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Radiation Report

RADIATION REPORT

Occupational and Environmental Radiation Measurements and Predictions

Prepared for Arafura Resources Limited

Nolans Project

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1 Executive Summary

The Nolans Rare Earths Project (the project) is located approximately 10 km west of Aileron Roadhouse and 135 km north of Alice Springs in the Northern Territory. It comprises an open pit mine at Nolans Bore, an associated concentrator and processing plant, with ancillary facilities including a tailings storage facility (TSF) for the beneficiation tailings, and residue storage facilities (RSFs) for waste from the processing plant. There will also be a water-supply borefield, gas-fired power plant and accommodation village. The project is intended to mine an average of about 900,000 tpa of ore for 42 years, and the processing plant will produce about 30,000 t of mixed rare earth chlorides for export to an overseas Arafura-operated facility for final separation of individual rare earth products.

The project will mine and treat ores containing approximately 2.5% rare earth oxides (REO), which are radioactive by virtue of their contaminant levels of thorium (Th) and uranium (U), of approximately 2,700 ppm and 200 ppm respectively. The beneficiation process will produce a mineral concentrate that will be upgraded in radionuclides to contain about 0.5% Th and about 0.05% U, equating to about 20 BqTh/g and about 5 BqU/g. Both ore and concentrate will contain the various Th and U chain decay daughter radionuclides, approximately in secular equilibrium.

As a consequence of the presence of these radionuclides, radiation control has been explicitly considered throughout the project design and in operational management systems so as to limit radiation doses to workers and to members of the public residing nearby, and also so as to protect against uncontrolled release to the environment, where there could be a potential threat both to the human foodchain and to non-human biota.

Control of radionuclide deportment into waste streams is also necessary to ensure quality control and saleability of final products. Radioactive content in these wastes will drive aspects of their management.

The operation will thus be regulated as a radiation practice under the Northern Territory's *Radiation Protection Act* and under the requirements of the *Mining Management Act* and *Work Health & Safety (National Uniform Legislation) Act 2011*.

Project activities to date have operated under a simple Radiation Management Plan first implemented in mid-2005, and expanded as required to cover bulk sampling campaigns.

It should be noted that measures required for control of radiation in rare earths mining and processing are very similar to those required in uranium and mineral sands mining and processing, are well-understood, and will be committed to in the design and operation of the project.

Key findings from the assessment as presented in this report are as follows:

- Due to the significant presence of uranium and thorium, design controls for radiation will be required to ensure that doses remain low and well controlled;

- The estimated doses to workers on the Nolans Project will be well within the allowable limit;
- Predicted project increment (additional) radiation will be small compared with the natural background and also small compared with the variability in natural background;
- The project incremental dose to members of the public resident at nearby centres (i.e. Aileron, being Aileron Roadhouse, campground and houses, and the Aileron Station Homestead and workers' accommodation – 10 km east; Alyuen Aboriginal Community – 15 km south-east) will be very low; and
- The risk of radiological harm to non-human biota has been assessed to be 'negligible'.

The results of over ten years of radiation monitoring on site, covering gamma radiation, radionuclides in airborne dust, radon and thoron and their progeny, show overall levels which are in line with the rest of inland Australia, except in the immediate environs of the outcropping Nolans Bore deposit. In addition, the monitoring results show (as indeed they do everywhere else) significant variations spatially across the project area, and significant variations with time, both on short and long time scales.

2 Aim of Report

This Radiation Report (report) has been prepared as part of the Environmental Impact Assessment for the project and will describe:

- The regulatory regime applicable to mining and processing of radioactive ores for radiation control;
- The underlying control philosophy and approach which will be followed;
- The present radiological background as derived from baseline monitoring results;
- Estimates of radiation source terms arising from proposed project activities;
- Estimated environmental radiation increments which will result;
- Estimated doses to workers and members of the public,
- Description of design and management controls for radiation; and
- Assessment of risk to non-human biota.

Radioactive emission source terms (i.e. gamma shine, releases of radon and thoron, and releases of dusts containing long-lived alpha emitting radionuclides), and radiation doses to workers and others from these sources, can be readily assessed based on well-known principles and on comparisons with other uranium, mineral sands, and rare earths operations.

These assessments are given in subsequent sections of this report.

3 Introduction to Radiation

Ionizing radiation was first discovered, and almost immediately began to be used in medicine, over 100 years ago, when Prof Wilhelm Roentgen discovered x-rays (1895) and Marie Curie discovered radium (1898). Very soon thereafter (within 2 to 5 years), the immediately damaging effects (burns) and longer term risk (of cancer) arising from excessive doses began to be reported in the literature.

