12

Radiation

12. Radiation

12.1 Introduction

This chapter provides an overview of the radiological environment of the Nolans Project including a summary of the natural levels of background radiation in the region and impacts from operating the project on workers, the public and the environment.

Detailed radiation reports are provided in Appendix P, including:

- Sonter, M. & Hondros, J. 2016, *Occupational and Environmental Radiation Measurements and Predictions*, Radiation report prepared for Arafura Resources Ltd, Noland Project, March 2016
- JRHC, 2016, *Nolans Rare Earths Project: Environmental and Public Radiation Technical Report*, JRHC Enterprises 2015
- Hussey, K. 2016, *Environmental Radiation and Geochemical Studies Associated with The Nolans Project EIS, Discussion And Analysis Of Some Results*, Arafura Resources Report ARU-15/008.

The TOR for the preparation for the project provided the following environmental objective in relation to radiation:

> *For all stages of the Project the Proponent is fully aware of potential for the Project to cause harmful radiation doses to people and/or the environment, proposed management will protect all people and the environment from harmful radiation doses resulting from the Project.*

This chapter addresses sections 21 and 22A under the EPBC Act (refer section 1.1.4).

This chapter also addresses the design, construction and operation of the proposed project to ensure that human and environmental radiation impacts comply with all legal requirements, Australian standards, codes of practice and guidelines as required in the TOR.

12.2 Methodology

Radiation doses to workers and to members of the public are regulated in all Australian States and Territories under the relevant state Radiation Safety, Control or Protection Acts and associated Regulations. The project would operate in the Northern Territory and would comply with all relevant Northern Territory legislation.

These Acts and Regulations in general conform with the codes and guidelines issued by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). The Australian approach is based on international guidance from the International Atomic Energy Agency (IAEA), the Recommendations of the International Commission on Radiological Protection (ICRP) and on the Reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

The main ARPANSA radiation codes that apply to the project are:

- *Code of Practice on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing, 2005* (also known as the Mining Code) (ARPANSA 2005)
- *Code of Practice on the Transport of Radioactive Material* (also known as the Transport Code) (ARPANSA 2008).

The internationally recognised basis of radiation protection is the ICRP recommended 'System of Dose Limitation'. This requires that planned doses to workers or to members of the public from industrial activities need to be justified, optimised and limited. The method of dose assessment for workers and the public is based on the recognised methods of the ICRP as outlined in national standards, including the Mining Code and ARPANSA (2010).

For occupational doses, estimates are made for mining and processing plant personnel. The locations of interest for public dose have been identified for the project and are:

- The accommodation village, located approximately five kilometres from the processing plant and nine kilometres from the mine site (two exposure scenarios have been modelled – fulltime occupation of the village (8,760h/y) and part-time occupation (4,000h/y));
- Aileron (includes Aileron Roadhouse, campground and houses, and the Aileron Station Homestead and workers' accommodation), located approximately 12 kilometres from the processing plant and 13 kilometres from the mine site; and
- Alyuen Community, located approximately 12 kilometres from the processing plant and 15 kilometres from the mine site.

A conservative assessment was undertaken on the assumption that a person resides for a full year at the location of the accommodation village and consumes only food that grows there. This situation simulates a worst case assessment of potential member of the public dose.

The environmental impact is assessed based on determining a change in exposure rates to standard species of flora and fauna as a result of emissions from the operation.

The assessments are based on the results of air quality modelling which provides estimates of radiation levels in the wider environment as a result of airborne emissions from the project area. The preliminary air quality modelling has been completed and the results that have been used for the radiological impact assessment are as follows:

- Radon and thoron concentrations at a number of potential receptor locations
- Total dust deposition at Aileron and the accommodation village and
- Total suspended particulates dust concentrations at Aileron and the accommodation village location.

Full details of the methodology, limitations and assumptions are provided in Appendix P.

12.3 Existing environment

12.3.1 Overview

Arafura commenced comprehensive baseline radiological studies of the Nolans site and of the region, including environmental and occupational radiation sampling and monitoring, in 2005. These studies are documented in ANSTO (2007), Sonter (2016a), Dean and Grose (2015) and Hussey (2016), and considered the following:

- Gamma monitoring
- Soil and sediment sampling
- Vegetation sampling
- Groundwater sampling
- Dust sampling
- Passive radon and thoron and

- Real time radon and thoron monitoring.

Gamma monitoring

A general area survey was conducted in a grid pattern across the mine site area and at sites remote (background) from the project area. Background sites include two measurements in Kerosene Camp Creek and two measurements at the Aileron Roadhouse.

The measurements were taken at locations on and off the Nolans Bore deposit and a summary of the results are provided in Table 12-1.

Table 12-1 Summary of gamma measurements

	Environmental Gamma Dose Rate (µSv/h)			Number
	Average	Max.	Min.	
On Deposit	0.38	0.63	0.18	12
Off Deposit	0.19	0.35	0.13	37
Background	0.17	0.18	0.15	4

The gamma radiation levels in the region have been extensively studied through a number of surveys. The primary sampling locations and summary results are shown in Figure 12-1 and Table 12-2 respectively.

