plots (see Figures 16 and 17) produced from the air quality model, show a project impact radon concentration of less than 5Bq/m^3 at the processing plant. Assuming a conservative equilibrium factor of 0.2 (see Appendix G for results of monitoring results) between the radon concentration and the RDP concentration, and assuming an exposure of 2,000h/y, the calculated occupational RDP dose in the processing plant is 0.05mSv/y.

4.4.4 Exposure during product packing

There would be exposure from gamma and dust inhalation in the uranium packaging and storage area due to the uranium product.

BHP Billiton 2009 reports examine that doses to full time product packers since commencement of operations has remained low at <2mSv/y. This is attributed to the specifically designed enclosed ventilated uranium packing booth, workers wearing powered respiratory protecting and disposable coveralls, and a strictly enforced management system. These features, including management procedures, are consistent with industry standard and would apply at the Wiluna Project processing facility.

The product packing facility would use a high degree of automation and would include radiation protection mechanisms such as control interlocks, dedicated dust extraction and scrubbing, and designs for ease of spillage clean-up. (See Section 8 of this report for more detail on controls in the product packing area).

The doses for product packing personnel are expected to be less than 2mSv/y.

4.5 Exposure to transport workers

Uranium Oxide Concentrate would be transported interstate to Adelaide for export either through the Port of Adelaide or Darwin. Truck drivers would be exposed to low levels of gamma radiation during transportation. Gamma radiation measurements in truck cabins transporting uranium oxide are reported in BHP Billiton 2009 reports as being, on average, 1μSv/h. For a 36-hour trip between Wiluna and Adelaide, this equates to 36μSv. A driver may make up to 12 of these trips per year giving a total dose of approximately 0.5mSv/y.

Drivers would also be employed to transport ore between the Lake Way deposit and the processing plant. Doses to drivers are expected to be similar to equipment operators in the pit.

4.6 Exposures to other workgroups

The other key workgroups for which doses have been assessed are:

- administration workers; and
- construction workers.

Administration workers are expected to receive low level exposure as the office will be located away from the mine and outside the processing plant. Air quality modelling shows that RDP concentration at the office area (at the plant location) the RDP concentration is 0.003µJ/m^3 and dust levels are 0.01mBq/m^3. Assuming the standard dose conversion factors (ARPANSA 2005), this equates to an annual does of less than 1mSv.

A construction workforce of up to 200 people would be employed to build the camp, processing plant and associated infrastructure. Processing of materials is not expected to occur during construction activities. Accordingly, there is not expected to be any radiation exposure above natural background levels and doses would be much less than the member of the public limit of 1mSv/y. Some limited construction may occur within the designated radiation areas once operations commence and workers would be managed and monitored in the same way as the production workforce.

5. Estimated Doses to Members of the Public

5.1 Introduction

Members of the public exposures are characterised by emissions from inside the operation impacting on receptors outside the operation.

Exposures to members of the public have been determined by identifying potential critical groups of people who may be affected by the operation. These groups are:

- Residents of Wiluna;
- Residents of Millbillillie, Nganganawili Community and Bondini Reserve;
- Toro's operations and construction camp residents;
- Workers at the Apex mine; and
- Residents of Lake Way station.

For the purpose of this ERMP, a hypothetical critical group, known as 'Local Gatherers' has been proposed. This is assumed to be a group of people who live off the land in the region of the mine. While living off the land, it is assumed that the group will consume food collected from the immediate vicinity of the mine area, but not within the fenced off operational area.

5.2 Approach to Public Dose Assessment

The method for dose assessment for members of the public is identical to the method used for workers as follows:

- the main potential radiation exposure pathways are identified;
- estimates of exposure for each of the pathways are made (based on monitoring data or modelled data);
- standard dose conversion factors are used to determine a dose for each of the pathways; and
- the doses from each pathway are summed to produce a total expected dose.

Doses to the critical groups are based on the modelled concentrations at the critical group locations, combined with the occupancy time and the appropriate dose conversion factors (ICRP 1996).

For members of the public, the main exposure pathways are as follows:

- inhalation of radioactive dust;
- inhalation of the decay products of radon;
- ingestion of animals or plants that have come in contact with emissions; and
- ingestion of radionuclides in waters.

Exposure from gamma radiation is not considered to be significant because the main sources of gamma radiation are the stockpiles and tailings which would be within the mine lease area, and are inaccessible. Gamma levels at the closest publicly accessible area would not be distinguishable from the current naturally background radiation.

Groundwater from the region is saline and unsuitable for human consumption. Therefore, there would be no exposure from this source.

Consumption of locally grown foods is a potential pathway and is considered in more detail later in this section.

The main exposure pathways are from air emissions. The exposure to airborne emissions is determined from the air quality model which provides an assessment of the project related dust and radon (and therefore RDP) concentrations at the critical group locations. The estimates of the long-term concentrations can be seen in Figures 14 to Figures 17, Table 26 and Table 27.

5.3 Total Members of Public Doses

The predicted total dose to the key critical groups has been determined and can be seen in Table 35. Inhalation doses from RDPs and radionuclides in dust have been determined by assuming that residents at the critical group locations are exposed for a full year (8,760h) to the modelled RDP and radionuclide in dust concentrations at these locations. Assumptions are provided in Appendix E.

Table 35: Predicted Dose to Critical Groups

Key Receptor Locations	Dose From Pathway (mSv/y) (for highest year of emissions)			
	Inhalation of RDP	Inhalation of radionuclides in Dust	Gamma Radiation	Total Dose
Wiluna Township	0.020	0.002	0	0.022
Bondini Reserve	0.014	0.001	0	0.015
Nganganawili Community	0.031	0.003	0	0.034
Millbillillie Station	0.020	0.001	0	0.021
Lake Way Station	0.005	0.000	0	0.005
Apex Village	0.042	0.005	0	0.047
Toro Energy Construction Camp	0.031	0.002	0	0.033
Toro Energy Operations Camp	0.015	0.001	0	0.016

Note that member of public dose limit is 1mSv/y.

5.4 Dose Estimate for Local Gatherers

An assessment of the potential doses from the consumption of foodstuffs grown close to the operation is provided in Appendix H.

The assessment is based on airborne emissions from the operations (modelled at years four and eight) after 15 years of deposition, mixing with soils and being taken up by plants and animals which may be consumed by humans.

Rather than model a hypothetical distribution of edible vegetation at the operation boundary, the most restrictive uptake factors for vegetation types for the long-lived radionuclides in the U^{238} decay chain from IAEA 1996 were applied (for example, for each of the long lived-radionuclides, the most restrictive uptake factors were applied for leafy vegetables, root vegetables or fruit).

Based on the modelled dust deposition levels at the operations' boundary and a soil mixing depth of 10 cm, it is calculated that by the end of operations, the radionuclides in soils at the boundary would increase over existing levels by the following amounts:

	$U^{238/U234}$	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
% Increase in Concentration	5	8	4	3	3

This is the relative increase over the average naturally occurring radionuclides in soil in the broader region as a result of dust deposition from the operations (but not including soil samples from on top of the ore deposit).

It could be expected that vegetation growing in this soil would take up the deposited radionuclides in addition to the existing soil radionuclides. If it is assumed that the increase in uptake is proportional to the increase in soil radionuclide concentrations, then it can be assumed that the radionuclides in vegetation would similarly increase by approximately 5 per cent (8 per cent in the case of Th^{230}).

If a person consumed 200 kilograms of vegetation from the immediate project boundary after 15 years of dust deposition, then it can be predicted that they could receive up to 1mSv as a result of the operation.

5.5 Public Dose following closure

Section 8.8 of this document provides an overview of Toro's closure plans.

Doses to members of the public above pre-mining natural background levels are expected to be negligible following closure and rehabilitation.

Toro's approach to closure is based on a plan approved by regulators which would ensure that the site was closed and rehabilitated to a standard consistent with the pre-mining environment. Tailings and remnant mined material would be returned to the pit and covered with inert material and topsoil.

In this situation, the potential radiation exposure pathways are increased through mobilisation of soluble radionuclides in the tailings when the groundwater starts to return and airborne emissions.

It is anticipated that radionuclides would be largely insoluble and remain bound in the solids, thereby effectively eliminating this exposure pathway. Toro is undertaking further test work to verify this.

The other potential exposure pathway is the airborne pathway, although this is expected to be minimal as the plan is to effectively cover any waste material to prevent release through dust.

6. Exposure to Non-Human Biota

6.1 Introduction

Radiation protection of non-human species has traditionally occurred by assuming that the systems that protect humans also protect other species. In recent years this approach has changed, and a more sophisticated approach has been developed and recommended by the ICRP. In ICRP 2003, a system for the protection of non-human biota was outlined and objectives were set for the radiological protection of non-human species, including an approach to assess exposure.

Based on the ICRP approach, the European Commission developed a software tool to conduct risk assessments called ERICA (Environmental Risk from Ionising Contaminants: Assessment and Management, ERICA Program 2007). ERICA is effectively a screening program which conducts assessments in three tiers:

- Tier one is a broad assessment to identify where there may be a potential radiological risk.
- Tier two is a more detailed assessment of species identified at risk in the tier one assessment, using best estimates of radiological parameters.
- Tier three is a detailed, site-specific assessment for species identified at risk in the tier two assessment.

Toro endorses the ICRP approach, even though it is yet to be adopted formally in Australia. BHP Billiton 2009 includes an ERICA assessment in a similar manner.

6.2 ERICA Assessment at Lake Way and Centipede

An ERICA assessment was undertaken to assess radiological impacts to non-human biota at the Lake Way and Centipede deposits. Airborne impacts were overlayed across maps of the region in the form of dust deposition contours from the air quality modelling. The ERICA tool was then used to determine whether there was any risk to any of the standard ecological communities. Following this, a search was undertaken to determine if those ecological communities existed within that deposition contour.

The risk of radiological harm is assessed as 'negligible' for all reference organisms (with the exception of lichen and bryophytes) at points where dust fallout is less than 15g/m2/month near the mine-sites, and 4 g/m2/month near the processing plant. Lichen and bryophytes are very resistant to radiation, and no effects are expected at any dust fallout level.

The areas where dust fallout levels are expected are approximately 2 kilometres across each of the two mine sites. Dust fallout from the processing plant is not expected to reach 4 g/m2/month. The areas in which reference organisms are potentially liable to be affected are small.

7. Radiation Monitoring

7.1 Introduction

Occupational and environmental radiation monitoring is undertaken to fulfil a number of different functions:

- Provision of data and information to assess the adequacy and effectiveness of radiation protection systems;
- Provision of information for radiation dose assessment;
- Identify tends or changes in working conditions; and
- Investigate possible exposure situations.

