ATTACHMENT 3

REVIEW OF OCCUPATIONAL, PUBLIC AND ENVIRONMENTAL RADIATION IMPACTS

FOR THE TORO ENERGY PUBLIC ENVIRONMENTAL REVIEW

APRIL 2016

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1 INTRODUCTION

This document provides a response to the issues raised by the Department of the Environment (DotE) from their review of Toro's Public Environmental Review (PER) (Toro Energy, 2015) for the mining and associated activities for the Millipede and Lake Maitland uranium deposits. These comments may also be suitable for questions and comments made by other government agencies and members of the public.

Table 1 addresses specific issues raised in comments.

Table 1: Issues Raised by the DotE

PER Item	Issue	Response
General	Assessment of radon decay product dose based on the revised International Commission on Radiological Protection (ICRP) dose factor and the impacts on dose estimates, commitments to radiation protection, and monitoring programmes.	See section 3.1 and table 10 of this document. The impact of the change has minimal impact on assessed dose and on commitments to radiation protection and monitoring programs.
Section 14	There seems to be an inconsistency with the ore grades quoted in this section and subsequently used in the assessment. Page 14-30 listed ore grade 0.055% reduced to 0.03% in dust Page 14-32 listed ore grade of 800ppm (0.08%) Page 14-35 lists ore grade of 0.08% (800mg/kg) reduced to 0.02% (200mg/kg) in dust.	The proponent has responded to this directly. For the purposes of public and environmental radiation impact assessment, a weighted average of all dust emissions from both Millipede and lake Maitland has been calculated to be 200mgU/kg.
Section 14.7	Statement that Millipede and Lake Maitland deposits are very similar in grade and therefore operation at both would mine to a similar ore grade cut-off and the impacts of mining similar ore grades are expected to be common—although in general this is true, impact will depend not only on ore grade, but other factors such as groundwater flow regimes and pH, wind flow patterns—therefore each site needs to be assessed separately	Occupational radiation impacts are expected to be practically identical (see table 2 and 3 of this document). For public and environmental radiation impacts, each site has been assessed separately. This document provides further detail on the assessment approach at Millipede and Lake Maitland.
Sections 14.7.4 and 14.7.5	Radiological impacts at Millipede and Lake Maitland—as per comment above, sections on Millipede and Lake Maitland should be separated	This document describes the assessment approach for Millipede which is consistent with the approach undertaken during EPA Assessment 1819 for Centipede and Lake Way. Clarification is also provided on inconsistencies identified by DotE in PER Appendix 10.60.
14.7.4 Page 14-30	Reference to the theoretical maximum exposure and Toro's estimate.	See comments in section 3.1 of this document.
Section 14.7.5	Inclusion or not of radioactive dust included in stockpiles is included in radiation exposure calculations.	See comments in section 3.5 and also comments in air quality review.

PER Item	Issue	Response
Section 14.7.5 – page 14-35	There is no quantitative evidence provided for the choice of 200 mg/kg as average concentration of uranium in dust	The average concentration was determined by reference to the characteristics of all mined materials of the Millipede and Lake Maitland deposits. A calculation is provided at section 3.4.
Appendix 10.60 – Table 5	Values presented in the table appear to be far too low and subsequently the assessment for the worker occupancy dose is also incorrect	Worker exposure at Lake Maitland discussed in section 3.5
Appendix 10.60 – Table 27	Some of the doses do not appear to be correct (e.g. radon doses seem far too low)—more detail should be provided as to breakdown of the contributions from each radionuclide	Public exposure at Lake Maitland discussed in section 4.
Appendix 10.60 – Appendix 10.59	Inconsistent assessment methodologies used when assessing for radiation doses due to gamma, dust and radon—assessment methodologies should be consistent	Agreed and this has now been clarified for Lake Maitland in this document.
Appendix 10.60 – Table 27	Radon doses do not appear to be correct—review the calculations for the radon measurements and doses	Noted. Revised public dose estimates, as a result of operations at Lake Maitland, are discussed in section 4 of this document.

The aim of this review is to summarise and clarify the radiological impact assessment in response to submissions on the PER.