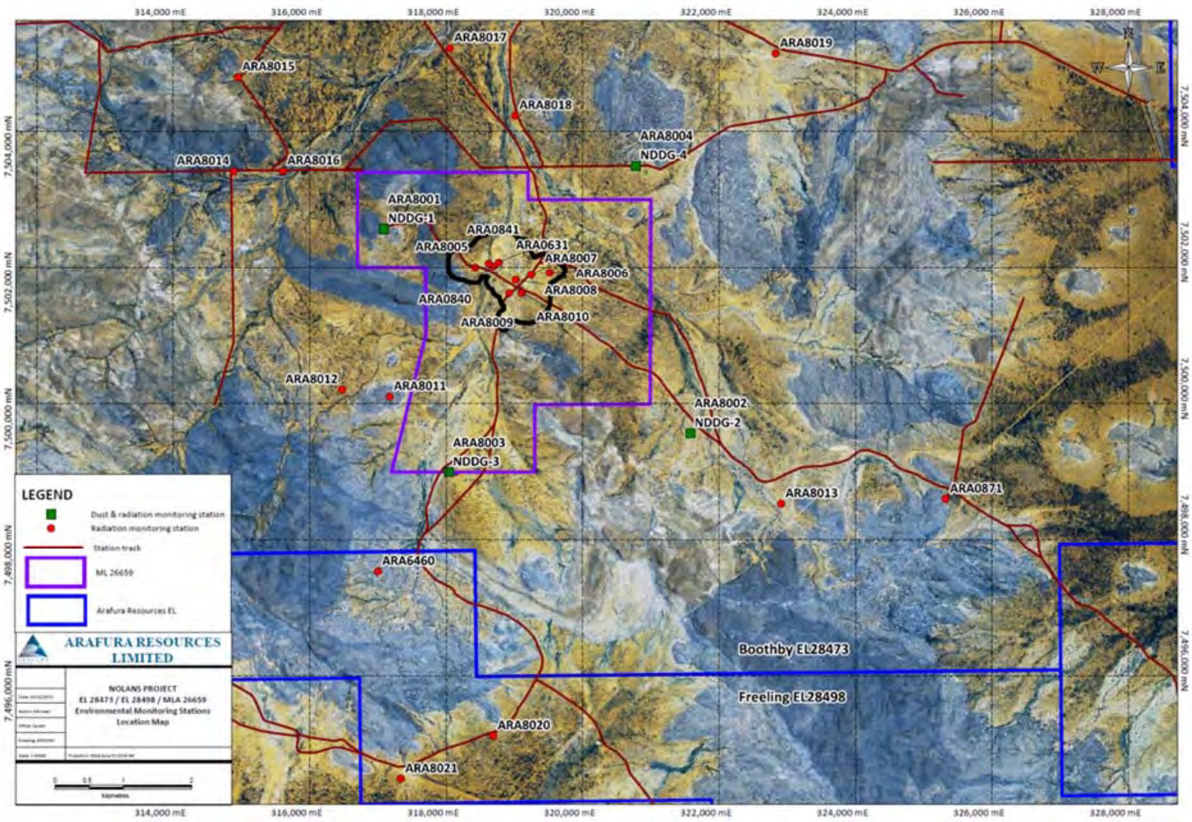

Figure 12-1 Location of environmental monitoring locations – Nolans site

Table 12-2 Summary of gamma monitoring results

Sample Program and Method	Average Results (µSv/h)
Nolans Bore (on deposit)	0.8 (highs to > 10)
Nolans Bore (off deposit)	0.25

Arafura has flown aerial radiometric surveys of the area and results are displayed in Figure 12-2.

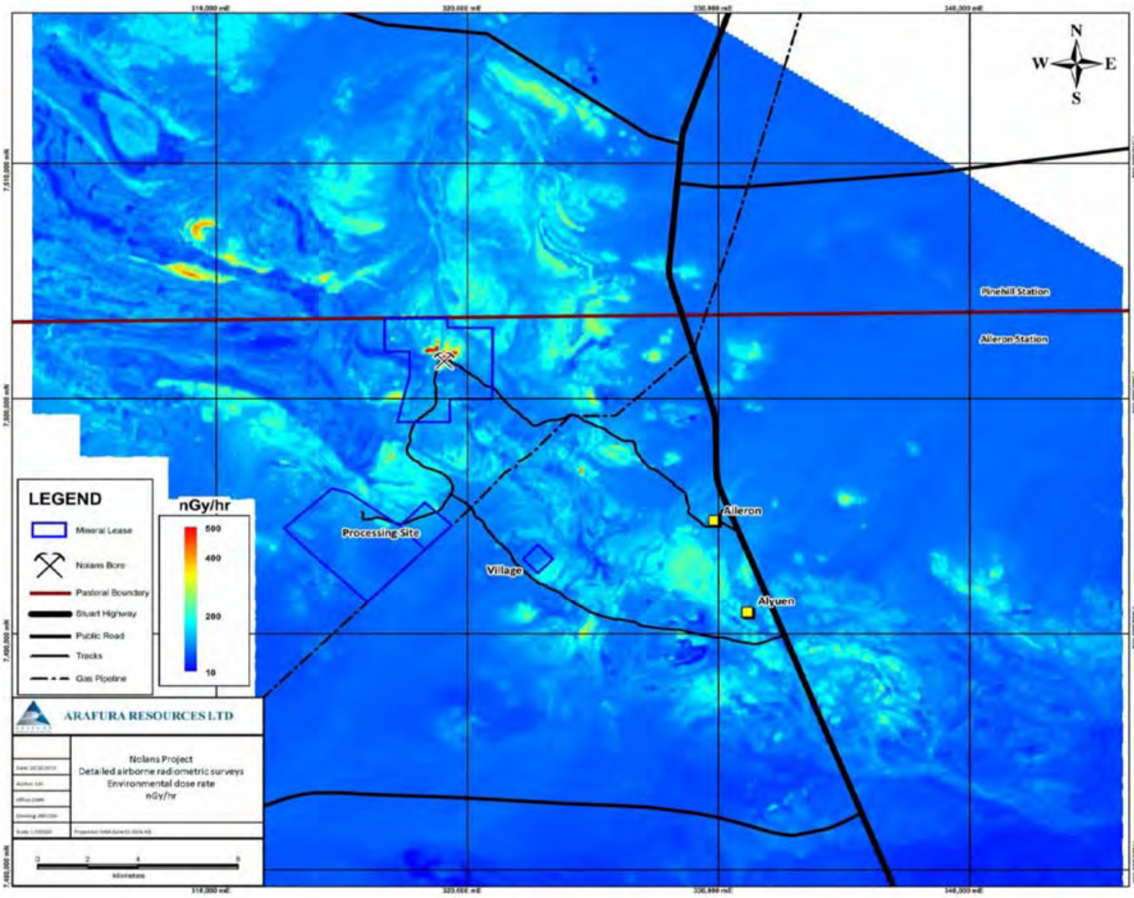

Figure 12-2 Aerial gamma surveys – Nolans Project area (Arafura 2009; Arafura 2013)

In general, the surveys provide consistent results and clearly show the gamma signature of the mineralised material and the large variation in gamma radiation across the region.