The health risks from ingesting and inhaling radioactive substances became obvious from the mid-1920s with the bone cancer deaths in the radium dial painters, and in response, the first workplace

radiation hygiene and airborne radioactivity standards were developed (by RD Evans of the US Public Health Service) in the early 1930s.

The first international recommendations for control of the health risks of x-rays and radium were published in 1928, by a committee of the International Congress on Radiology, later to evolve into the ICRP (see below).

A suitable general introduction to radiation protection in mining and processing of radioactive ores, including rare earth ores, is the Radiation Workers' Handbook, developed as a joint publication of the Commonwealth Department of Resources Energy & Tourism, and the Australian Uranium Association, and available on the AUA web site (www.aua.org.au).

Radiation, the effects of radiation, and radiation controls are generally very well understood and control measures together with active monitoring ensures that potential exposures remain low. Radiation is also very well regulated, consistent with international guidance and standards, as discussed below.

4 National & international regime for radiation control

4.1 Overview

Radiation doses to workers and to members of the public are (and have been since the 1950s) controlled in all Australian States and Territories under the various state Radiation Safety, Control or Protection Acts and associated Regulations. These Acts and Regulations are (as required by COAG rules) in general conformity with Codes and Guidelines issued by the Commonwealth agency, being the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), under its National Directory for Radiation Protection (RPS #6). ARPANSA, in turn, bases its advice on guidance documents published by the International Atomic Energy Agency (IAEA), being primarily IAEA Basic Safety Standards, Safety Series Publication #115; on the Recommendations of the International Commission on Radiological Protection (ICRP), being primarily ICRP Publication 103; and on the Reports of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR).

The specific ARPANSA radiation code which will apply is the Code of Practice on Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing, 2005 (RPS #9).

Therefore, radiation and radiation protection is very well understood and regulated, with a very structured and mature internationally agreed approach, developed over many decades.

The Nolans Project will operate in the Northern Territory. There are multiple regulatory agencies which will be involved namely, the Department of Mines and Energy (DME), NT Worksafe, and the Department of Health; the regulatory requirements for radiation safety in mining and processing of radioactive ores are set down in the NT *Mining Management Act and Regulations* (MMA). The MMA requires a Mine Management Plan and within it a Risk Management Plan. In this instance there will also be a requirement for a Radiation Management Plan (RMP) and Radioactive Waste Management Plan (RWMP).

The Territory Acts and Regulations also address the requirements for avoidance or minimisation of detrimental impact on the environment.

Arafura will commit to a RMP and RWMP as described under the ARPANSA Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing 2005 (Radiation Protection Series #9; the 'Mining Code').

A 'top-level' draft or outline RMP and RWMP are included in this document as an Appendix, in fulfilment of the EIS ToR item 5.7.3; however, it is noted that the final RMP and RWMP will be approved by the local regulator as part of the operation's licencing.

Arafura will comply with all relevant NT legislation and will be guided by all relevant ARPANSA Codes and Safety Guides.

4.2 ICRP System of Dose Limitation, ALARA, and Regulatory Limits

ICRP promotes (and the Australian regulatory regime adopts) a 'System of Dose Limitation' whereby all planned doses to workers or to members of the public from industrial activities need to be (a) *justified*; (b) *optimised*; and (c) *limited*.

Justification means generally that the benefits must be recognised by society to outweigh the detriments of any incurred dose. In the context of a uranium mine, 'justification' is demonstrated by regulatory approval of the proposal, and issue of licence to mine.

Optimisation means that doses are to be controlled so as to remain 'as low as reasonably achievable (ALARA), social and economic factors being taken into account'. In the mining industry context this implies at the design stage that 'best practice' choices will be made; and in operations, that there will be implemented an approved RMP incorporating an appropriate radiation monitoring program. 'ALARA' is thus a primary tool for control, prompting application of design standards in the design stage, and a philosophy of continuous improvement in operations.

Limitation means that doses will be controlled so as to remain below statutory limits, and is achieved by active management so as to ensure that workers' doses and doses to members of the public are kept well under the limits.

It is to be noted that these doses are project-origin, and thus above or in addition to dose from natural background, and they also exclude any dose arising from medical procedures.