This section outlines the methods and systems for effective radiation monitoring and provides an indicative monitoring program that would be subject to approval by the appropriate authorities.

7.2 Methods

Table 36 provides an outline of the parameters to be monitored and the method of monitoring.

Table 36: Methods of Monitoring

Radiation	Method	Primary Purpose
Gamma	Personal TLDs	Dose assessment
	Location dose rate measurements using hand held gamma radiation monitors	Operational control
	Environmental gamma monitor	To identify changes
Radon	Continuous real time environmental sampling	To identify changes
	Passive radon detectors for radon concentrations	To identify changes
	Charcoal cups for radon emanation	
RDP	Continuous real time samplers	Dose assessment
		Dose assessment
	Spot sampling	Dose assessment
Dust	Personal dust pumps	Dose assessment
	Microvol dust pumps	To identify changes
	High volume dust pumps	To determine changes in radiation levels
		Public dose assessment
	Dust deposition gauges	To determine changes in radiation levels
		Dose assessment and impacts on non-human biota
Radionuclides in water	Grab sampling opportunistically following rainfall events, then radionuclide analysis	To determine changes in radiation levels
		Public dose assessment
	Borehole sampling, then radionuclide analysis	To determine changes in radiation levels
Radionuclides in soil, flora and fauna	Sampling of soils, flora and fauna, then radiometric analysis	To determine changes in radiation levels
		Public dose assessment and doses to non-human biota

Monitoring programs will be supported by:

- 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 monitoring program and system.

7.3 Environmental Radiation Monitoring Program

The environmental radiation monitoring program implemented to collect background and baseline information would continue during the operational phase. The program would be based around two main monitoring sites. The proposed key environmental monitoring is outlined below:

- Meteorological data collection at the meteorological station would be continued
- Radon concentrations
  - Real time continuous radon concentration monitoring would continue at the environmental monitoring sites
- RDP Concentrations
  - Real time RDP monitoring would continue at the environmental monitoring sites
- Flora and fauna
  - Vegetation would be sampled every five years and analysed for radionuclides using the same species and the same locations as those used in the baseline study
  - Fauna sampling and analysis, developed in conjunction with Traditional Owners
- Airborne Dust sampling
  - Environmental dust measured using high-volume and low-volume samplers and passive dust deposition gauges

  - Dust filters weighed to provide monthly trends of dust levels and filters composited for radionuclide analysis
  - Low-volume filters would be analysed to provide an indication of total long-lived alpha radiation in air. Passive dust would be analysed for radionuclides on a quarterly basis
- Water Sampling
  - A network of monitoring bores would be sampled quarterly and analysed for radionuclides and other constituents
  - Opportunistic surface water sampling following significant rainfall events
  - Frequency of analysis would be continuously reviewed and adjusted as necessary
- Gamma Radiation
  - Annual environmental gamma surveys would be conducted, focusing on the localities of critical groups.

Development and finalisation of the operational monitoring program would be in consultation with the Department of Environment and Conservation.

7.4 Occupational Radiation Monitoring Program

The final occupational monitoring would be detailed in the approved Radiation Management Plan. It is anticipated that the overall radiation monitoring would consist of two main objectives; dose assessment monitoring and operational control monitoring. The proposed radiation measurements and frequency of sampling are shown in Table 37 and Table 38.

Table 37: Proposed radiation monitoring program A – Dose Assessment Monitoring Program

Radiation Exposure Pathway	Mine area	Mill area	Product packers	Admin
Gamma radiation	Quarterly TLD badges	Quarterly TLD badges	Quarterly TLD badges	Area TLD badge
Airborne dust	Fortnight personal samples for all occupation groups (e.g. drillers, geologists)	Fortnightly personal samples in each plant area	Personal samples each packing session	Fortnightly area samples
Radon Decay Products	Continuous RDP sampling is work areas each month	Weekly grab samples in each plant area	(included in general mill area sampling)	Monthly grab sample

Table 38: Proposed radiation monitoring program B – Operational Management Monitoring Program

Radiation Exposure Pathway	Mine area	Mill Area	Product Packers	Admin
Gamma radiation	Weekly gamma spot samples in each work area	Monthly gamma survey of mill area	(as part of mill area survey)	N/A
Surface Contamination	Weekly survey in change rooms and crib rooms	Weekly survey in change rooms and crib rooms	(as part of mill area survey) weekly survey of U_3O_8 area	Monthly survey in office
Airborne dust	Weekly samples on mining equipment	Weekly samples in: • crushing/grinding • leach • tailings	Area dust sampling during all drumming operations	N/A

Radon Decay Products	Real time continuous RDP monitoring in pit	Real time continuous RDP monitoring at various locations	N/A	N/A

7.5 Calculating Doses

There are standardised methods for calculating occupational radiation doses, based on the recommendations of the ICRP (ICRP 2007).

In general, ‘dose’ is a standardised measure of radiation detriment or harm, and is usually measured in Sieverts (Sv). The recognised occupational dose limit is 20 mSv/y. As noted earlier, there are different ways that radiation doses can be received, (such as gamma irradiation, dust inhalation and ingestion), and the dose depends upon a number of factors (such as solubility, class of the dust through to type of radiation and chemical characteristics of the material). The dose incorporates these factors to produce one measure of radiation detriment.

A simplified model of assessment of radiation exposure is as follows:

- radiation is emitted;
- a receptor (human or non-human) is exposed to the radiation;
- a measurement of exposure is made;
- the mechanism of exposure (inhalation, ingestion, etc.) and the form of exposure is factored; and
- standardised conversion factors are used to determine a dose.

The method for calculating doses for workers is outlined in the Western Australian Uranium Mining Guidelines and is consistent with the national mining code (ARPANSA 2005) and the internationally accepted methods defined by the ICRP.

7.6 Radiation Protection Resources

Toro would appoint an appropriately qualified Radiation Safety Officer (RSO) who would be part of the operation management team and directly influence the day-to-day operation of the mine site.

The RSO would be provided with support staff and sufficient resources in order to achieve the requirements of the Radiation Management Plan, including monitoring. The RSO would be provided with professional development opportunities and appropriate support.

8. Management of radiation

8.1 Introduction

Radiation emissions and exposures are one of the hazards associated with the mining and processing of radioactive ores. Like all other hazards, radiation can be effectively managed in the design stage and in operations. Ideally, hazards are primarily controlled through design and then further reduced through operational management systems.

Toro's approach towards the management of radiation is consistent with the recommendations of the ICRP, in particular, the principle of ALARA. Proper and appropriate implementation of the ALARA principle assists to manage and control radiation. In this section, the management and control of radiation is described within the broader context of ALARA.

8.2 ALARA in design

Detailed design of the proposed pits and processing facilities has yet to occur, however, Toro has considered radiation protection at this early stage of the project through:

- the establishment of radiation design criteria for the project; and
- a preliminary radiation risk assessment.

The design criteria provides fundamental instructions that require final verification by appropriately qualified radiation protection personnel. It includes measures such as:

- All tanks and process vessels that contain radioactive process material must be concrete bunded with hose-down facilities and sumps;

- All liquid spills must be able to be cleaned up when wet, water outlets must be provided to ensure this;
- Where there is potential for large spills, access must be provided to allow bobcats or similar equipment to clean-up;
- Where there is dry process material that cannot be cleaned up with hoses and water vacuum systems will be installed to affect clean-up;
- All process material transfer points must be covered and active ventilation should be used;
- Dust extraction systems will be designed to ensure ease of maintenance (to minimise exposures). Wet scrubbing systems should be used; and
- For uranium products there must be specific design requirements developed in consultation with a qualified radiation safety officer.

Toro undertook a radiation risk review of design of the project. The work is summarised in Table 39.

Table 39: Radiological Risk Review

Area and Process	Radiological Risk	Mandatory Risk Control/Mitigation
Mining – ore removal/movements	Dust from loading or haul roads	Availability of dust suppression mechanisms to minimise dust, and regular watering of haul roads
Mining – Mining	Build-up of RDP concentration during still or inversion conditions	Real time RDP monitoring equipment would be available in the mine and for all mining equipment fitted with filtered air conditioners. Air conditioned vehicles would be required to operate with windows closed at all times. Routine maintenance program for air conditioning units.
Mining - Stockpiles	Dust from stockpiles	Availability of appropriate dust suppression mechanisms. Design limits for stockpile heights.
Transport of material	Dust generation	Covering haul trucks transporting from Lake Way to the processing plant.
Processing – Tanks	Spill leading to loss of control materials	All tanks bunded with adequate clean-up systems (ie: sloped floors to sump, concrete, access for bobcat)
Crushing and Screening	Dust generation	Installation of a dust enclosure and water sprays for tipping to grizzly. Dust extraction on conveyors and transfer points.
Processing – Product packing	Exposure to UOC	Dedicated best practice control system based on automation, containment, dust control and ease of clean-up.
Processing – Laboratory	Radioactive water and waste	Appropriated nominated area for disposal

Processing – Workforce etc	Spread of contamination	Segregated change-rooms to be installed. Wheel wash for all vehicles leaving the site. Certain vehicles to remain on site at all times (mining).

8.3 Radiation Control in Uranium Precipitation and Packing Area

Uranyl peroxide or uranium peroxide hydrate (UO4.2H2O) would be precipitated from the pregnant liquor solution (PLS) through the addition of hydrogen peroxide and then sodium hydroxide. The uranyl peroxide slurry would be then thickened, centrifuged, dried in a rotary kiln and cooled before packaging in 205litre plastic lined, steel drums. Due to the concentration of uranium in the product, there would be specific radiation protection requirements in this area. Once the uranium comes out of the solution, it is a dry product that may produce dust. To minimise exposure, the standard design practice of sealing the dry product in the process stream will be adopted by Toro. This involves drying the product in the kiln before transferring it to a feed bin via a sealed screw conveyer. Drums will be packed automatically in a sealed, filtered, negatively pressured booth.

Drums will be conveyored through a series of air lock doors, passing under a feed hopper which will lower to the drum to fill them. Once all drums are filled, an operator with appropriate personal protection equipment (respiratory protection, coveralls and gloves) will enter the booth and place lids and seals on the drums.

The operator would exit the booth before the drums would be washed conveyored out of the booth. The operator would remove drums with a forklift, reweigh the drums and then label the drums prior to placing them into a storage area or directly into a shipping container.

The following radiation protection measures would be an integral part of the design of the product packing area:

- Filling drums would be totally automated and controlled by an operator outside the product packing booth. The door to the packing booth would be interlocked with the drum filling control systems. This ensures that drums cannot be filled when the booth door is open or the operator is in the booth (to do this, one key may be used to operate the filling machine and open the door).