Typical gamma background levels across Australia are presented in Table 12-3.

Table 12-3 Environmental gamma results elsewhere in Australia

Location	Average Environmental Gamma Levels (µSv/h)	Reference
Australian average	0.07	Inferred from ARPANSA (2005)
Central South Australia	0.1	BHP Billiton (2009)
Honeymoon U deposit	0.1 (no surface outcrop)	Southern Cross Resources (2006)
Kintyre U deposit	0.09 (no surface outcrop)	Cameco (2013)
Mulga Rock U deposit	0.06 (no surface outcrop)	Vimy Resources (2015)
Lake Way U deposit (on deposit)	0.9	Toro Energy (2015)
Lake Way U deposit (off deposit)	0.1	Toro Energy (2015)
Yeelirrie U deposit (on deposit)	0.9	Cameco (2015)
Yeelirrie U deposit (off deposit)	0.09	Cameco (2015)

Soil and sediment samples

Surface soil sampling was undertaken at three locations: one upstream from the Nolans Bore deposit in the mine site (Area 1), one downstream (Area 2), and the third at a site distant (Background) from the project area near the Aileron Roadhouse. Results are presented in Table 12-4.

Table 12-4 Soil radionuclide analyses

	Radionuclide Concentration (Bq/kg)									
	U238	U234	Th230	Ra226	Pb210	Po210	Th232	Ra228	Th228	K40
Area 1	27	20	25	23	15	20	56	77	75	805
Area 2	25	18	24	18	10	17	32	42	42	891
Background	77	30	72	53	45	47	118	118	121	925

The results show that the concentrations of uranium and thorium in the soil samples from the roadhouse are naturally elevated compared to the samples from the mine region and comparable to the Australian average.

Extensive soil and sediment sampling has also been completed across the region, and these results are shown in Table 12-5.

Table 12-5 Summary of soil and sediment sampling

	Number of Assays	Uranium (average and range in parts per million (ppm))	Thorium (average and range in ppm)
Crustal average		2.7	10.5
Soils (on deposit)	9	22 (3.28-83.3)	328 (44.1-950)
Soils (off deposit)	17	5.51 (2.47-24.3)	63.2 (23.2-416)
First drill metre (on deposit)	142	55.6 (1.4-655)	791 (10.4-8730)
First drill metre (off deposit)	18	5.85 (1.6-19)	50.5 (9.55-149)
Stream sediments	51	3.16 (1.36-13.7)	44.5 (14.6-180)
Stream sediments (fine grained fraction)	51	8.21 (2.81-21.5)	119 (31.7-360)

Uranium and thorium concentrations for a range of samples have been determined and show that:

- Soils and stream sediments in the region have above crustal average uranium and thorium concentrations
- Uranium and thorium compositions of the soils and stream sediments are broadly similar
- Soils on top of the Nolans Bore deposit have higher average uranium and thorium compositions than those outside of the deposit, although there is considerable overlap and
- It is difficult to distinguish the stream sediment signature of the Nolans Bore deposit because of the masking effect of elevated levels of radioelements in the region.

Vegetation samples

Sampling of vegetation was undertaken at the same three locations as the soil samples. The results are shown in Table 12-6.

Table 12-6 Vegetation radionuclide analyses

	Radionuclide Concentration (Bq/kg)									
	U238	U234	Th230	Ra226	Pb210	Po210	Th232	Ra228	Th228	K40
Area 1	0.9	2.1	0.3	14.0	25.5	21.6	0.4	22.0	7.2	433
Area 2	1.3	2.3	1.0	8.5	29.0	19.5	2.4	20.0	7.5	609
Background	1.1	1.6	1.1	26.5	38.0	23.3	2.4	69.5	21.9	531

The enhanced concentrations of Po210 and Pb210 are generally observed and primarily due to the decay of atmospheric radon (UNSCEAR 2000).

Extensive vegetation sampling has also been completed across the region, and these results are shown in Table 12-7.

Table 12-7 Summary of vegetation sampling

	Number of Assays	Uranium (average and range in ppm)	Thorium (average and range in ppm)
Grass (on deposit)	9	0.022 (<0.01-0.06)	0.22 (0.1-0.39)
Grass (off deposit)	17	0.015 (<0.01-0.12)	0.14 (0.02-1.37)
Tree leaves (on deposit)	10	0.046 (<0.01-0.06)	0.15 (0.03-0.59)
Tree leaves (off deposit)	17	0.01 (<0.01-0.08)	0.02 (<0.01-0.04)
Tree leaves (on deposit)	75	0.077 (<0.01-0.48)	0.537 (0.01-5.31)
Tree leaves (off deposit)	1127	0.016 (<0.01-0.71)	0.021 (<0.01-0.34)

Groundwater samples

Two groundwater samples were taken and analysed. The results are presented in Table 12-8.

Table 12-9 presents the additional groundwater sampling within and upstream of the Nolans Bore deposit.

Table 12-8 Groundwater radionuclide analyses

	Radionuclide Concentration (Bq/L)									
	U238	U234	Th230	Ra226	Pb210	Po210	Th232	Ra228	Th228	K40
Nolan Bore (stock bore)	2.5	8.6	<0.05	0.15	<0.01	0.004	0.015	3.1	0.32	1.1
Aileron Roadhouse Bore	6.4	20.8	0.12	0.26	0.33	0.314	0.034	0.78	0.16	0.7

Table 12-9 Summary of groundwater sampling

	Number of Assays	Uranium (average in ppm)	Thorium (average in ppm)
In deposit	5	0.354	<0.0001
Upstream and off deposit	9	0.361	<0.0001

The results show that the groundwater radionuclide concentrations are elevated and highly variable across the region.