4.3 Dose Limitation

The world-wide (and NT) annual limits for radiation doses to be accrued from planned and licenced human activities ('practices'), as recommended by ICRP, are 20 millisieverts per year (mSv/y) to

'radiation workers'[1], and an annual dose limit to members of the public (incremental to natural background, and arising from nearby radionuclide-emitting industrial activity), of 1 mSv/y.

These limits apply only to doses arising from work or industrial activities, i.e. from controllable and licensable activities, and do not include dose from natural background, nor medical doses incurred during diagnostic tests or therapeutic procedures. (This is because natural radiation is not amenable to control by the company, and medical doses are separately justified).

It is the responsibility of a company mining radioactive ores, just as it is of any other radiation-producing operation, to ensure that the doses of all of its workers are kept below the annual limit of 20 mSv (1), and indeed, 'As Low As Reasonably Achievable' (ALARA) below that limit; and that the doses from the operation or practice, received by residents living nearby, are kept well below the limit for members of the public, that being 1 mSv/y.

Arafura Resources recognises the System of Dose Limitation outlined by the ICRP, and understands implementation of ALARA to mean establishing design criteria and radiation risk assessments, and that doses will be effectively monitored, and controlled, using good industrial practices, so as to minimise doses, via active management and review.

It is noted that the definition of dose constraints as a management tool (and the associated management tool of Action Levels) will be discussed and determined in consultation with the regulator at the time of development of the operational RMP.

5 Natural Background Radiation

Radiation is ubiquitous, present everywhere. Worldwide, natural radiation doses to populations arise from exposure to cosmic rays, gamma radiation from uranium and thorium in soil and rock, from inhalation of radon in air which has passed over continental landmass, and from radionuclides ingested in food and water.

The average level of uranium and thorium in rocks and soils, worldwide, is about 3 and 10 parts per million (ppm) respectively.

Natural background radiation is highly variable: worldwide annual average dose to the human population is quoted by UNSCEAR to be about 2.4 mSv/y, with a range of 1-10 mSv/y. However, some locations incur doses which are more than tenfold higher than the average, including Guaripari in Brazil (35 mSv/y), Kerala, India (35 mSv/y) and Ramsar in Iran (a small area within the city giving 260 mSv/y), due to the presence of radium, uranium or thorium in the local soils and rocks (UNSCEAR, 1993).

It is noteworthy that populations living in areas having higher levels of background radiation do not show any epidemiological evidence of health problems. (Dobrzynski et al, 2015).

Australian averages and variability will be discussed in subsequent sections (Hussey, 2016; etc.)

[1] Averaged over 5 years, with a maximum in any one year of 50 mSv

5.1 Radiation types and origins

Thorium and uranium atoms break down to produce 'decay product or 'daughter' radioactive elements, or radionuclides, in a succession of transitions called the U and Th decay chains. During each transition, alpha (α), beta (β) or gamma (γ) radiation is emitted from the decaying atom. Each radionuclide decays with its own characteristic half-life, giving out its own specific energy radiation.

From an occupational dose control perspective, it is important to understand the type of radiation, in order to have effective controls. Alpha radiation is only an internal exposure hazard, delivered by inhalation or ingestion of an alpha-emitting element, and its control therefore calls for minimization of airborne activity levels, or air filtration; while gamma and beta radiation doses can result from exposures from outside the body, and thus their control may call for some engineered shielding.

Uranium and thorium bearing minerals thus contain a 'suite' of 'daughter' radioactive elements, produced by the nuclear breakdown or transformation of the parent element, as described in the section below.

5.2 Uranium and Thorium decay chains

The sequence of radionuclide transformations in the uranium and thorium chains are shown below:

U-238 Decay Chain

Nuclide	Radiation	Half-life
Uranium 238	α	4.5 billion years
Thorium 234	β, γ	24 days
Protactinium 234	β	1.2 minutes
Uranium 234	α	250 000 years
Thorium 230	α	80 000 years
Radium 226	α, γ	1600 years
Radon 222 (gas)	α	3.8 days
Polonium 218	**α**	**3 minutes**
Lead 214	**β, γ**	**27 minutes**
Bismuth 214	**β, γ**	**20 minutes**
Polonium 214	**α**	**160 microsecs**
Lead 210	β, γ	22 years
Bismuth 210	β	5 days
Polonium 210	α	140 days
Lead 206	---	stable

α = alpha particle, doubly charged helium nucleus, 2 protons + 2 neutrons, emitted from nucleus.
β = beta particle, high speed electron emitted from nucleus.
γ = gamma ray, electromagnetic radiation, similar to x-ray.
The radon daughters are shown in Bold.
The main gamma emitter is Bi214with its main emission at 609 keV.