This review is based on the published PER information, previously published information, standard dose assessment methods and further analysis by the author. This review consists of the following:

- An overview of the relevant radiological characteristics of the Millipede and Lake Maitland mines;
- Consideration of occupational and public doses; and
- Consideration of radiological impacts to non-human biota.

The key issues addressed in this review (that refer to the PER radiation assessment) are:

- Lack of clarity about how impacts were assessed;
- Confusion regarding which base data were used for assessment; and
- Limitations in impact assessment due to the approach taken in the air quality modelling.

2 RADIATION ASPECTS OF MILLIPEDE AND LAKE MAITLAND

The main aspects of proposed operations at Millipede and Lake Maitland that are important to the radiological impact assessment are as follows:

- The life of the processing plant is extended from the processing of ore from Millipede and Lake Maitland
- The Millipede mine is an extension of the Centipede mine; they are separated only by a Department of Mines and Petroleum (DMP) tenement boundary.
- The Millipede and Centipede mineralisation characteristics are for all practical radiological purposes, identical.
- The Lake Maitland mineralisation (and deposit) characteristics are very similar to the Millipede and Centipede deposits.
- A common mining method is to be used at Centipede, Lake Way, Millipede and Lake Maitland.
- The radiological impacts of the Centipede and Lake Way deposits and the processing plant have previously been assessed; and
- The processing plant throughput (or ore processing rate) is unchanged from that previously assessed.

Radiological impact assessment from operations at Centipede, Lake Way and the processing plant is provided in the document, Environmental Review and Management Programme EPA Assessment No 1819 July 2011, Toro Energy Limited, Wiluna Uranium Project (ERMP).

A summary of the radiological impacts for Millipede and Lake Maitland are shown in Table 2 and Table 3.

Table 2: Millipede Radiation Impacts

	Radiological Considerations	Comment[1]
Occupational	Miner doses are expected to be the same as doses to Centipede and Lake Way miners because of the same mining methods and similar grades. No additional doses to processing plant workers due to no change in processing plant throughput or ore characteristics.	See dose assessment methods in ERMP which give approximately 3.9 mSv/y for miners and 1 mSv/y for processing plant workers.
Public Dose	Annual public doses not expected to increase because there are no additional annual emissions.	See dose assessment in ERMP which gives maximum public doses of 5% of public limit (at Apex Minesite).
Public Dose - Ingestion	Potential ingestion dose may increase due to additional cumulative deposition from extended mining and processing plant life.	In the ERMP, the potential ingestion dose impact was estimated from 15 years of deposition at the Project boundary. This gave a maximum modelled increase of 5% in doses over that which would be naturally received. In the most conservative case, the ingestion dose at the Project boundary may increase by a total of 10% if the operational life doubled.

	Radiological Considerations	Comment[1]
Non-human Biota	Extended life of operations in region may result in additional dust deposition and therefore impacts to non-human biota	ERICA impact assessment conducted at project boundary in ERMP. Assessment base on longer plant operation conducted in this review.

Note: 1. The ERMP assessment is modelled for Year 4 of operations when the main focus of mining is on the Centipede deposit.

Table 3: Lake Maitland Radiation Impacts

	Radiological Considerations	Comment
Occupational	Miner doses expected to be similar to Centipede and Lake Way miners because of the similar mining method and ore characteristics.	See estimates in Table 2.
Public Dose	Public doses have been calculated in this document using air quality modelling.	Assessments conducted in this review for two sensitive receptor locations. PER dust deposition rates and annual average total suspended particulate (TSP) dust concentration results used for dust assessments. Radon concentration results calculated using dispersion factors found in UNSCEAR 2000 and are used to calculated radon decay product concentrations.
Non-human Biota	Change in soil radionuclide concentrations based on modelled dust deposition used as basis of ERICA assessment.	Assessment conducted in PER for two sensitive receptor locations. The PER findings are verified in this document.

The proposed mining at Millipede and Lake Maitland effectively extends the life of the processing. Annual radiological impacts are not expected to change because the processing plant has a constrained throughput. However, there will be additional deposition of dust due to the extended operating life.

3 RADIOLOGICAL REVIEW

This review considers the occupational, public and environmental doses as a result of mining at Millipede and Lake Maitland.

A sensitivity analysis has also been conducted to take account of the potential for more material to be stockpiled at the processing plant, which may result in increased emissions of radon.