Dust Deposition

Dust deposition gauges were placed at four locations approximately two to three kilometres distant from the proposed mine area in approximately north west, south east, north east and south west directions, being downwind, upwind, and orthogonal to prevailing wind direction. A summary of the results are provided in Table 12-10.

Table 12-10 Dust deposition

	Total Dust Deposition ($g/m^2/day$)	Thorium Deposition ($\mu g/m^2/day$)	Uranium Deposition ($\mu g/m^2/day$)
NDDG-1 (NW)	0.067	0.36	0.20
NDDG-2 (SE)	0.017	0.16	0.07
NDDG-3 (SW)	0.041	0.40	0.29
NDDG-4 (NE)	0.025	0.14	0.08

The uranium and thorium concentrations in the deposited dust are relatively consistent at approximately 3 ppm and 10 ppm respectively. These figures are consistent with worldwide background levels of radionuclides in soils (UNSCEAR 2000).

For comparison, average dust deposition figures of 1.5 g/m^2/month were reported in the Kintyre region of Western Australia (Cameco 2013).

Dust concentrations in air

Between September 2010 and March 2011, dust concentration sampling was conducted to measure PM_{10} dust. The results show daily average PM_{10} dust concentrations varying between 1 and 35 $\mu g/m^3$ over the sampling period, with an average dust concentration of 16 $\mu g/m^3$. Radionuclide analyses were not conducted on the dust; however, based on the soil concentrations and the dust deposition results, giving uranium and thorium concentrations of 3ppm and 10ppm respectively, and assuming that the dust is resuspended soil, the radionuclide concentrations in air can be calculated. The results are 0.4 mBq/m^3 for uranium and 1.2 mBq/m^3 for thorium.

Radon and Thoron concentrations

During 2015, real time radon and thoron monitoring was carried out at Nolans Bore (Dean and Grose 2015; Sonter 2015). The results indicate a high level of variability in both radon and thoron concentrations, up to two orders of magnitude, consistent with variations observed elsewhere.

The natural airborne radon and thoron concentrations are variable, ranging well over an order of magnitude in a typical 24 hour cycle, and possibly up to three orders of magnitude (Figure 12-3).

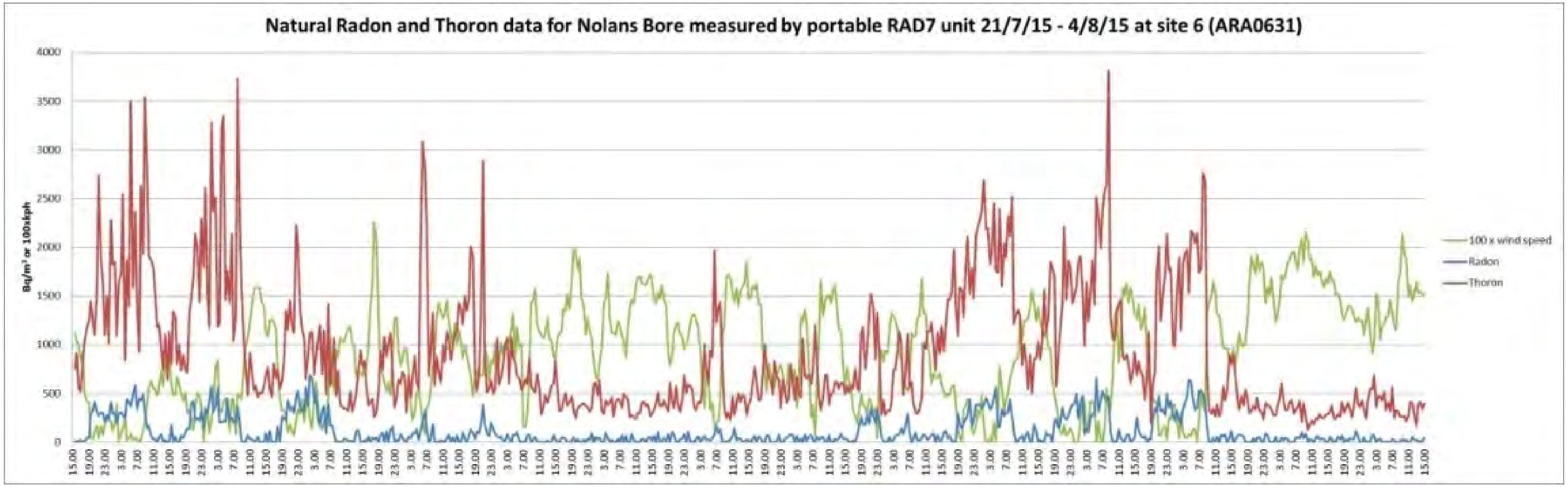

Figure 12-3 Real time radon and thoron concentrations

During the sampling period, the average radon concentrations were calculated to be approximately 80 Bq/m^3, with average thoron concentrations being approximately 800 Bq/m^3.

The thoron activity concentrations are significantly higher than the radon activity concentrations. However, this is as expected (Sonter and Hondros 2015) and due to both the higher thorium content of the outcropping deposit and the shorter half-life of the thoron.

In addition to real time monitoring, longer term concentration averages were determined. Detectors were placed into the field for a period of four months. The average concentrations of these results are provided in Table 12-11.

Table 12-11 Passive radon and thoron averages

Location	Average Concentration	
	Radon (Bq/m^3)	Thoron (Bq/m^3)
Within mine footprint	44	470
Outside mine footprint (regional)	29	120

During 2015, daily thoron decay product (TnDP) concentrations were manually monitored on the deposit at Nolans Bore at dawn and later afternoon each day (Sonter 2016a).

Average concentrations were:

- Morning – 0.166 $\mu J/m^3$
- Afternoon – 0.039 $\mu J/m^3$
- All average – 0.085 $\mu J/m^3$.