- The rotary kiln would have a water seal with off gases being scrubbed prior to emission. The gases would go through an initial dry scrub followed by a wet scrub, with residues being returned to the leach circuit.
- The product packing booth would be under constant negative pressure to prevent dust release. The negative pressure would be maintained by an extraction ventilation system, with all air being scrubbed prior to release. Typically, uranium product packing scrubbers remove more than 99 per cent of exhausted dusts and particulates.
- It is expected that the uranium product would be packed in batches of up to six drums, typically on day shift only with two operators on duty at all times to ensure safety.
- Access to the product packing area would be strictly controlled using swipe cards in conjunction with biometric security systems. The individual cards would ensure that access to certain areas could only occur by authorised personnel.
- Product packing operators would change prior to working in the area, and then be required to change when leaving, including lunch breaks.
- Maintenance work in the product packing area would be under the control of a work permit, with specific radiation safety requirements for the jobs, such as additional personal protective equipment.
- A special wash down facility or decontamination facility would be installed in the controlled product packing area to clean equipment that needed to be removed from the area for maintenance or repair.

8.4 Radiation Control in the Processing Plant

In the broader plant, radiation controls would include:

- Controlled access to the site, and around the site, through security swipe cards;
- Vehicle wheel wash prior to leaving the main gate;

- Change rooms for all radiation workers at the site, requiring workers to change into overalls when entering the site and to shower and change prior to leaving the site;
- Lunch and control rooms with adjacent ablution facilities;
- A decontamination facility would be installed including high pressure hose and sump with wash water recycled to the mill;
- The plant would be designed with multiple hose mounts, sumps for spill collection and concrete bunding;
- The tailings pipeline would have leak detection and be bunded its entire length to contain any spills;
- All equipment and materials leaving site would be required to be tested for radioactive contamination and issued a radiation clearance before removal from site; and
- An onsite laboratory would undertake sample preparation, analytical and metallurgical work with all the wastes recycled to the process plant or disposed to tailings.

8.5 ALARA in Operation

Operational ALARA would include the following:

- Training of all workers (including inductions and regular retraining);
- Additional specialised training for product handlers, supervisors and others;
- Controlled access to the whole of the working area with further controls for certain areas of the plant;
- Review of design modifications from a radiological perspective, meaning that radiological considerations would be an integral part of the change management process;
- Operational procedures will include:
    - use of clean/dirty procedures to segregate and isolate contamination;
    - establishment of radiation work procedures (RWP) for specific tasks such as work in the final product shed, and during maintenance shutdowns;
    - strict procedures for equipment or materials leaving designated radiation areas; and

- investigative monitoring results to identify anomalies, and implement remedial measures as required.

8.6 Operational and Administrative Controls

Toro would implement a series of operational and administrative controls for radiation protection. The Project would be divided into supervised and non-supervised areas for the administrative control of radiation exposure to workers. Individuals working in designated areas would be workers who make contact with radioactive ores as part of their everyday work. These individuals would be monitored regularly. Designation of areas would adhere to guidance in ARPANSA 2005 and the NORM Guidelines published by the Department of Mines and Petroleum.

An induction program forall employees and contractors will include occupational health and safety training. Part of the training would include a session on radiation protection and responsibilities. Workers would receive a radiation safety manual which would outline their responsibilities in respect to radiation safety, including notifying Toro of previous radiation exposure or pregnancy. A handbook would also cover the specific radiation safety rules and regulations, and would also be a source of information for all workers regarding radiation.

All workers would receive a pre-employment medical, followed by regular medical check-ups during employment with Toro.

Workers' dose and radiation monitoring records would be collected and maintained in accordance with relevant requirements. Dose records would be made available to the Australian National Dose Register. In addition, Toro would make dose and monitoring records available to the Western Australia Boswell System.

8.7 Action Levels

Toro has established an operational control management system based on the results of the routine monitoring results and these can be seen in Table 40.

Table 40: Exposure Action Levels and Actions

Radiation	Action Level	Actions
Gamma	10µSv/h	Investigate and ensure work in the area is only undertaken once authorised by the RSO who may take such actions as placement of inert material to shield or clean-up up if spillage is present. Area to be worked under the Radiation Work Permit System until monitored levels are below action level.
RDP	10µJ/m^3	Monitor inside of equipment. If results exceed action level then work is only permitted to continue under Radiation Work Permit as authorised by RSO who will ensure controls are in place.
Dust	10mg/m^3	Identify source and suppress (e.g. water suppression, housekeeping and ventilation)
TLD - (¼ly result)	1mSv	Investigate and identify source. Redesign workplace or tasks to reduce exposure.
TLD – quarterly result	1mSv	Investigate, remove from area, and resolve exposure source so that levels are reduced

8.8 Closure considerations

Radiological considerations for closure relate to the potential doses to members of the public or the potential for increases in the natural radiation levels in the region following the mine's closure and rehabilitation.

As described in this document, the pre-existing natural radiation levels are elevated, and variable and post closure radiation levels need to be considered within this context.

Toro's objective for mine closure is to ensure that radiation levels are consistent with the radiation levels that existed prior to the commencement of mining. Toro aims to ensure that radiation doses to members of the public are less than 1mSv/y above natural background. To do this, Toro intends to encapsulate all remaining radioactive material (such as tailings, sub-economic ore and contaminated soils and equipment) in the mined-out voids or approved sub-surface disposal area on site. Tailings would be progressively disposed in the mined-out pits and other material would be disposed there during decommissioning and closure. At the end of operation, the aim would be to decontaminate, recycle and salvage as much plant and equipment as possible. However, in many cases, this would not be feasible and the plant or equipment would be buried with the tailings.

The mined-out pits are to be covered with a suitable depth of inert material to contain materials and to minimise the release of radon. This is likely to be at least one-metre.

The closure design is to contain all radioactive material. Accordingly, radiation doses would be low.

9. Summary

9.1 Table of Potential Impacts

A summary of the radiological impacts of the Wiluna Uranium Project is in Table 41.

Table 41: Summary of Radiation Impacts

	Expected Impact	**Limit/Standard**
Workers Doses	< 5mSv/y	20mSv/y
Member of Public Doses	< 0.1mSv/y	1mSv/y
Non-Human Biota	No impact	

9.2 Statement of Impact

Impacts of radiation from the Wiluna Uranium Project are expected to be low.

APPENDICES

A **Comparison of Radiation Levels**

B **Bibliography and References**

C **Radon Source Estimates**

D **Example of Dose Assessment**

E **Assumptions and Dose Factors**

F **Historical Review of Radon and RDP concentrations at Lake Way**

G **Recent Radon and RDP concentrations at Lake Way**

H **Assessment of Food Chain Doses**

I **Radiological effects on non-human biota arising from the Wiluna Uranium Project**

APPENDIX A: Comparison of Radiation Doses

The following tables have been included to provide information on the relative levels of radiation.

Table 1: Occupational radiation exposures (adapted from Table 3 – report to the general assembly UNSCEAR 2000)

Source/practice	Average annual effective dose (mSv/y)
Nuclear fuel cycle (including uranium mining)	1.8
Industrial uses of radiation	0.5
Medical uses of radiation	0.3
Air crew	3.0
Mining (other than coal)	2.7
Coal mining	0.7

Table 2: Annual average effective doses in year 2000 from natural and man-made sources (adapted from Table 4 – report to the general assembly UNSCEAR 2000)

Source	Worldwide annual per capita effective dose (mSv)
Natural background	2.4
Diagnostic medical examinations	0.4
Nuclear power production	0.0002

Table 3: Radiation Doses at Operating Uranium Mines

Mine	Total Average Annual Dose (mSv)
Ranger uranium mine	1.0
Rossing uranium mine	2.1
Olympic Dam underground mine	3.8

Honeymoon pilot plant	< 0.1
Beverly uranium mine	0.7

Table 4: Average radiation doses from natural sources (UNSCEAR 2000)

Source	**Worldwide average annual effective dose (mSv)**	**Typical range (mSv)**
External exposure		
Cosmic rays	0.4	0.3 – 1.0
Terrestrial	0.4	0.3 – 0.6
Internal exposure		
Inhalation (mainly radon decay products)	1.2	0.2 – 10
Ingestion	0.3	0.2 – 0.8
Total	2.4	1 – 10

APPENDIX B: Bibliography and References

AAEC 1979	Lake Way Joint Venture Appendix 4 – Radon Emanations, - AAEC 1979
ARPANSA 1995	Recommendations for Limiting Exposure to Ionizing Radiation, Radiation Protection Series, vol. 1, Australian Radiation Protection and Nuclear Safety Agency , Yallambie, Victoria.
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 Yallambie, Victoria
ARPANSA 2008	Code of Practice for the Safe Transport of Radioactive Material (2008), Australian Radiation Safety and Nuclear Safety Agency Yallambie, Victoria
RPS Aquaterra 2010	Centipede Groundwater Impact Assessment 2010
BHP Billiton 2009	Olympic Dam Expansion Draft Environmental Impact Statement 2009
Cember 2009	Herman Cember; Introduction to Health Physics 4th edition, ISBN 978-0-07-142308-3
CRC 1981	CRC Handbook or Physics and Chemistry 64th edition
Hardege 2008	Environmental Radioactivity Monitoring in Australia 2005 and 2006, Australian Radiation Safety and Nuclear Safety Agency, Technical Report No. 149
IAEA 1996	International Atomic Energy Agency, International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, in Basic Safety Standards. 1996: Vienna.
ICRP 1991	Annals of the ICRP, Publication 60, 1990 Recommendations of the International Commission on Radiological Protection
ICRP 1993	Annals of the ICRP, Publication 65, Protection Against Radon-222 at Home and at Work
ICRP 2007	Annals of the ICRP, Publication 103, The 2007 Recommendations of the International, Commission on Radiological Protection, Editor J. Valentin
Kutty 2010	Keeping Radiation Management at Beverly Uranium Mine at Best Practice; Plans, Responses and Outcomes; S. Kutty, P. Woods, A, Jagger, Presented at 35th ARPS Conference Adelaide 2010.
NHMRC 2004/NRMMC 2004	Australian Drinking Water Guidelines 6, 2004 National Health and Medical Research Council and Natural Resource Management Ministerial Council
Thompson 1994	Thompson, RS 1994, 'Residence Time of Contaminants Released in Surface Coal Mines – a Wind-tunnel Study', proceedings. 8th Air Pollution and Meteorology Conference, American Meteorological Society.
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.