3.1 Occupational Doses

As noted in Table 2 and Table 3, occupational doses are expected to be similar to doses already estimated and presented in the PER and ERMP. This includes allowing for the ICRP predicted change in dose factor for exposure to radon decay products.

The assessment in the PER and ERMP was based on the currently recognised dose factor of 1.2 Sv/J, as recommended by the ICRP and published in the Mining Code (ARPANSA, 2005). In 2015, the ICRP noted that the dose factor for exposure to radon decay products would increase by a factor of 2.4. This has yet to be adopted in legislation in Australia.

With the potential doses to mine workers (as outlined in the PER and ERMP), a conservative equilibrium factor was used. If a more realistic equilibrium factor is used in the dose estimation, then it is expected that the final calculated dose will not change.

Toro's estimate for mine worker exposure follows a logical assessment framework. The theoretical exposure to mine workers described in the PER of approximately 3.9mSv/a is based on empirical modelling undertaken through the ERMP. The characteristics of the Millipede and Lake Maitland deposits are nearly identical from a radiological perspective. There is no reason to believe that empirical assessment undertaken in the ERMP would not be applicable to Millipede or Lake Maitland at this stage of the assessment process. It has been observed in other open cut mining operations in Australia and overseas that actual does rates from these mines are significantly lower than the theoretical assessments. That experience suggests applying a factor of four to theoretical results is defendable. Even if one were to challenge that factor, it would not, from a radiological perspective lead to different conclusions to radiation risks or management than what Toro has drawn in the PER.

The ERMP provides examples of actual doses received in other operational open cut mines, specifically Ranger, Rossing and McLean Lake. The actual monitored gamma dose rates from these mines (with higher uranium grade, in the case of Ranger) show that doses are likely to be much less than the modelled results. Therefore gamma doses were estimated to be approximately 1mSv/y. The assessment in the PER concludes that impacts from gamma radiation to workers will be low, and therefore further assessment work is not considered to be necessary.

Doses are expected to be low and can be well controlled adopting standard industry practices.

3.2 Public Doses – Sensitive Receptors

The sensitive receptor locations for Lake Maitland are:

- Barwidgee Pastoral Station – located approximately 20 km north-west of the mine site; and
- The proposed mining accommodation camp – located approximately 5 km from the mine.

For the Millipede mine, the sensitive receptors are identical to those in the ERMP and are as follows:

- Wiluna township;
- Millbillillie, Nganganawili Community and Bondini Reserve;
- Toro accommodation camp;
- Apex mine; and
- Residents of Lake Way station.

For Millipede, this review includes the location of the highest exposure, which is the Toro accommodation camp.

3.3 Assessing Impact

When assessing radiological impacts to people, the exposure pathways considered are:

- Irradiation by gamma radiation;
- Inhalation of radionuclides in dust;
- Inhalation of the decay products of radon; and
- Ingestion of animals or plants that have come in contact with emissions.

Table 4 provides a summary of the dose assessment methods for the different exposure pathways.

Table 4: Exposure Estimation Methods

Exposure Pathway	Assessment Method
Gamma Radiation	Estimated from first principles
Inhalation of radionuclides in dust	Estimation based on air quality modelling results
Inhalation of radon decay products	Estimation based on air quality modelling results
Ingestion of radionuclides	Estimation based on modelled dust deposition and transfer factors

For environmental impact the ERICA assessment software (ERICA, 2016) is used to determine nominal dose rates to standard species of plants and animals. The software uses changes in the radionuclide concentration of media (such as soil and water) due to the operation to determine a risk quotient. The method for determining the change in media concentration is via modelled dust deposition results.

3.4 Dose Assessment Criteria

The following criteria have been used in the radiological impact assessment and are valid for both Millipede and Lake Maitland.

3.4.1 Production Factors

- Average total mining rate – 5 -6Mtpa (ore and waste rock);
- Average ore (mineralised material) mining rate – 1.3 Mtpa;
- Average uranium grade of mined and processed ore – 800 ppm;
- Average uranium grade of inert waste rock – 5 ppm; and
- Average uranium grade of all material mined – 200 ppm (refer Table 5).