Manual grab sampling of radon decay product (RnDP) concentrations were undertaken during radiation monitoring campaigns in 2005 and 2008 (Sonter 2016a). A summary of the results is:

- 2005 sample average of 0.27 $\mu J/m^3$ (11 daytime samples)
- 2008 sample average of 0.02 $\mu J/m^3$ (27 daytime samples).

Note that the difference in averages is due to the time of year of samples. The 2005 samples were acquired during winter and the 2008 results were during summer.

The thoron concentration and thoron decay product monitoring data was used to calculate a naturally occurring equilibrium factor. This was shown to be very low, ranging from between 0.001 and 0.004 for the data obtained (Sonter and Hondros 2015).

Studies into radon emanation from ores were carried out on two drums of Nolans ore in 2015, giving approximately one $Bq/m^2/s$ for Rn222 and about 300 $Bq/m^2/s$ for Rn220 (Sonter 2016b).

The experimental emanation rates were extrapolated to the life of mine average uranium and thorium grades, giving 0.4 $Bq/m^2/s$ for radon and 200 $Bq/m^2/s$ for thoron.

12.3.2 Summary

The key findings from these extensive radiation studies are as follows:

- The project area is radiologically identified by the extensive near-surface orebody
- There are areas in the broader region that exhibit elevated gamma radiation levels
- The broader area is characterised by a large number of areas with higher concentrations of uranium and thorium compared to the Australian continent average
- There is elevated radon and thoron in the region due to the outcropping areas of elevated uranium and thorium
- Radon and thoron concentrations in the air are elevated near the deposit and vary by up to two to three orders of magnitude
- The Nolans Bore deposit has a radiological signature for thoron, radon and gamma radiation
- There is a clear variation in radon and radon decay product concentrations throughout the day and
- The thoron concentrations in the region are significant; however the thoron decay product concentrations are low as expected.

These findings, however, are not dissimilar to those found in the vicinity of other near-surface undeveloped uranium and rare earths orebodies.

12.4 Assessment of potential impacts

12.4.1 Radiation exposure to workers

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

- Gamma radiation
- Inhalation of radon decay product and thoron decay product and
- Inhalation of radionuclides in airborne dust.

The recognised limit for radiation doses to workers arising from work or industrial activities is 20 millisieverts per year (mSv/y), averaged over five years, with a maximum of 50mSv in any one year. For members of the public, the limit is 1.0 mSv/y (ARPANSA 2005).

The assessment indicates that the overall radiation environment, at the mine, the concentrator and the processing plant, would be broadly similar to the radiation environments found in similar workplaces at the Ranger uranium mine. This is based on the similar gamma radiation levels, dust activity concentrations and radon decay product concentrations, which have been measured during the exploration work at Nolans Bore. There is also a similar level of thorium in the Nolans Bore deposit as there is uranium in the Ranger deposit.

Gamma dose rates

In general, the in-pit gamma dose rates would be low because the level of contained thorium is low. There would be limited gamma from process material in the concentrator. There would be more significant gamma from higher specific activity thorium hydroxide waste residue in key sections of the processing plant.

Miners

Using the gamma factor and mine average ore grades of about 200 ppm uranium and 2,700 ppm thorium, a gamma dose rate of five µSv/h can be calculated.

Mining would involve an ore to waste ratio of 1:5 and applying this proportionally to the exposure results in approximately a fivefold reduction in average dose rate to approximately one µSv/h. The instrumental gamma surveys over the deposit area gave a 'global' dose rate figure of approximately 0.8 µSv/h (Hussey 2016), which is consistent with the average dose rate.

At a nominal dose rate of 1 µSv/h, the annual gamma doses to in-pit on-foot workers such as mine surveyors, geologists and grade control technicians, who spent about 50 per cent of their time in the mine (1,000 hours per year), would be approximately 1.0 mSv/y.

For mine drillers, shielding by their equipment is expected to reduce gamma radiation levels by an estimated 50 per cent, although they would be essentially full time in the pit, therefore the gamma doses would still be approximately 1.0 mSv/y.

In-mine heavy equipment operators are likely to have their gamma doses attenuated by approximately 50 per cent to 70 per cent, due to the mass of equipment between them and the surrounding ground. Therefore, it is expected that their gamma doses would also be approximately 1.0 mSv/y.

Concentrator and processing plant operators

Gamma doses in the concentrator and processing plant are expected to be low because the ore and process materials would be in slurry form and in vessels. Experience at the Olympic Dam, Ranger and Beverley uranium operations shows that processing plant workers generally receive gamma doses of approximately 1.0 mSv/y. This is expected to be the situation at the Nolans concentrator and processing plant.

The assessment noted that there is likely to be an area that would require additional controls due to gamma radiation levels. This is the area producing and handling barren liquor acid neutralisation residue. This residue comprises an iron-thorium hydroxide, and would be of significant specific activity. The equipment surface dose rates in this area would depend on total mass and contained activity, and ingrowth time.

Doses from exposure to radon decay product and thoron decay product

Miners

The radon and thoron concentration in the mine can be estimated using a box model (Cember and Johnson 2009). Modelling was carried out for a 'worst case' situation of still air in the mine for a period of two hours.

For radon, the experimentally determined emission rate is 0.4 Bq/m^2/s. For an ore exposure area of 40 ha, the calculated radon concentration is 8 Bq/m^3 after two hours. This equates to a potential alpha energy concentration (PAEC) of approximately 0.04 µJ/m^3. For full time exposure, (2,000 hours per year), the calculated potential dose is 0.11 mSv/y (using the radon decay product dose conversion factors in the Mining Code (ARPANSA 2005)).

For thoron, assuming a mine area of 40 ha and an emission rate of 200 Bq/m^2/s, and completely still air, the equilibrium concentration (which occurs after about ten minutes) is approximately 45 Bq/m^3. For full time exposure, (2,000 hours per year), the calculated potential dose is 0.05mSv/y (using the radon decay product dose conversion factors in the Mining Code (ARPANSA 2005)).

These concentrations are low due to the very large dilution volume of the mine.