Toro Air Quality Assessment 2011	TORO Energy Limited, Wiluna Uranium Project, Air Quality Assessment, Prepared by Air Assessments, February 2011
Thomson and Wilson 1980	Thomson, JE & Wilson, OJ 1980, Calculation of Gamma Ray Exposure Rates from Uranium Ore Bodies, Australian Radiation Laboratory, Yallambie, Victoria.
Western Australian Department of Mines and Petroleum 2010	Naturally occurring Radioactive material (NORM) in Mining and Mineral processing Guidelines (also known as the NORM guidelines)
1981 DEIS	Lake Way Joint Venture Draft Environmental Review and Management Programme Environmental Impact Statement - Lake Way Uranium Project prepared by Brian Lancaster and Associated March 1981.
AAEC 1980	Lake Way Joint Venture. Environmental Impact Statement Lake Way Uranium Project. March 1981. Appendix 4. Predictions of Radon Emissions Due to Mining and Milling Operations at Lake Way Uranium Prospect by S. Whittlestone. October 1980. A consultant report to Wyoming Corporation from the Australian Atomic Energy Commission (AAEC)
AAEC 1979	Lake Way Joint Venture. Environmental Impact Statement Lake Way Uranium Project. March 1981. Appendix 4. Baseline Environmental Radon Survey at Lake Way W.A. September 1979, by J. Casteleyn, B. O'Brien and S. Whittlestone. A consultant report prepared by Australian Atomic Energy Commission (AAEC).
ARPANSA 2005 - Information Sheet	ARPANSA 2005 - Information Sheet "What's Background Radiation?"
Mudd 2002	Mudd, G M, 2002, Uranium Mining in Australia : Environmental Impact, Radiation Releases and Rehabilitation. Invited Presentation at "SPEIR 3 - Symposium on Protection of the Environment From Ionising Radiation", Darwin, NT, July 2002
DMP 2010	Former Kalgoorlie Research Plant Site Radiation Survey Report, Government of Western Australia, Department of Mines and Petroleum, Resources Safety, March 2010
Honeymoon EIS	Honeymoon Uranium Project - Environmental Impact Statement - Southern Cross Resources Australia Pty Ltd. 2006
Kaste 2007 -	Short-term soil mixing quantified with fallout radionuclides, James M. Kaste, Arjun M. Heimsath and Benjamin C. Bostick. Geological Society of America, March 2007
Chiang 1987	Airborne dust distribution in longwall faces, H. S. Chiang, Y. Luo and S. S. Peng, Geotechnical and Geological Engineering, Volume 5, Number

	4, 1987
WMC 1982	Environmental Impact Statement for the proposed Olympic Dam Mine.

APPENDIX C: Radon Source Estimates

Introduction

Estimates of radon emanation from the proposed project have been based on earlier work outlined in *Predictions of Radon Emission due to Mining and Milling Operation at Lake Way Uranium Project*, Australian Atomic Energy Agency, October 1980 (the AAEC report). The work predicted that the total radon emanation from the project would be 2.3MBq/s which is twice the natural background emissions from a 3-kilometre radius disc over the undisturbed mine centre. It was noted that after mining, the emission levels would return close to the levels before the development. Uncovered fine tailings were expected to emit up to 8MBq/s.

A summary of the radon estimates are as follows:

Ore and Tailings

For ore stockpiles and dry tailings, AAEC reports radon emanations as:

$$\phi_D = G \times 60.4 \mathrm{Bq/m^2s}$$

where G is the uranium ore grade (%).

For the proposed operations, the average ore grade (G) is 600ppm (0.06 per cent). Low grade ore is assumed to be 200ppm (0.02 per cent). Estimates are based on an emanation coefficient of 0.2.

Saturated ore or wet tailings are estimated to be G x 0.67Bq/m^{2}s.

For the purpose of radon emanation estimates, backfilled pits, once appropriately covered are assumed to be the same as the natural background levels.

Processing Plant

The radon release rate for the processing plant is estimated by the AAEC report to be:

$$R = 0.304 \times P \times G \ \mathrm{Bq/s}$$

where P is annual ore processed per year (tonnes) and G is average ore grade (%).

Pit Water Disposal

It was assumed that all radon contained in groundwater would be released within minutes of leaving the dewatering pump outlet. For an assumed rate of 3ML/d, the estimated radon release per year is 9.2kBq/s.

Total Radon Release

The total radon release is dominated by the releases from exposed ore and can be seen in Table 1. Toro is undertaking further test-work to better define these estimates.

Table 1: Estimated Radon Release and Emanation

Radon Source	Radon Emanation Rate (Bq/m^2s)	Radon Release Rate kBq/s
Pit	3.6	
Stockpile – low grade	1.2	
Stockpile – ore	3.6	
Processing plant (assume 2Mt/y ore)		40
Tailings – dry	3.6	
Tailings – saturated	0.05	
Groundwater		9

Appendix D: Example of Dose Assessment

Calculating worker or member of the public radiation dose is based on radiation measurements and follows an internationally standard process. There are a number of steps which involve calculations based on the results of monitoring and standard conversion factors. The process is outlined in Table 1. The conversion factors are provided in Appendix E.

The total dose is the sum of the doses from each of the exposure pathways.

Table 1: Example of occupational dose assessment.

Radiation Exposure Pathway	How Exposure Is Measures	How Dose is Calculated
Gamma Irradiation	Personal TLD badges. If no badge is assigned or it is lost, the person receives the workgroup average.	The results from the analysis of TLD badges are in microSieverts
Inhalation of radioactive dust	Dust sampling pumps are issued to workers in specific workgroups. Area samplers are also placed to give a workplace average. Usually many samples are taken and the sampled dust is analysed for radionuclides and an average is worked out. The workers timesheets then provide information on where they were working or what workgroup they were in. Combining the workgroup average and the time in the workgroup provides a measure of 'exposure'.	Using a conversion factor (supplied in ARPANSA 2005), the dose can be calculated based on workplace averages and workers exposure times.
Inhalation of Radon Decay Products (RDPs)	Workplace sampling of air is undertaken (using grab samples or continuous monitors) and the concentration of RDPs is determined and an average exposure level for workers or workgroups is determined.	There is a standard dose conversion factor for RDPs which converts the RDP exposure to a dose. This conversion factor is from ARPANSA 2005.

APPENDIX E: Assumptions and Dose Factors

Throughout this document, assumptions have been made for various calculations. The main assumptions and their justification can be seen in the following table.

Assumption	Justification
Average uranium grade of mined ore is 600ppm	Based on mine plan
Average uranium grade of ore dust is 600ppm	Based on ore grade
Average uranium grade of mined material is 300ppm	Based on 50 per cent ore and 50 per cent overburden being mined
Average uranium grade of mining dust is 300ppm	Based on mined material grade
Average grade of all dust produced from mine is 200ppm	Based on grade of all mine material and component for road dust
Average dust concentrations during mining is 1 mg/m^3	Various sources indicate coal dust concentrations of approximately 1 mg/m^3 (Chiang 1987)
Assumed soils mixing depth of 10 centimetres for life of the mine	Kaste 2007
Natural uranium concentration in soil is 3ppm	From UNSCEAR 2000
Member of the public DCF for radon decay products is 1.1 $uSv/(uJh/m^3)$	From ICRP 1993
Member of the public DCF for radioactive dust is 51 uSv/Bq	Derived from figures in IEAE 1996 and uses AMAD of 1 micron and 'S' lung solubility class
Occupational DCF for radon decay products is 1.4 $uSv/(uJh/m^3)$	From ARPANSA 2005
Full year exposure for a member of the public is 8,760 hours	Assumes exposure all year
Full year exposure for a workers is 2,000 hours	Assumes exposure only while

	working
Worker breathing rate is 1.2 m^3/h	

APPENDIX F: Historical Review of Radon and RDP Information for Lake Way

Introduction

The radiological assessment for the 1981 DEIS (Lake Way Joint Venture – Appendix 4 Radon Emanations) included an investigation into the pre-existing radon and RDP environment in the region. The work was conducted by the AAEC (see Appendix F of this report) and a summary of the results is provided here.

Additional radon related work was undertaken in 2007 and 2008 and these results have also been summarised.

In general, these earlier results are consistent with the findings of the more recent work including the assessments undertaken in 2010 for this ERMP. The earlier work also included an estimate of radon emissions from the proposed project.

AAEC Work

During September 1979, the AAEC undertook a 10-day field survey conducting measurements of the following environmental radiological parameters:

- Radon concentrations in air using spot sampling (Lucas cells), continuous radon monitoring and long term passive track etch radon sampling;
- RDP concentration in air monitoring using spot sampling (Rolle method);
- Surface radon emanation using the drum accumulator method;
- Radon concentrations in water; and
- Radon emanation from ore samples.

Radon and RDP sampling

Sampling was undertaken at a number of locations in the region with comparisons made between the radon and RDP concentrations at these sites and the key findings of the work are summarised here.

In summary, the data shows that there are two mechanisms contributing to radon concentrations (and hence RDP concentrations) in the region. Firstly, the mine area is an enhanced source of radon and secondly, the atmospheric conditions can lead to a build-up of radon concentrations. The data shows the following:

- The mine area is a broadly distributed source of radon emitting about 10 times as much radon as from a distance of > 6 km;
- On one sampling run, RDP concentrations were simultaneously measured to be 30 mWL at a sampling site on the mine area and 3mWL at a proposed camp site (approximately 6 kilometres from the mine area) when the wind was downwind of the mine;
- The work noted a strong correlation between radon, RDP and meteorological data under very stable atmospheric conditions (stability class F and G), with radon concentrations during very stable conditions measured to be 10 times higher than during unstable conditions;
- The data show that the average equilibrium factor (ratio of RDP concentration to radon concentration) is 0.2;
- Predicted concentrations at the mine site were made as follows; 5 to 10mWL and 200 to 300Bq/m^3. It was noted that under extreme stability for 12 hours, concentrations could reach 0.6WL and 2160Bq/m^3; and
- The data shows that surface radon emanation is 0.3Bq/m^{2}s up to 2 kilometres from the mine, and 0.044Bq/m^{2}s beyond 2 kilometres from the mine area.

Radon in Water

- Water from mine bores range 1,000 to 10,000Bq/L, with an arithmetic average of 1,600, geometric mean of 1,000 and a median of 1,200Bq/L
- Regional bores are all less than 690Bq/L (excluding one outlying result)
- The radon concentration in groundwater is 17 times higher from groundwater from the mineralised area
- Potable water supplies were measured at 81Bq/L

Radon Emanation

Radon emanation test-work was undertaken on a range of samples (12) with uranium grade varying from 400 - 1,500ppm uranium. The results show an average emanation co-efficient of 0.08Bq(Rn^{222})/Bq(Ra^{226}) in ore (range 0.05 - 0.17).

Summary of 1979 Monitoring results

Note that the following results are summarised form the earlier work by the AAEC. The original units have been maintained.