Table 5: Weighted average grade of material mined at Millipede and Lake Maitland

Ore tonnes mined ('000)	Ore grade PPM U_3O_8	Waste and overburden tonnes mined ('000)	Waste and overburden grade PPM U_3O_8	Average grade of total material mined PPM U_3O_8
9,415	709	27,901	50	215

Source. Toro ASX announcement January 2014 and are based on scoping study level of accuracy as discussed in that ASX announcement.

3.4.2 Exposure Factors

- Member of the public exposure hours – 8670 h/y;
- Member of the public breathing rate – 1.0 m^3/h; and
- Camp worker exposure hours (working year) – 4000 h/y (assumes 2000 h/y working and 2000 h/y residing).

3.4.3 Physical Property Factors:

- Relationship between uranium grade and radionuclide activity is 1 ppm U = 12.3 mBq(U238)/g;
- Uranium ore is in approximate secular equilibrium when mined;
- Deposited dust will mix in the top 10 mm of soil (over the life of the deposits);
- Radon emanation rate from ore is 50 Bq(Rn222)/m^2.s per %U; and
- Specific gravity (density) of soil in the environment is 1 m^3 = 1.5 t.

3.4.4 Radon and Dust Dose Factors:

- The relationship between radon and radon decay products (RnDP) is expressed by the following equation (UNSCEAR, 2000):

  $F = PAEC / (5.56 \text{ x } C(Rn222))$

  Where: F is Equilibrium Factor,

  PAEC is potential alpha energy concentration of the radon decay products (μJ/m^3), and

  C(Rn222) is the concentration of radon (Bq/m^3)

- The radon decay product dose factor is currently 1.2 Sv/J. However, a recent recommendation of the ICRP is that the factor be increased to 2.8 Sv/J; and
- Dust inhalation dose conversion factor derived from individual radionuclide figures in ICRP 1995, using activity median aerodynamic diameter (AMAD) of 1 μm and most restrictive lung solubility class and assuming secular equilibrium for the decay chain radionuclides and is 3.94 x 10^{-5} Sv/Bq(U238) (Note that this figure assumes a material with decay products in secular equilibrium with the head of chain).

3.5 Lake Maitland Dust Emissions and Impacts

An air quality assessment was conducted for the Lake Maitland mining operation (PER Appendix 10.66) and provides a summary of the emission rates for total suspended particulates (TSP) and the consequent increments in air concentrations and dust deposition rates.

Dust sources for the air quality assessment were identified and included; mining, processing, stockpiles and tailings and are based on standard emission factors for equipment and processes. The air quality modelling calculates an increase in dust concentration at the selected locations for TSPs in units of μg/m^3 and also calculates a project originated dust deposition in units of g/m^2.month.

The assessment was based on the year of maximum production and therefore maximum dust emission rate for the mine contemplated at the time. Toro Energy does not plan to process at rates higher than those modelled. Therefore the original air quality modelling is conservative and remains relevant. .

It is worthy to note that since the year of maximum emissions is used for modelling, it is likely that any calculated dose from inhalation of project originated radionuclides will be conservative.

As discussed in Section 3.3, the radionuclide concentrations of all dust emissions are on average 200 ppm of uranium. Assuming that the decay products of uranium are in secular equilibrium, this gives a specific activity of 2.5 Bq/g.

The predicted annual average TSP dust and radionuclide concentrations at the locations of interest are shown in Table 6.

Table 6: Annual Ground Level Concentrations

Location	Ground Level Concentrations Total Dust (µg/m³)	Equivalent Uranium Chain Radionuclide Concentration (µBq/m³)
Mining Village	52	130
Barwidgee Station	9.6	24

To determine the impacts from deposition of radionuclides, the deposition rate for the maximum emission year is used and the results are multiplied by the number of operational years. This gives a worst case estimate of the deposition of dust into the environment which is used for estimates of human doses from ingestion of food that has taken up radionuclides and is also used for media concentration estimates for the environmental assessment.

The air quality modelling has calculated the annual dust deposition (modelled for Year 7 of operations) and this is shown in Table 7.