Processing plant operators

Metallurgical test work has indicated that isotopes of thorium and radium would accumulate in parts of the processing plant and, as a result, emissions of thoron are conservatively estimated to be approximately 200 MBq/s. As noted, this is also due to the short half-life of thoron, and therefore relatively high activity.

For the purposes of determining an average thoron concentration in the processing plant, a box model was used. It was assumed that a box with dimensions 500 m long by 500 m wide by 50 m high would collect all emissions. This would give an equilibrium thoron concentration of 2 kBq/m^3. Note however that any air movement at all would significantly reduce this by inducing vertical mixing and dilution.

The test work has also indicated that the equilibrium factor, even in stable atmospheric conditions is approximately 0.001 to 0.004. However, the research notes that the equilibrium factor may reach 0.01 and therefore this figure was used to estimate potential doses for processing plant operators.

For an equilibrium thoron concentration of 2 kBq/m^3 and total exposure for 2,000 hours per year, the calculated potential dose is 1.4 mSv/y (using the thoron decay product dose conversion factor from the Mining Code (ARPANSA, 2005)).

See Appendix P for further details on the assessment method.

Doses from Inhalation of long-lived radionuclides in dust

Assessment of occupational dose from inhalation of airborne ore dust is based on the following assumptions:

- Dust concentrations of 1 mg/m^3
- At 10 BqTh/g activity in the ore dust (the 'global average' for Nolans ore) the mass concentration equates to 0.06 α dps/m^3
- A 1:5 ore to waste ratio applied to in-pit dust emissions and
- 2,000 h/y exposure.

This results in an occupational dose of approximately 0.25 mSv/y, without controls.

Summary

A summary of the predicted doses can be seen in Table 12-12

Table 12-12 Summary of worker dose estimates

Worker category	Radiation dose (mSv/y)			
	Gamma	Dust	RnDP/TnDP	Total
Mine on-foot	1.0	0.3	0.2	1.5
Mine heavy equipment operator	1.0	0.3	0.2	1.5
Processing plant operator	1.0	0.3	1.5	2.8

On the basis of modelling and analysis of occupational and environmental baseline data, it is concluded that worker doses at the Nolans operation are expected to be less than 5.0 mSv/y.

12.4.2 Radiation exposure to the public

Gamma radiation

The recognised limit for radiation doses to for members of the public is 1.0 mSv/y.

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

Gamma radiation intensity reduces significantly with distance (as one divided by the distance squared when the source is at a distance to be considered to be a point source). The gamma levels at the closest accessible area would be barely detectable and for a full year, the gamma dose is calculated to be less than 1.0 µSv/y.

Airborne dose estimates

Doses from inhalation of both dust and decay products of radon and thoron are based on the estimated annual average concentrations at each of the locations of interest. A summary of the inhalation dose estimates is provided in Table 12-13.

Table 12-13 Public inhalation dose estimates

Location	Total Suspended Particles (TSP) Dust		RnDP/TnDP*	
	U in Dust Dose (mSv/y)	Th in Dust Dose (mSv/y)	RnDP Dose (mSv/y)	TnDP Dose (mSv/y)
Accommodation village (part time)	0.000	0.003	0.001 (0.002)	0.005 (0.012)
Accommodation village (full time)	0.000	0.006	0.001 (0.003)	0.011 (0.026)
Aileron	0.000	0.002	0.000 (0.001)	0.003 (0.008)
Alyuen Community	0.000	0.002	0.001 (0.001)	0.003 (0.007)

* Note that 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 it is assumed that the factor would be applied to both radon and thoron (both are isotopes of radon). The revised doses can be seen in parentheses in the table.

Ingestion dose estimates

The estimate of the potential annual dose from the ingestion exposure pathway has been modelled for representative persons living at each of the locations of interest. The assessment is conservative based on the assumption is that all food consumed over the year is from the location and this provides a maximum ingestion dose that could be received as a result of operations. The assessment method assumes that dust emissions from the mining operation in the surrounding environment 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.

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

- 100 kg/y meat (assumed to be 100 kg beef) and
- 90 kg/y vegetable (30 kg/y each of non-leafy, leafy and root vegetables).

Using the standard ICRP ingestion dose conversion factors (ICRP 1995), the human doses can be calculated for residents at the sensitive receptor locations, with results shown in Table 12-14.

Table 12-14 Ingestion dose assessment

Location	Dose (mSv/y)		
	Vegetation Ingestion	Meat Ingestion	Total Ingestion
Accommodation village*	0.027	0.005	0.032
Aileron	0.009	0.002	0.011
Alyuen Community	0.009	0.002	0.011

*Note: For the accommodation village, occupancy time has been assumed to be 8,760 hours per year

Total dose estimates

The total dose estimates at the sensitive receptors are provided in Table 12-15. Note that the doses are based on 100 per cent occupancy (that is 8,760 hours per year) at Aileron, Alyuen and the accommodation village.

Table 12-15 Public total dose estimates

Location	Exposure Pathway Dose (mSv/y)1					
	Dust (U)	Dust (Th)	RnDP	TnDP	Ingestion	Total Dose
Accommodation village	0.000	0.006	0.001 (0.001)	0.011 (0.026)	0.032	0.050 (0.065)
Aileron	0.000	0.002	0.000 (0.001)	0.003 (0.008)	0.011	0.016 (0.025)
Alyuen Community	0.000	0.002	0.001 (0.001)	0.003 (0.007)	0.011	0.017 (0.021)

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

Bush tucker assessment

Consumption of local bush tucker in the Nolans region is unlikely to occur in any significant quantities. This is due to the lack of suitable animals and plants in the region which in turn is due to the lack of a reasonable supply of surface water sources.

Nonetheless, a standalone estimate of the potential dose to people living at the sensitive receptor locations from consuming bush tucker from that immediate location has been made. The analysis used conservative assumptions and the dose has been shown to be approximately 0.1 mSv/y at the two closest non-operational receptors, as indicated in Table 12-16.