Table 1: Summary of radon and RDP Monitoring (at location 4000S and 5000E), 5 Sept to 15 Sept 1979

Time	Radon Concentration (Bq/m^3)		RDP Concentration (mWL)	
	Active	Passive	Active	Long Term
0000-0800	180		16.9	
0800-1700	45		1.6	
1700-2400	97		5.7	
0000-2400	101	101	7.1	6.7

Table 2: Additional long term sampling was also undertaken.

Location	Time	Bq/m^3	mWL
4250N 3500E	0000-2400	75	1.4
250S 14500E	0000-2400	101	2.6

Table 3: Summary of radon emanation

Location	Radon Concentration (Bq/m^{2}s)
Regional (> 3 km)	0.044
Outer mine (2-3 km)	0.136
Inner mine (0-2 km)	0.3

Table 4: Radon in Potable Water (Bq/L)

Location	Concentration (Bq/L)
Town Supply	6 – 11
Baldy Well	28 – 34
Mission Bore – non production	0
Mission Bore – production	41 – 50
Millbillillie Homestead – bore	81
Millbillillie Homestead – tank	25

Summary of Radon Concentrations Results (2007/2008)

Additional radon concentration monitoring was undertaken in 2007 and 2008 in the region. Monitoring was conducted using passive track etch devices. The results of the monitoring are summarised in Table 5. Track etch devices provide a long term average. Potential sources of error are noted in NRPB 2005.

Table 5: Passive Radon (Track Etch) Average Radon Concentrations (Bq/m^3)

Location	Aug– Nov 2007	Feb – Aug 2008	Aug 2008 – Mar 2009
Lake Way	41	71	16
Nth Lake Violet Mining Operations	20	58 (30*)	23
Centipede	30	46	25
Wiluna South Operations	15	23	17
Wiluna	22	14	22
Average	26	37	21

Note: Aug 2007 – Nov 2007 – track etch detectors from RDS.

Feb 2008 – Aug 2008 and Aug 2008 – Mar 2009 – track etch detectors from ARPANSA.

(*) Without outlying result

APPENDIX G: Recent Radon and RDP Concentrations at Lake Way

Introduction

In 2010, Toro Energy conducted radon and RDP monitoring at the Lake Way and Centipede deposits.

Monitoring included:

- Real time RDP monitoring using an ERDM (environmental radon decay monitor) between June 2010 and November 2010;
- Real time radon monitoring using a Durridge Rad 7 in November 2010; and
- Long term passive radon monitoring using track etch devices since June 2010.

The primary monitoring location for the real time detectors was the existing works areas at the Centipede site as a power supply was available at this location. The track etch monitors were placed more widely.

Additional monitoring continues and will be reported as part of the regular monthly monitoring program or when results become more available.

The sampling was conducted during the time of year when atmospheric conditions are most stable.

Results

Radon

Due to instrument difficulties, limited real time radon sampling was undertaken. A time plot for the radon concentrations at the sampling locations can be seen in Figure 1.

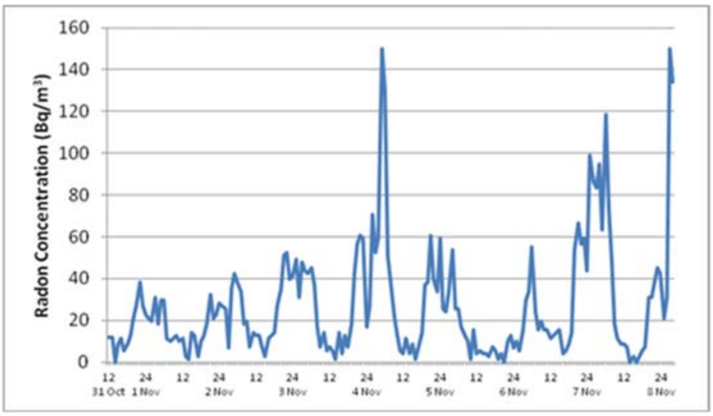

Figure 1: Radon concentration by time of day

The data showed:

- Regular and clear diurnal variation with peaks occurring on most nights
- Average radon concentration during sampling period was 27Bq/m^3.
- Peaks of up to 150Bq/m^3 are observed

Passive Radon Monitoring

In addition to the active real time radon and RDP monitoring, passive radon detectors were used to assess the long term radon averages in the region. These devices use track etch technology and were placed into the field for a period of approximately three months. Fifteen locations were sampled as presented on Figure 1 using a pair of monitors.

Individual sampling results range from 14 to 83 Bq/m^3 for the sampling period. Concentrations were higher closer to the ore body, and lower away from the mineralised area. Average results were:

- Close to Lake Way average is 46Bq/m^3
- North west of Lake Way is 33Bq/m^3
- South east of Lake Way is 27Bq/m^3
- Total average for region is 38Bq/m^3

RDP Concentrations

Real time RDP monitoring has been conducted at the site office at Centipede since June 2010. The monthly plots can be seen in Figures 2 to 6, and clearly show the effect of stable conditions during night.

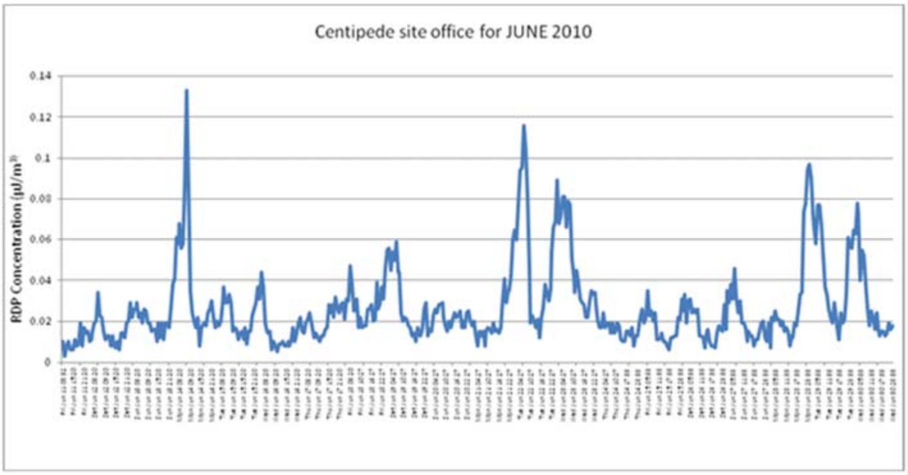

Figure 2: RDP Concentration June 2010

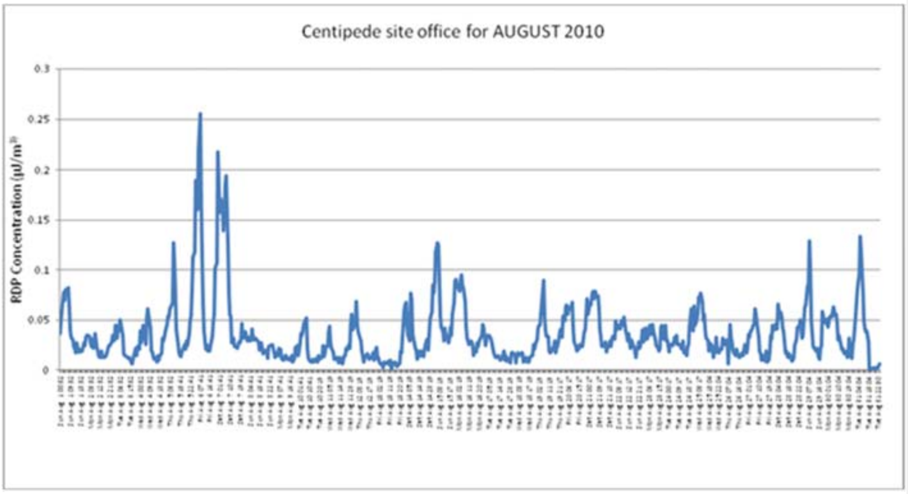

Figure 3: RDP Concentration August 2010

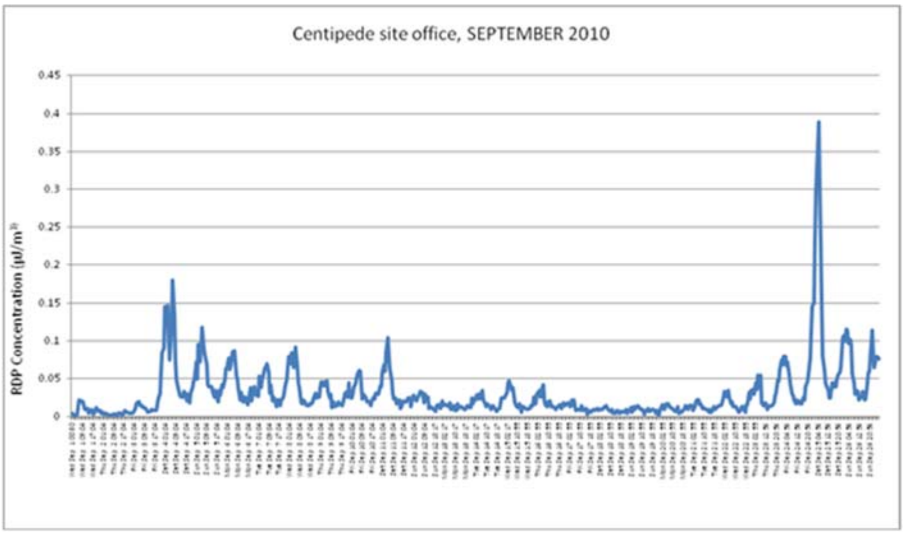

Figure 4: RDP Concentration September 2010

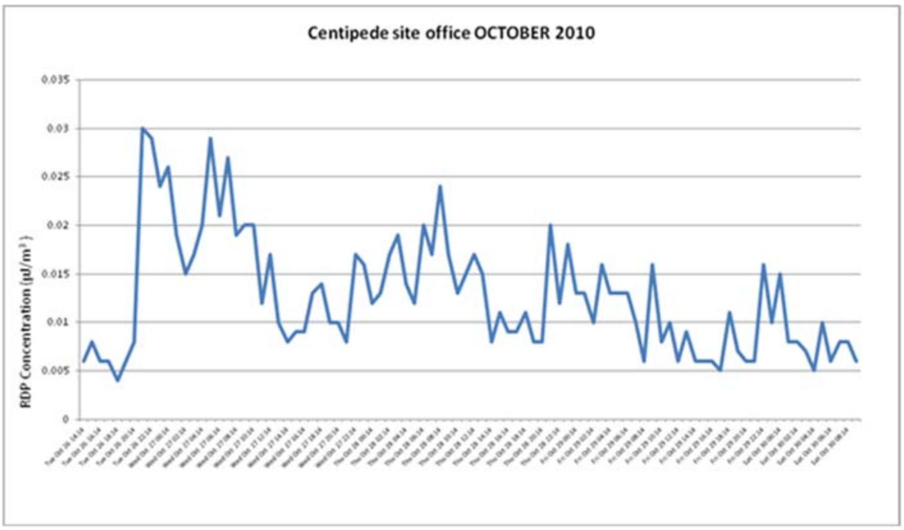

Figure 5: RDP Concentration October 2010 (note that only short run time occurred)