Table 7: Dust Deposition (7 Years)

Location	Dust Deposition (g/m²/month)	Cumulative Deposition After 7 Years (g/m²)	Cumulative Deposition After 7 Years (Bq/m²)
Mining Village	0.14	11.8	29.5
Barwidgee Station	0.031	2.6	6.5

3.6 Lake Maitland Project Radon Emissions and Impacts

The modelled radon concentrations, presented in PER Appendix 10.66 are for a 24 hour average. This significantly overestimates the annual averages. For dose assessments, annual averages are generally used. Accordingly, the radon impacts from Lake Maitland have been reassessed based on the general dispersion model provided by UNSCEAR (2000).

UNSCEAR provides a reference for general dispersion and this is reprinted in Table 8 as dilution factors that convert a source emission rate to a long-term concentration.

Table 8: UNSCEAR Dispersion Factors

Downwind distance (km)	Dilution factor (Bq/m³ per Bq/s)
0.5	9.7×10^{-7}
1	5.3×10^{-7}
2	2.5×10^{-7}
5	7.1×10^{-8}
10	2.5×10^{-8}
20	8.7×10^{-8}
50	2.2×10^{-9}

To utilise these dispersion factors, an assessment of the total radon emission rate from the Lake Maitland mining needs to be made.

The radon emission from Lake Maitland is based on the following assumptions:

- Mine pit area of 567.8 ha;
- Ore pads of 40 ha;
- Radon emission rate of 50 $Bq/m^2.s$ which is equivalent to an average emission rate of 1.0 $Bq/m^2.s$ (for an average uranium grade of 200 ppm);
- The calculated total radon emissions are approximately 5.7 MBq/s; and
- To take account of other stockpiles, an additional 0.5 MBq/s has been added to the emission rate (based on the estimates used for stockpiles in the ERMP), giving a total emission rate of 6.2 MBq/s.

Using the UNSCEAR factors, the average concentrations at the sensitive receptor locations can be calculated and are shown in Table 9.

Table 9: Annual Average Radon Ground Level Concentrations

Location	Project Originated Ground Level Radon Concentrations Annual Average (Bq/m^3)
Mine Accommodation (5 km)	0.4
Barwidgee Station (20 km)	0.05

3.7 Millipede Emissions and Impacts

For operations at Millipede, the rate of dust and radon emissions are expected to be identical to those previously modelled for Centipede in the ERMP for the following reasons:

- The mining rate from Millipede and Centipede is restricted to the rate at which it can be processed. Therefore, the emissions from the combined Millipede and Centipede mining will be practically identical to the emissions from solely mining at Centipede.
- The processing plant throughput is restricted to the plant design capacity, which is not expected to change.

Therefore, the impacts of dust emissions as previously modelled and presented in the ERMP remain valid and further assessment of public dose in this document has not been conducted. This is the same conclusion that was presented in the PER.

A sensitivity analysis for radon has been conducted which takes into account the impacts of simultaneous mining occurring at Millipede and Centipede (see Section 6 of this report). The analysis assumes that the radon emissions rates in the Centipede/Millipede area are doubled.

Note also that the final cumulative dust deposition in the processing plant area will increase due to the extended life of processing and mining. For this assessment, it is assumed that the deposition of dust is doubled.

4 LAKE MAITLAND PUBLIC DOSES

This section provides estimates of doses based on the emissions at Lake Maitland.

4.1 Gamma Radiation

Gamma radiation exposure to members of the public from sources within the mining area is considered to be negligible due to the distance between the sources and the public. The sources of gamma radiation (e.g. ore stockpiles) are well within the Project boundary and inaccessible by the public.

4.2 Airborne Dose Estimates

Doses from inhalation of both dust and decay products of radon are based on the modelled annual average concentrations at each of the locations of interest.

4.2.1 Dust

The dust dose is calculated for 8760 h/y (full time occupancy), a breathing rate of 1 m^3/h and individual radionuclide inhalation dust factors as outlined in ICRP Publication 68 (ICRP, 1995).

The equation is:

$$\begin{aligned}\text{Dose from U238 Radionuclides } (\mu Sv/y) = &\ \text{Uranium Series Dust activity concentration } (Bq/m^3) \\ &\times \text{Breathing rate } (1.0\ m^3/h) \\ &\times \text{Hours per year } (8760\ h/y) \\ &\times \text{Dose Conversion Factor } (39.4\ \mu Sv/Bq)\end{aligned}$$

4.2.2 Radon Decay Products

The radon decay product (RnDP) dose is calculated from the modelled radon concentrations at the sensitive receptors.