Table 12-16 Ingestion dose assessment from bush tucker

Location	Dose (mSv/y)		
	Vegetation Ingestion	Meat Ingestion	Total Ingestion
Accommodation village	0.097	0.231	0.329
Aileron	0.032	0.076	0.108
Alyuen Community	0.032	0.076	0.108

Summary

On the basis of modelling and analysis of environmental baseline data, it can be concluded that the Project would result in negligible or minor radiological impacts to the public.

12.4.3 Flora and fauna impact assessment

For the assessment of radiological impacts to flora and fauna, a worst case location of interest has been selected, which is the accommodation village.

For flora and fauna, the assessment method is via the ERICA assessment software (ERICA 2016) which uses changes in the radionuclide concentration of media (such as soil and water) as a result of the operation to determine a risk quotient. The method for determining the change in media concentration is via modelled dust deposition results.

The assessment included two user-defined species with characteristics as follows:

- Wallaby (mass: 15 kilograms, height: 0.7 metres, width: 0.2 metres, length: 0.2 metres)
- Kangaroo (mass 50 kilogram, height 1.5 metres, width 0.75 metres and depth 0.75 metres).

The output of the assessment is shown in Table 12-17 which shows that after 42 years of dust deposition, the 10 µGy/h screening level is not exceeded for any species.

Table 12-17 ERICA assessment output

Species (all ERICA Default Species Unless Noted)	Total Dose Rate (µGy/h)
Amphibian	0.09
Annelid	0.12
Arthropod - detritivorous	0.09
Bird	0.05
Flying insects	0.07
Grasses & Herbs	0.89
Lichen & Bryophytes	2.92
Mammal - large	0.06
Mammal - small-burrowing	0.08
Mollusc - gastropod	0.10

Species (all ERICA Default Species Unless Noted)	Total Dose Rate (µGy/h)
Reptile	0.10
Shrub	0.62
Tree	0.04
Wallaby (user defined)	0.07
Kangaroo (user defined)	0.48

Summary

The ERICA assessment indicates no radiological risk to reference plants and animals from emissions from the Nolans Project. On the basis of modelling and analysis of environmental baseline data, it can be concluded that the Proposal would result in negligible or minor radiological impacts to non-human biota and the environment.

12.4.4 Closure

The closure goals for the Project are to ensure that radiation levels are such that they are consistent with pre-operational levels. Therefore, it is expected that there would be no long term radiological impacts of the project following closure.

To consider future scenarios, Arafura conducted an assessment (using the FEPs methodology (IAEA 2011)) to identify potential failures in the TSF and RSFs (Appendix J). The radiation exposures for the scenarios were then calculated.

The assessment considers a range of features, events and processes that may affect the disposal facilities into the future. The method is widely used for assessing the long term safety of radioactive waste disposal facilities.

The design and closure characteristics of the project's TSF and RSFs were assessed against a set of predefined criteria and potential failure scenarios are developed. Radiological assessments of the possible exposure scenarios were conducted and a summary of the potential doses is shown in Table 12-18

Table 12-18 Summary of assessment on potential doses in event of future failure

Failure scenario	Radiological impact	Comment
RSF liner failure leading to groundwater contamination	Ingestion of 1,000 litres per year of groundwater at Aileron gives an incremental annual dose of approximately 0.016 mSv/y	Radiological impact is negligible
RSF liner failure leading to groundwater contamination	Ingestion of 1,000 litres per year of groundwater at Aileron gives an incremental annual dose of approximately 0.016 mSv/y	Radiological impact is negligible
Erosion of TSF or RSF wall due to excessive rainfall	Loss of containment would result in doses to flora and fauna exceeding the ERICA	Radiological impacts are likely to be minor compared to other impacts of a failure

Failure scenario	Radiological impact	Comment
leading to overtopping and loss of containment	default screening level of 10u Gy/h Full time occupation may result in human doses up to 2.7m Sv/y	
Future drilling into TSF or RSF following closure while conducting exploration	Total occupational dose from gamma and dust for one year is estimated to be 3.2 mSv/y (for TSF drilling) and 4.1 mSv/y (for RSF drilling)	It is unlikely that exploratory drilling would continue for an extended period without workers becoming radiation workers and being monitored
Occupation of rehabilitated TSF and RSF with following cover materials: Regional surface material (natural background) Mine waste rock and regional material (conservative average of 3 Bq/g)	Human dose < 0.5 mSv/y Human dose approximately 2.0 mSv/y	Considered to be consistent with existing natural background levels Considered to be consistent with existing natural background levels

Note that the qualitative risk assessment indicated that it is highly unlikely that the identified failures could occur; however the radiological assessment was conducted on the scenarios to determine the potential doses should the failure occur.

12.5 Mitigation and monitoring

12.5.1 Mitigation

The overall aim is to ensure that radiation is controlled in the design stage of the project using a risk management approach. This means that the design and proposed operation would be reviewed to determine likely radiation sources and levels, and options for control would be identified for these sources. Options would be chosen on the basis of effectiveness, robustness and simplicity, and following the hierarchy of controls as far as possible, with substitution and engineering prioritised before administration and personal protective equipment.

The ALARA principle (doses to be kept As Low As Reasonably Achievable, social and economic circumstances being taken into account), would be followed, both in design and in operations. This would be achieved by implementing a radiation management plan, and by regular senior management review of, and response to, the data generated by ongoing monitoring.

Radiation Management Plan

A draft radiation management plan (RMP) (Appendix X) has been developed which is structured so as to follow closely the headings given in the Mining Code, covering:

- Description (of operations, and of measures for control)
- Demonstrated access to expertise
- Monitoring plan and method for dose assessment
- Provision of appropriate and adequate equipment, staff, facilities and operational procedures

- Details of induction and training
- Details of record keeping and reporting
- Plan for dealing with incidents accidents and emergencies and
- System of periodic assessment and review to achieve continual improvement.

The draft RMP would describe the operations and identify the radiological attributes of the operation and their management.

The record keeping, reporting, dose calculation, and management review processes would be described, together with the means of periodic assessment of effectiveness to achieve continual improvement.