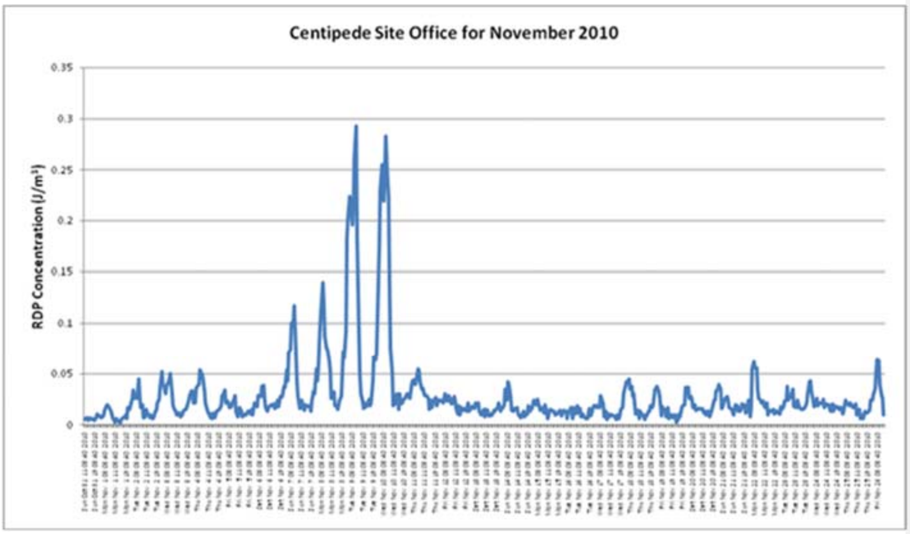

Figure 6: RDP Concentration November 2010

Figure 7 shows the average RDP concentrations by time of day for each month of sampling and better highlights the diurnal variation that occurs.

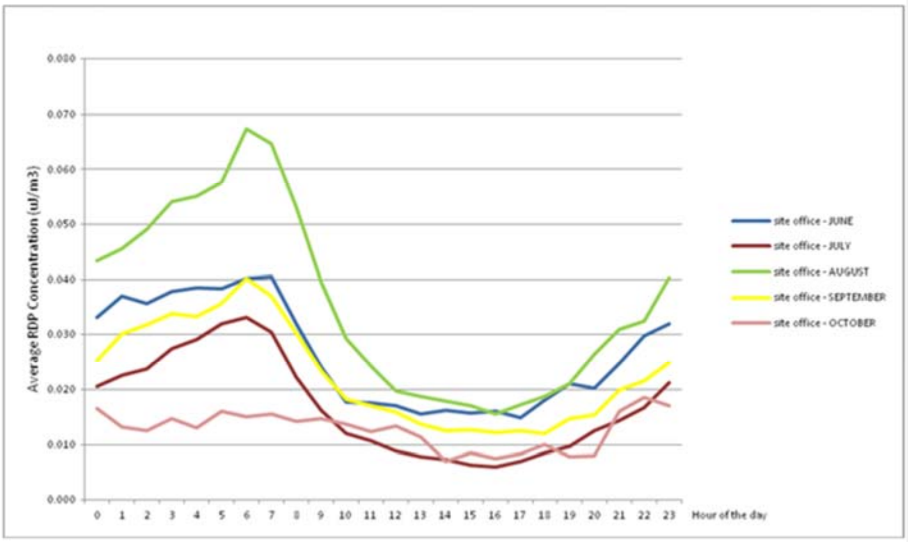

Figure 7: Monthly RDP Concentration Comparison

During the sampling period, Toro excavated a test pit to obtain a bulk sample for metallurgical testing. The RDP sampling occurred during this period and a comparison of the average hourly concentrations can be seen in Figure 8.

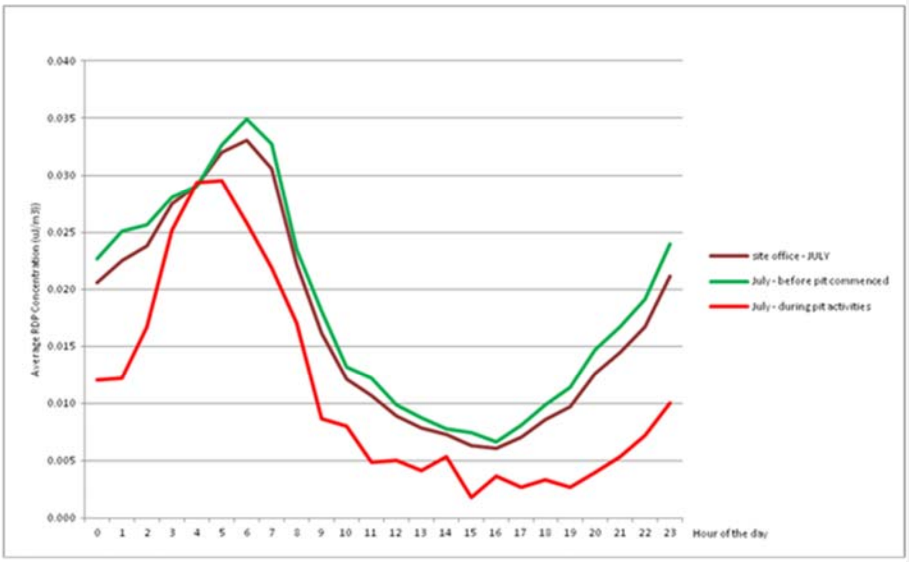

Figure 8: Comparison of RDP Concentrations Before and During Test Pit Excavation Work

As can be seen, there is no significant difference.

The comparative statistics for the RDP data can be seen in Table 2.

Table 2: RDP Data and Statistics

Dates	RDP Concentration (uJ/m3)			
	Ave	Max	Av(day)	Av(night)
11/6 – 30/6	0.026	0.133	0.010	0.038
1/7 – 31/7	0.017	0.127	0.010	0.033
1/8 – 31/8	0.036	0.256	0.015	0.065
1/9 – 27/9	0.031	0.398	0.010	0.055
26/10 – 30/10	0.013	0.030		
31/10 – 27/11	0.029	0.293	0.015	0.052

(Note: due to instrument malfunction, there is insufficient data for all analyses for October)

The data show similar trends to the radon concentration data and the highlights are:

- Peaks occurring on the majority of nights during the sampling period
- Average night time concentrations are three to four times the day light concentrations

Comparison of Radon and RDP Data

Monitoring was conducted during November at the Centipede site office for radon and RDP concentrations providing comparison data.

The following figure shows the radon and RDP concentrations over the sampling period on an hourly basis. As can be seen, there is good correlation between the two sets of results, with peaks in both data sets occurring concurrently over the period.

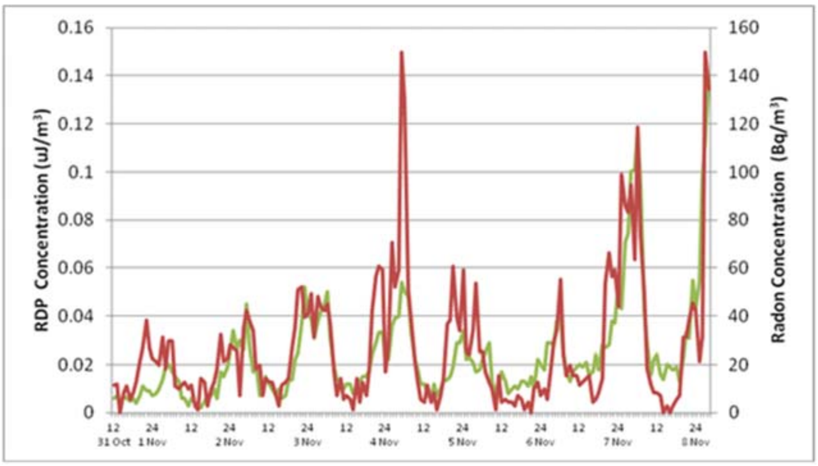

Figure 9: RDP and Radon Concentration

Equilibrium Factor

The equilibrium factor is a measure of the ratio of the RDP concentration and the radon concentration in air and is expressed by the following formula:

E = 56.2 x RDP concentration (uJ/m^3) / radon concentration (Bq/m^3)

The side by side radon and RDP data from the Centipede site provides a real time measure of the equilibrium factor and shows that the average is 0.08.

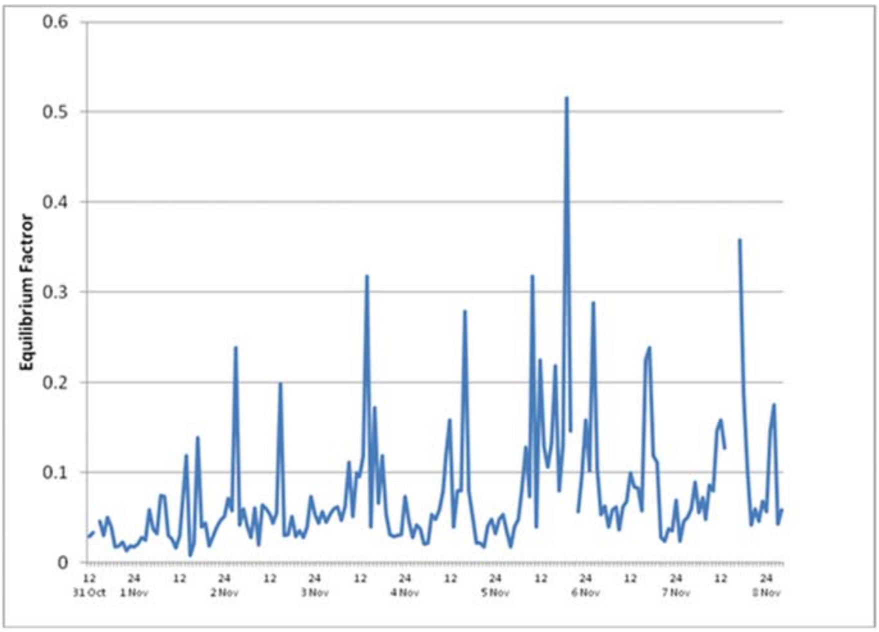

Figure 10: Equilibrium Factor

APPENDIX H: Assessment of the Potential Radiological Food-chain Impacts of Operations at Lake Way

Introduction

The Wiluna Uranium Project may result in the transfer of radionuclides into the environment and potentially to people who may obtain food from the land.