The first step is to convert the modelled radon concentration to a RnDP concentration as follows (from UNSCEAR, 2000):

$$\text{RnDP Concentration } (\mu J/m^3) = \text{Equilibrium factor} \times 0.00556 \times \text{Rn concentration } (Bq/m^3)$$

For this assessment, a conservative equilibrium factor of 0.4 has been used, as recommended by UNSCEAR (UNSCEAR, 2000).

The RnDP dose is then calculated using the following equation (ARPANSA, 2005):

$$\begin{aligned}\text{Dose } (mSv/y) = &\ \text{RnDP Conc } (mJ/(mm^3)) \times \text{Exposure hours } (8760\ h/y) \\ &\times \text{Dose Conversion Factor } (1.4\ mSv.m^3/mJ.h)\end{aligned}$$

4.2.3 Inhalation Dose Estimates

A summary of the inhalation dose estimates is provided in Table 10.

Table 10: Public Inhalation Dose Estimates

Location	TSP Dust		Radon/RnDP[1]	
	Concentration ($\mu Bq/m^3$)	Dose (mSv/y)	Radon Concentration (Bq/m^3)	RnDP Dose (mSv/y)
Mine Accommodation	130	0.041	0.4	0.011 (0.026)
Barwidgee Station	24	0.008	0.04	0.001 (0.003)

Note: 1. The ICRP has recently recommended an increase in the dose conversion factor for radon decay products (ICRP, 2015), although this has yet to be adopted in Australia. The increase is a factor of 2.4 and the revised doses can be seen in parentheses in the table.

4.3 Ingestion Dose Estimates

The potential annual dose from the ingestion exposure pathway has been estimated for people living at the Lake Maitland mining accommodation camp and Barwidgee Homestead. The conservative assumption is that all food consumed over one year is from these locations and is therefore a maximum ingestion dose that could be received as a result of operations.

The assessment method assumes that dust emissions from the operation deposit in the surrounding environment and are taken up by plants and animals. Exposure to people occurs when the plants and animals are consumed. The assessment only considers the Project-originated radionuclides and does not include naturally occurring radionuclides.

There are three main factors to consider when making an ingestion dose assessment:

- Food consumption rate and characteristics;
- Uptake factors into foods (also known as concentration ratios); and
- Additional radionuclides available for uptake.

The ingestion dose assessment is based on consumption rates as follows:

- 100 kg/y meat (assumed to be kangaroo); and
- 100 kg/y vegetable matter (assumed to be 50 kg/y of short-lived vegetation and 50 kg/y of long-lived vegetation).

Published concentration ratio values are available from a number of sources, including ARPANSA (2014) and IAEA (2010). There are also published data that can be used to calculate concentration ratios, for example in the ERMP.

Toro's ERMP provided data to determine concentration ratios for species of vegetation. Although the specific species may not be consumed, the results provide generally relevant values for the region. It is noted that the standard values published in IAEA (2010) are generally much lower than the experimentally determined values from the local species. For example, the IAEA values are an order of magnitude lower for uranium and thorium, similar for radium and at least two orders of magnitude lower for lead and polonium.

Table 11 provides published and calculated concentration ratio values for the elemental form of the various radionuclides.

Table 11: Concentration Ratios Used in Ingestion Assessment

Species	Elemental Concentration Ratio (Bq/kg (species))/(Bq/kg (soil))					Source
	Uranium	Thorium	Radium	Lead	Polonium	
Red Kangaroo[1]	0.007	0.00016[3]	0.41	0.022	0.55	ARPANSA 2014
Long lived Vegetation[2]	0.21	0.02	0.05	1.06	0.58	Toro Energy 2011
Short Lived Vegetation[2]	0.23	0.17	0.09	0.33	0.34	Toro Energy 2011

Notes: 1. ARPANSA (2014) figures are reported as concentration ratios – average of two sample sets used.
2. Figures have been derived from reported vegetation and soil concentrations. The activity concentrations reported did not provide information on whether vegetation samples were wet or dry. For this assessment, it has been assumed that the reported are 'wet' which is the conservative assumption.
3. No figure for thorium available in ARPANSA (2014) therefore the ERICA concentration ratio for large mammal is used.