U-235 Decay Chain

Nuclide	Radiation	Half-life
Uranium 235	α, γ	710 million years
Thorium 231	β	25.5 hours
Protactinium 231	α	33 000 years
Actinium 227	β	22 years
Thorium 227	α	18 days
Radium 223	α	11 days
Radon 219 (Actinon)	α	4 seconds
Polonium 215	α	1.8 milliseconds
Lead 211	β	36 minutes
Bismuth 211	α, γ	2.1 minutes
Thallium 207	β	4.8 minutes
Lead 207	nil, stable	infinite, lasts forever

Note: In nature, e.g. in ore or mineral samples, U-235 is about 5% of the activity of U-238 (and about 0.7% of the mass of U-238). Similarly, each U235 decay chain daughter is approx. 5% of the activity of each U-238 decay chain daughter.

Th-232 Decay Chain

Nuclide	Radiation	Half-life
Thorium 232	α	14 billion years
Radium 228	β	5.7 years
Actinium 228	β, γ	6.1 hours
Thorium 228	α, γ	1.9 years
Radium 224	α, γ	3.6 days
Radon 220 (Thoron)	α	55 seconds
Polonium 216	α	0.15 seconds
Lead 212	β, γ	10.6 hours
Bismuth 212	β (64%), α (36%), γ	61 minutes
Polonium 212 **(64%)**	α	300 nanoseconds
Thallium 208 **(36%)**	β, γ	3.1 minutes
Lead 208	nil, stable	infinite, lasts forever

Main gamma emitters are Tl-208, photon energy 2.6 MeV, and Ac-228, about 1 MeV. These gammas are much more penetrating than those from the U decay chain

All of these elements are present in thorium- and uranium-bearing minerals, and are present in the Nolans ore. In cases where there is no active leaching from or deposition in the ore of radionuclides, the decay chain elements will come to a state of 'secular equilibrium', in which the activity concentrations (in Bq/g) of all radionuclides are the same. These radionuclides give out alpha, beta, and gamma radiation, and the intensity or strength of the emissions depends on the amount (or 'activity') present in the ore or mineral, i.e. the grade.

5.3 Radiation Dose Delivery Pathways

The main pathways by which employees and members of the public may receive radiation doses at or from the Nolans Project operations (or indeed any mineral sand or rare earths mining project) are

identified below, together with their likely significance, and the measures that are to be taken to control these 'dose delivery pathways' are identified. They are as follows:

- Direct gamma irradiation from radioactive material. This is only significant if long periods are spent by workers close to large volumes of low specific activity radionuclide-bearing material, i.e. ore, or high activity radioactive sealed sources. This is minimized using *time, distance and shielding* – minimizing time spent near radioactive sources, maximizing distance from sources, and when that is not practical, placing shielding between workers and sources. Gamma doses to workers are to be monitored and controlled as required.

- Inhalation of short-lived alpha emitters, being the radon and thoron decay progeny. This is generally only a concern in enclosed spaces, such as in underground mines, or inside covered tanks or ore bins. This is minimized through ventilation; and by use of air filtration. There may be intermittently (mainly during winter season), 'spikes' in concentrations requiring active control measures during early morning periods of low level atmospheric temperature inversions and very low wind speeds. This implies the need for continuous monitoring at mine and plant.

- Inhalation of airborne dusts containing long-lived alpha-emitting uranium, thorium, and radium (ore dust, process dust, product dust, or tailings dust). This pathway will be minimised by use of normal dust suppression methods, mainly by watering of haul roads.

- Ingestion and absorption of radioactive material. Ingestion of radionuclide bearing dust by transfer from dirty hands to mouth is minimised by good personal hygiene: hands and face must be washed before eating, and workers may only eat in designated regularly cleaned crib rooms and offices.

- Absorption through skin (e.g. through cuts or abrasions). To prevent absorption through skin, any injury must be reported to the site health centre and treated.

All these pathways contribute differently, depending on the physical and chemical characteristics of the material, the radionuclide content, the work circumstances, and the controls in place. All these pathways will be monitored and controlled. Estimates for these pathway doses are provided in the following sections.

6 Historical and Baseline Studies

6.1 Overview of Studies

The Nolans Bore deposit was discovered and explored by the Japanese government-owned PNC Exploration Pty Ltd during the period 1994-95. Geological studies by Arafura commenced in 1999. Environmental and occupational radiation monitoring by Arafura commenced in 2005 (Sonter, 2016a; Dean and Grose, 2015; Hussey, 2016).