The aim of this note is to estimate the likely radiological consequences of radionuclide emissions from the proposed operations on the human food-chain, with a focus on individuals who may 'live off the land'.

This assessment will only consider the potential doses from radionuclides that are the result of the operations.

Background

The Lake Way region is an area of pre-existing, enhanced, naturally occurring radionuclides. This is because the Lake Way area is a deposition basin which has resulted in the natural accumulation and enhancement of metals, including uranium. Levels of all naturally occurring radionuclides in the uranium decay chain are enhanced in the region compared to world average concentrations.

Assessment Method

Toro has conducted baseline monitoring which can be used to determine the doses that could naturally be received by consumption of locally grown foodstuffs.

The first step of the assessment is to determine what is deposited in the environment. The air quality modelling (including dust deposition modelling) provides a measure of the amount of dust, and therefore radionuclides, that are deposited into the environment.

The air quality dust deposition modelling shows that apart from inside the delineated mining, processing and ore transport corridors, the dust deposition levels are approximately 0.5 g/m^2 per month. A conservative approach to the assessment has been undertaken and it has been assumed that this figure applies to all deposition beyond the mining area boundary. In practice, this is not the case as the deposition drops off rapidly (as can be seen in the contour plots). However, it has been applied here to demonstrate worst case.

By determining the grade of the uranium in the dust, the concentrations of radionuclides can be calculated. The average ore grade is 600ppm of uranium. However, the airborne radiological assessment noted that a large proportion of the dust is overburden or road dust, and does not contain uranium ore. Therefore, it was calculated that the average uranium grade of all of the dust emissions from the project was approximately 200ppm which equates to a radionuclide concentration of 2.5Bq/g (for each radionuclide).

Assumptions in Assessment

The following assumptions have been used in this assessment:

- Consumption of foodstuff at project boundary (for this assessment, the 0.5g/m^{2}month deposition contour has been used);
- The average uranium grade of deposited dust is 200ppm;
- Assessment is done at the end of 15 years of deposition (mine life is 10 to 14 years);
- The IAEA 1996 transfer factors are used;
- The background radionuclide concentrations in vegetation and soil are calculated from the average of samples away from the mining area; and
- Dust deposits and only mixes in the top 10cm of soil.

Findings

Based on the assumptions, the modelled increases in radionuclide concentrations in soils are as follows:

	$U^{238/234}$	Th^{230}	Ra^{226}	Pb^{210}	Po^{210}
% Increase in Concentration	5	8	4	3	3

It should be noted that these changes are small and within the range of measured natural background concentrations.

The changes in soil concentrations, as a result of the dust deposition, provide the basis to model changes in the vegetation radionuclide concentrations.

Through uptake modelling and using the most conservative uptake factors from IAEA 1996 (either for leafy vegetables, root vegetables or fruit), doses to humans through consumption of the vegetation can be calculated to increase (above those received naturally) by less than 5 per cent.

Conclusions

The results imply that the radiological effects in the region are dominated by the naturally enhanced levels of radiation. The increase in radionuclide levels in the environment at the boundary of the operation at completion of operations is calculated to be approximately 5 per cent.

APPENDIX I:Radiological effects on non-human biota arising from the Wiluna Uranium Project

21st Feb 2011

A report prepared for

Toro Energy Limited

by

Philip Crouch BSc(Hons) PhD MARPS

Papari Radiation Services

February 2011

Executive Summary

An assessment of the potential for radiological effects on the environment resulting from the operation of the Wiluna Uranium Project has been conducted using the ERICA assessment tool.

The Assessment indicates that any potential for harmful effects is restricted to small areas, up to 2 kilometres across, around the two mining sites.

Contents

Figures

1. Introduction

Toro Energy Limited (Toro) intends to develop the Wiluna Uranium Project in central Western Australia. The resource is in two deposits, Centipede and Lake Way, together containing approximately 11,000 t of U_3O_8. A processing plant is expected to be established near the southern (Centipede) deposit. Each deposit will be mined over approximately five years, with ore from the Lake Way deposit being trucked to the processing plant. Both orebodies are shallow and will be mined by open-cut methods. Uranium production is expected to be at the rate of approximately 800 t per annum [1].

This report concerns the potential radiological effects on non-human biota (NHB) of the proposed operations. It is concerned only with the dispersion of radionuclides into the environment through airborne pathways, and does not consider any effects that may arise from transport of radionuclides in surface or groundwater.

2. 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 [2, 3]. 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 [4]. 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 has recommended that environmental radiological effects should be assessed on a series of 'reference organisms', and these are incorporated into the ERICA tool [5].

The starting point for an ERICA assessment is the radionuclide concentrations of the medium in 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 factors' from the ERICA database are used to calculate the radionuclide concentrations in the organisms to be calculated, and hence the internal dose rates.

The assessment process can be carried out in three tiers. Tier one is a simple, highly conservative assessment, designed to easily identify situations which can be considered of negligible radiological concern. Tier two is used where a tier one 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 if there is a likelihood that populations are likely to suffer harm. Tier three is not a screening tier but is designed to provide guidance in further investigation of situations where tier two indicates that there may be a significant concern of radiological harm.

The default screening dose rate adopted by ERICA is 10 µGy/h. This dose rate (described as the “predicted no-effect dose rate”, PNEDR) was derived from the dose estimated to give a 10 per cent effect (ie to one of the end points noted above) to 5 per cent of the species present by applying a safety factor of five. This screening rate is thus expected to protect the most radiosensitive organisms likely to be present in an environment [6]. The ERICA tool allows other screening dose rates to be adopted. For example, several organisations have suggested that no measureable effects would be observed for dose rates of 40 µGy/h (terrestrial animals) and 400 µGy/h (terrestrial plants) [7-9]. The ERICA tool presents the results as the dose rates to the organisms, and also in terms of the ‘Risk Quotient’: the ratio of the dose rate to the screening rate. Dose rates and risk quotients are presented both for the ‘expected value’ and a ‘conservative value’. The default conservative value is three times higher than the expected value and represents the value at which there is only a 5 per cent 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 them be described in terms of three dose rate bands [2]:

- RQ_{Expt} > 1 (ie expected dose rate > 1)
  Screening dose is exceeded. Further assessment needed.

- RQ_{Cons} > 1 but RQ_{Exp} < 1 (ie expected dose rate 3.3 – 10 µGy/h)
  Substantial probability that screening dose rate is exceeded. Assessment should be reviewed.
- $RQ_{Cons)}$ <1 (ie expected dose rate <3.3 µGy/h)
  Low probability that screening dose rate will be exceeded. Environmental risk is arguably negligible.

A disadvantage in using the ERIC tool for Australian situations is that many of the parameters are derived for temperate northern hemisphere conditions. The most obvious is the case of kangaroos. ICRP has recommended a 'large mammal' as one of the set of references and deer were chosen because of their widespread occurrence (in the northern hemisphere), and the large amount of radioecological data available for them [5]. In Australia, the equivalent niche (grazing mammal) is filled by kangaroos, but the radioecological data for them is relatively sparse [10]. For the purposes of this assessment, the kangaroo is assumed to have the same radiological parameters as the deer. As will be noted below, this assumption is not likely to affect the overall conclusions of the assessment.

Environmental radionuclide concentrations

The only pathway of significance in this assessment is dispersion of project generated radioactive dust. As noted above, waterborne 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 do not accumulate in the vicinity of the project.

Atmospheric dispersion modelling has been conducted for the project, and as part of this dust deposition contours have been calculated [11]. Figures 1 and 2 show these contours: Figure 1 shows year four of the project, when the Centipede ore body is being mined, and Figure 2 shows year eight when the Lake Way ore body is mined. These two plots do not include dust generated from ore haulage between the two mine sites and the processing plant. This haulage will be along roads which are surfaced with materials that are not mineralised and thus have radionuclide concentrations typical of normal soils from the area. Consequently, deposition of dust arising from this source will have no significant effect on the radionuclide concentrations in the surrounding areas.

To estimate the increase in soil radionuclide concentrations as a result of this dust deposition, the first step was to calculate the radionuclide concentrations of the dust. For the mining operations, the uranium ore grades of ‘all mined material’ (that is, ore plus waste) were estimated by Toro as 303ppm (Centipede) and 197ppm (Lake Way). For the purposes of the assessment, 300ppm was used for both mines. The overall grade of ‘ore’ is approximately 600ppm U and this concentration was used for dust arising from the processing plant. It was assumed that each mine site would operate for five years, and the processing plant would operate for 10 years.

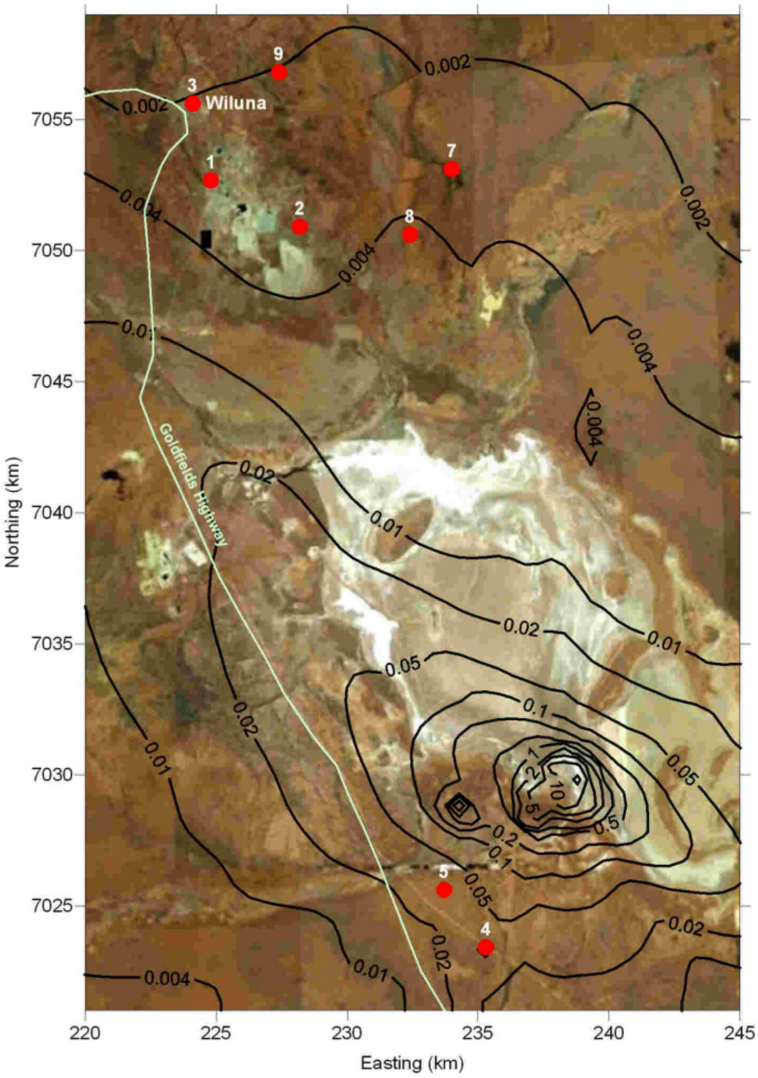

Figure 21 Dust deposition from mining and processing the Centipede deposit (g/m^2/month)