Incident, accident and emergency response

A radiological accidents or emergencies plan would be prepared to identify response requirements for unexpected loss-of-control situations. This would include:

- Advice to first aid / fire-fighting /emergency responders
- Evacuation of non-essential personnel and boundary control
- Stabilisation and containment of the situation
- Dose estimation and controls
- Decontamination and debriefing of affected personnel
- Recovery planning, implementation and reinstitution of control and
- Post recovery investigation, root cause analysis, actions to prevent recurrence, and follow-up counselling.

Unplanned in-plant spillage possibilities would be taken into account in planning, through the provision of bunding to hold 110 per cent of the contents of the largest tank (within the bund) which has lost integrity, or of a tank which may require emergency or planned draining. There would be adequate space for access by clean-up equipment. The design would include concrete flooring and wash to sump pits for pump back to process for spill occurrences.

Radiation control in the mine

The doses to mine workers are expected to be low. Controls to ensure that doses remain low include:

- Restricting access to the main mining areas to ensure that only appropriately trained and qualified personnel are able to access the work areas
- Ensuring that all heavy mining equipment is air conditioned to minimise impacts of dust
- Minimising dust using standard dust suppression techniques (e.g. wetting of materials before handling, wetting of roadways, provision of dust collection systems on drills) and protective measures to reduce subsequent exposure (e.g. use of respiratory protection)
- Monitoring the levels of dust generated during tipping of material onto stockpiles and implementing standard dust control techniques as necessary and
- A separate wash-down pad within the site for vehicles that have come from the mine area.

Radiation control in the processing facilities

For the concentrator and processing plant, the material would be both wet and dry, requiring specific design considerations for dust control and spillage containment. This includes:

- Crushers and conveyor systems fitted with appropriate dust control measures such as dust extraction
- Use of scrubbers or bag houses where appropriate
- Bunding to collect and contain spillages from tanks containing radioactive process slurries, with bunding to capture 110 per cent of the largest tank within the bund in the event of a catastrophic failure
- Pipeline corridors bunded to control spillage of tailings or process residues due to pipeline failures
- Sufficient access and egress for mobile equipment to allow clean-up where there is the possibility for large spillages
- Wash-down water points and hoses supplied for spillage clean-up and
- Procedures to control exposures during the maintenance of the ventilation systems and plant work.

If the monitoring shows that there are elevated levels of dust in the workplace, respiratory protection will be used until a more permanent means to reduce dust is established.

There will be areas in the processing plant that would require installed shielding, with access restrictions. The areas will be defined as control areas, and require work under radiation work permit conditions specific to the task. Spillage will be contained with wash down via concreted sloped flooring and sump.

12.5.2 Monitoring measures

Occupational radiation monitoring

An occupational radiation monitoring program will be developed for operations. The aims of this program are to provide data for the assessment of worker doses and radiation controls for off-site impacts to be effective.

A detailed monitoring plan would be prepared for approval prior to construction commencing. An outline of the elements of such a plan is shown in Table 12-19.

Table 12-19 Outline of proposed occupational radiation monitoring plan

Environmental Pathway	Measurement Method	Location and Frequency
Gamma Radiation	Thermoluminescent dosimeter (TLD) badges issued quarterly	All plant and mine personnel Used for dose data
	Electronic Personal Dosimeters (EPDs) Daily issue as required to potential high dose rate workers	Specific in-pit and maintenance tasks Used for operational control
	Gamma survey with hand held meter Monthly survey	Routine surveys Used for checking effectiveness of controls

Environmental Pathway	Measurement Method	Location and Frequency
Radionuclides in Dust	Personal Air Samplers (PAS) plus drawer assembly count Conducted weekly on representative personnel	Issued to personnel in each workgroup Used for dose estimation
	Locational area samplers Conducted weekly on representative in appropriate work area	Used for investigative purposes
Radon and Thoron Decay Product Concentrations	Grab samples (Borak or Rolle method	Used for investigative purposes and checking effectiveness of controls
	Continuous monitors	Used in workplaces for control and investigation Used for investigative purposes
	Track-etch personal badges	Issued to personnel in each workgroup Used for dose estimation
Surface Contamination	Large-area alpha probe surveys Conducted monthly in appropriate work areas	Surveys in workplaces, offices and lunch rooms Used for investigative purposes and checking effectiveness of controls Used for checking cleanliness of equipment leaving the operational area

In conformity with good ALARA practice, and as a management tool, there would be pre-determined responses at particular trigger levels. These will be defined in consultation with regulators at the time of development and submission for approval of the operational RMP.

Environmental radiation monitoring

In addition to the occupational monitoring program, an environmental radiation monitoring program would occur during operations. The aim of this program is to provide data for the assessment of doses to the public in order to measure any radiological impacts on the off-site environment and to ensure that the radiation controls for off-site impacts are effective.

A detailed environmental monitoring plan would be prepared for approval prior to construction commencing and an outline of the elements of such a plan is shown in Table 12-20.

Table 12-20 Outline of proposed environmental radiation monitoring plan

Environmental Pathway	Measurement Method	Location and Frequency
Direct (external) gamma	Handheld environmental gamma monitor Passive environmental monitors	Annual survey at perimeter of operational area Monitors places at environmental monitoring sites quarterly

Environmental Pathway	Measurement Method	Location and Frequency
Radon and Thoron Gas Concentrations in Air	Passive Environmental Monitors	Monitors places at environmental monitoring sites quarterly
Radon and Thoron Decay Product Concentrations	Real time monitors	Monitor would rotate between off-site locations
Dispersion of dust containing long-lived, alpha-emitting radionuclides	High volume samplers	Monitors would rotate between approved off-site locations
	Dust deposition gauges	Sampling at identified locations
Seepage of contaminated water	Groundwater sampling from monitoring bores	Representative monitoring bores will be sampled annually and analysed for radionuclides
Run off of contaminated water	Surface water sampling	Opportunistic surface water sampling would occur following significant rainfall events
Radionuclides in potable water supplies	Sampling and radiometric analysis	Annually