The calculated change in soil radionuclide concentrations at each of the locations of interest is shown in Table 12 and is based on soil density of 1.5 t/m^3 and a mixing depth of 10 mm (which gives 15 kg of soil per square metre). It is also assumed that the uranium decay chain is in secular equilibrium.

Table 12: Change in Soil Radionuclide Concentration (Assuming 7 Years of Operations)

Location	Radionuclide Deposition (Bq/m^2)	Change in Soil Radionuclide Concentration (Bq/kg)
Mine Accommodation	29.5	2.0
Barwidgee Homestead	6.5	0.4

Using the standard ICRP ingestion dose conversion factors (ICRP, 1995) and the estimated consumption rate, the potential human doses can be calculated for residents at the sensitive receptor locations. Results are shown in Table 13. (Note that the estimates are worst case as it is unlikely that all food consumed will be from the one location).

Table 13: Data for Ingestion Dose Assessment

Location	Dose (mSv/y)		
	Vegetation Ingestion	Kangaroo Ingestion	Total Ingestion
Mine Accommodation	0.22	0.16	0.38
Barwidgee Homestead	0.04	0.03	0.07

4.4 Total Dose Estimates

The total dose estimates at the sensitive receptors are shown in Table 14. Note that the doses are based on 100% occupancy (that is 8760 h/y) at these locations.

Table 14: Public Total Dose Estimates

Location	Exposure Pathway Dose (mSv/y)[1]			
	Dust	RnDP	Ingestion[2]	Total Dose
Mine Accommodation Camp	0.041	0.011 (0.026)	0.380	0.432 (0.447)
Barwidgee Homestead	0.008	0.001 (0.003)	0.070	0.079 (0.082)

Notes: 1. As noted in Section 4.1, the gamma dose is negligible (<0.001 mSv/y).
2. This assumes that all food is consumed from the specified location for one year.

5 FLORA AND FAUNA IMPACT

5.1 Assessment for Lake Maitland

The approach to assessing the impacts to non-human biota is described in PER Section 14.7.6. The dust deposition modelling was used to estimate the change in media concentration, which was used as input to the ERICA software.

The PER assessment concluded that the radiological impact to standard species of flora and fauna in the Lake Maitland region is negligible.

5.2 Assessment for Millipede

The ERMP notes that the closest sensitive receptor to the Millipede deposit is the Toro Accommodation Camp where the dust deposition levels were modelled resulting in a cumulative increase in soil radionuclide concentrations of approximately 0.4 Bq/kg.

To account for additional operating life of the processing plant and also the operation of the Millipede mine, it was conservatively assumed that the change in soil radionuclide concentration was 1 Bq/kg at the camp location.

Using the ERICA assessment as described in the PER and a media concentration of 1 Bq/kg for all uranium-238 decay chain radionuclides, the assessment indicates that no standard species exceed the reference level of 10 µGy/h at this location.

6 SENSITIVITY ANALYSIS – MILLIPEDE

The sensitivity analysis was based on the assumption that dust and radon emissions from the Millipede/Centipede region would double. The consequence in terms of radon, radionuclide in dust concentrations and radionuclides in dust deposition of this is that the impacts would also double. The original impacts were assessed in the ERMP. Table 15 shows the original calculated inhalation doses and the revised doses, taking into a count a doubling of emissions. The dose estimate also includes the revised dose conversion factor for radon decay products (RnDP).

Table 15: Predicted Annual Inhalation Dose at Closest Receptor (Accommodation Camp)

From ERMP		Sensitivity Assessment[1]	
RnDP (mSv)	Radionuclides in Dust (mSv)	RnDP (mSv)	Radionuclides in Dust (mSv)
0.015	0.001	0.030 (0.072)[2]	0.002

Note 1: The sensitivity assessment is based on a doubling of emissions from the Centipede and Millipede region.
Note 2: See note beneath Table 10

The assessment shows that inhalation doses remain low.

7 CONCLUSIONS

The aim of this review has been to provide some clarity to the radiation assessment presented in the PER. The main finding of this review is that the radiation impacts as a result of mining at Millipede and Lake Maitland are as described in the PER. That is, doses to people and the environment are low.

8 REFERENCES

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