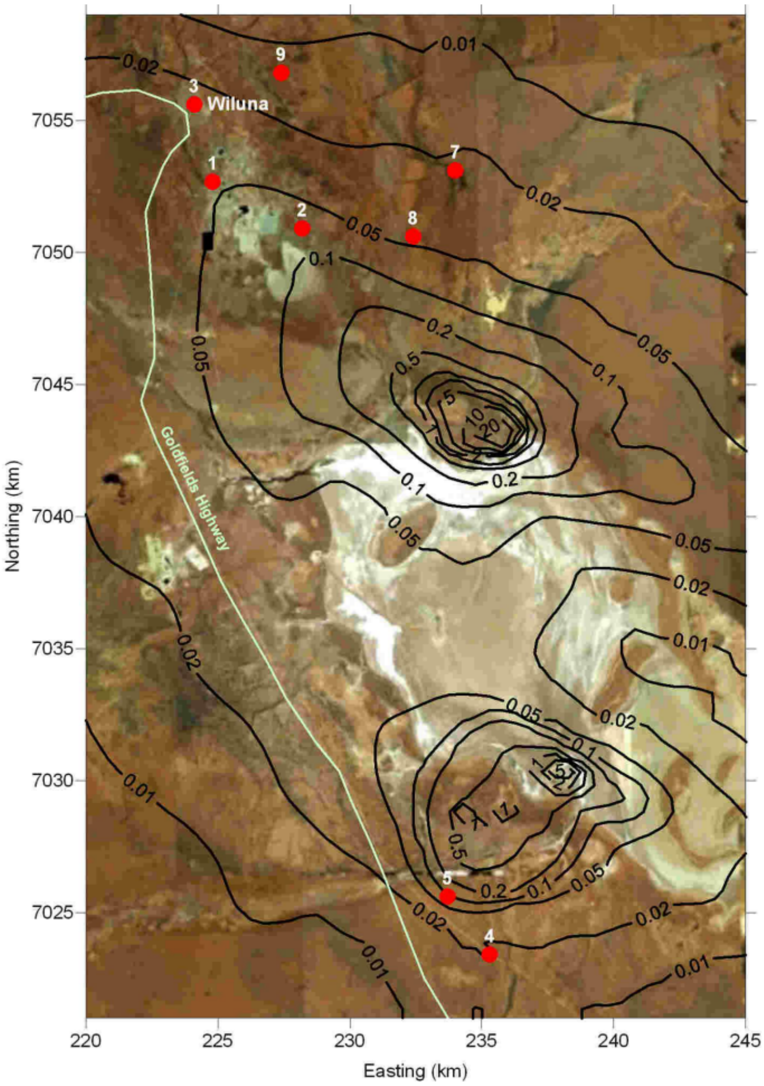

Figure 22. *Dust deposition from mining and processing the Lake Way deposit (g/m²/month)*

After depositing on the soil surface, dust will mix with the soil through a combination of physical, chemical and biological processes. For the purposes of this assessment, it was assumed that the mixing depth was 10 mm. The soil density was assumed to be 1.5 t/m³.

For a location where dust deposition from mining was 1g/m^2/month, the amount of dust deposited over a five-year mining period would be 60g/m^2. This would contain 3.75 Bq/g of uranium (U^{238}), and thus the resulting increase in soil radionuclide concentration would be 15 Bq/kg for each uranium series radionuclide. For areas affected by dust deposition from the processing plant, the soil radionuclide content resulting from ten years' deposition at 1g/m^2/month will be 60 Bq/kg.

3. Assessment

A tier one assessment was conducted, using a soil radionuclide concentration of 150 Bq/kg (each uranium series radionuclide), equivalent to the 10 g/m^2/month dust deposition contour for the mine sites. The result of this assessment was that at least one organism (lichen and bryophytes) was above the 10 µGy/h screening level, and accordingly, a tier two assessment was conducted.

The tier two assessment again used 150 Bq/kg soil radionuclide concentration and used the ERICA default values for concentration ratio, and the 10 µGy/h screening level. The resulting derived dose rates are shown in Table 1.

Table 1. Derived dose rates for the reference organisms based on a soil concentration of 150 Bq/kg

Organism	**Dose Rate (µGy/h)** (expected value)	**Dose Rate (µGy/h)** (conservative value)
Lichen and bryophytes	35	104
Detritivorous invertebrate	2.1	6.3
Soil Invertebrate (worm)	2.1	6.3
Flying insects	2.0	6.0
Grasses and herbs	1.7	5.2
Gastropod	1.1	3.4

Shrub	1.1	3.4
Bird	0.8	2.5
Amphibian	0.8	2.4
Bird egg	0.8	2.4
Reptile	0.8	2.4
Mammal (Rat)	0.7	2.0
Mammal (Deer)	0.6	1.8
Tree	0.3	0.9

For the area surrounding the processing plant, a deposition rate of 2.5 g/m^2/month gives the same increment in soil radionuclide concentration over the project life (150 Bq/kg) and consequently the same result would be obtained from ERICA.

The dose rates for all organisms are significantly below the screening level (10 µGy/h) with the exception of lichen and bryophytes.

4. Discussion

4.1.1 Lichen and Bryophytes

The expected dose rate derived for lichen and bryophytes is approximately 3.5 times the screening level (at a deposition rate of 10 g/m^2/month), and is more than 15 times higher than any other organism. 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 upon them. Consequently, they might be expected to receive a higher dose from the fallout of mine and processing dusts than is the case for other organisms.

To investigate the consequences of this higher dose rate, the radio sensitivity of the group was considered. In fact, they are extremely radio resistant: a threshold no-effect dose rate was estimated at approximately 125,000 µGy/h, and some diversity reduction was observed at 1.1 Gy/h [7]. These dose rates are over 10,000 times the default screening dose rate used in ERICA, and indicate that no effect at all would be expected from any doses that are potentially achievable in uranium mining.

4.1.2 Non-vertebrates

The expected dose rate to the non-vertebrate groups are approximately 2 µGy/h, one-fifth of the ERICA screening rate. Thus, at the 10 g/m^2/month deposition contour, no effects would be expected. However, if the conservative dose rates are considered (approximately 6 µGy/h at the 10 g/m^2/month mine contour), a deposition rate of approximately 15 g/m^2/month would be required to exceed the screening level around the mining sites, or approximately 4 g/m^2/month around the processing plant.

This group can be considered the critical organisms, in the sense that if doses to members of this group are assessed to present a negligible risk, then all other reference organisms will also be protected.

4.1.3 Vertebrates

All vertebrate groups gave expected doses of less than 1 µGy/h at the 10 g/m^2/month deposition contour, approximately one-half that of the invertebrate groups, and less than one- tenth of the screening level. At any level of deposition, the vertebrates will be not be at risk if the non-vertebrates are protected.

It is relevant to comment on the use of deer to represent the likely doses to kangaroos. The (conservative) dose that is derived for deer is approximately one-third of that of the 'critical organisms' noted above. Thus the choice of deer to represent kangaroos would have to underestimate the kangaroo doses by an approximate factor of three for the conservative kangaroo dose to exceed the screening level at the 15 g/m^2/month contour. It should also be noted that kangaroos generally range widely, and thus would be expected to only spend a fraction of their time in the potentially affected areas, which would significantly reduce doses from project emissions..

4.1.4 Affected areas

All reference organisms (excepting lichen and bryophytes) have been assessed as receiving doses less than the screening level (with a conservative uncertainty factor of three), and thus having a negligible risk, in areas receiving dust fallout less than 15 g/m^2/month around the mining sites, and 4 g/m^2/month around the processing plant. From Figures 1 and 2 it can be seen that for the two mine sites these areas are small – approximately 2 km across. These areas will include the mine operational areas: the pits, stockpiles and other facilities. The area in which reference organisms are potentially at risk is thus very small. For the processing site, dust deposition does not appear to exceed the 4 g/m^2/month level at any point, and so no organisms will be at risk in the vicinity of the plant.

In the long term (after closure of operations) mixing of deposited radionuclides with soil is expected to continue, with a consequent reduction in concentrations in the surface soil. The doses to the reference organisms would therefore be expected to reduce over time.

5. Conclusions

The risk of radiological harm is assessed as 'negligible' for all reference organisms (with the exception of lichen and bryophytes) at points where dust fallout is less than 15 g/m^2/month around the minesites, and 4 g/m^2/month around the processing plant. Lichen and bryophytes are very resistant to radiation, and no effects are expected at any dust fallout level.

The areas where such dust fallout levels are expected are approximately 2 km across at each of the two mine sites. Dust fallout from the processing plant is not expected to reach 4 g/m^2/month. The areas in which reference organisms are potentially liable to be affected are thus quite small.

References

1. Toro Energy Limited, *Wiluna Uranium Project Environmental Scoping Document*. 2010: Perth.

2. Brown, J.E., et al., *The ERICA Tool.* Journal of Environmental Radioactivity, 2008. **99**: p. 1371-1383.

3. Larsson, C., *An overview of the ERICA Integrated Approach to the assessment and management of environmental risks from ionising radiation.* Journal of Environmental Radioactivity, 2008. **99**: p. 1364-1370.

4. Copplestone, D., J. Hingston, and A. Real, *The development and purpose of the FREDERICA radiation effects database.* Journal of Environmental Radioactivity, 2008. **99**(1456-1463).

5. 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): p. 201-270.

6. Garnier-Laplace, J., et al., *Issues and practices in the use of effects data from FREDERICA in the ERICA Integrated Approach.* Journal of Environmental Radioactivity, 2008. **99**: p. 1474-1483.

7. UNSCEAR, *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.

8. US Dept of Energy, *A graded approach for evaluating radiation doses to aquatic and terrestrial biota*, in *DOE Standard*. 2002: Washington.

9. IAEA, *Effects of ionizing radiation on plants and animals at levels implied by current radiaiton protection standards*, in *Technical Reports Series*. 1992, International Atomic Energy Agency: Vienna.

10. Johansen, M.P. and J.R. Twining, *Radionuclide concentrations in Australian terrestrial wildlife and livestock: data compilation and analysis.* Radiat Environ Biophys, 2010. **49**: p. 603-611.

11. Air Assessments, *Wiluna Uranium Project Air Quality Assessment*. 2011, Air Assessments: Perth.