ANSTO Minerals (ANSTO) conducted a comprehensive radiological assessment of the region in 2006.

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

- The project area is radiologically determined by the extensive outcropping orebody;
- The local region has locally defined enhancement of gamma radiation levels;
- The broader area is characterised by a large number of areas with higher levels of uranium and thorium (and hence airborne dust radioactivity levels);
- There is locally elevated radon and thoron in the region due to the outcropping areas of elevated uranium and thorium; and
- Radon and thoron concentrations in the air vary by up to 2 to 3 orders of magnitude.

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

This section reports on two sets of baseline studies. The first is an independent study conducted by ANSTO in 2006 and the second set collates the results of surveys conducted by Arafura Resources.

6.2 ANSTO Studies

During 2006, ANSTO Minerals conducted a baseline radiological survey of the region (ANSTO, 2007). A summary of the results are provided below and the survey included:

- Gamma monitoring;
- Soil sampling;
- Vegetation sampling;
- Dust sampling; and
- Groundwater sampling.

6.2.1 Gamma Monitoring

A general area survey was conducted in a grid pattern across the mine site area and at sites remote from the project area. The remote sites are referred to as “background sites” and include two measurements in Kerosene Camp Creek and two measurements at the Aileron Roadhouse.

In all 53 measurements were taken using a sodium iodide crystal detector at a height 1m above the ground. The measurements were taken at locations on and off the Nolans Bore deposit and a summary of the results can be seen in Table 7.1.

Table 7.1: Regional Gamma Radiation

	Environmental Gamma Dose Rate (µSv/h)			
	Average	**Max**	**Min**	**Number**
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

6.2.2 Soil sampling

Duplicate surface soil samples were taken from three locations consisting of two sites in the region of the mine site ("Areas 1 and 2", the former site located upstream from the Nolans Bore deposit, and the latter located downstream) and one site ('Background') near the Aileron Roadhouse. Samples were analysed by ANSTO for the main long lived natural radionuclides and a summary of the results is shown in Table 7.2.

Table 7.2: ANSTO 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

*Note that the analyses were undertaken using both alpha and gamma spectroscopy for some radionuclides. For this summary, the higher value has been used.

The key observations from these sample results are as follows:

- The radionuclides in the U238 decay chain are in approximate secular equilibrium;
- The radionuclides in the Th232 decay chain are in approximate equilibrium;
- The concentrations of uranium are less that the average natural background concentrations across Australia (usually quoted at approximately 3 ppm, which is equivalent to approximately 40 Bq/kg for each of the U238 decay chain radionuclides); and
- The concentrations of thorium are consistent with the average natural background concentrations across Australia (usually quoted as about 10 ppm, which is equivalent to approximately 40 Bq/kg for each of the Th232 decay chain radionuclides).

The results show that the concentrations of uranium and thorium in the soils samples from Aileron Roadhouse are elevated compared to the samples from the mine region and compared to the Australian average.

6.2.3 Vegetation Samples

Sampling of vegetation was undertaken at three locations. ANSTO reports that approximately 30 kg of leafy green vegetation was collected. No species were identified in the report. The results can be seen in the following Table 7.3.

Table 7.3: Radionuclides in Vegetation

	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

*Concentrations for U238 were measured using two techniques. One technique (gamma spectroscopy) gave results for all samples as less than the detection level. Therefore the alpha spectroscopy results are reported here.

It is noteworthy that in all samples there is an enhancement in radium (both Ra226 and Ra228), and significantly in Pb210 and Po210. The Po210 and Pb210 enhancements are widely reported as 'natural fallout' arising from plate out on leaf surfaces of radon decay products from the atmosphere. The enhanced Th228 is likely to be due to ingrowth from the Ra228. This effect is observed in vegetation generally (UNSCEAR, 2000).

6.2.4 Groundwater Samples

Two samples were taken during the ANSTO survey. Results can be seen in Table 7.4.

Table 7.4: Radionuclides in Groundwater

	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

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

6.3 Arafura Studies

6.3.1 Overview

Arafura Resources has been carrying out environmental monitoring across the general region since 2010. A number of the sampling locations are shown in Figure 7.1. These surveys have comprised:

(i) soil sample collection and assay;

(ii) environmental gamma via thermoluminescent dosimeter (TLD) badges;

(iii) passive dust deposition and assay, and active airborne dust campaign;

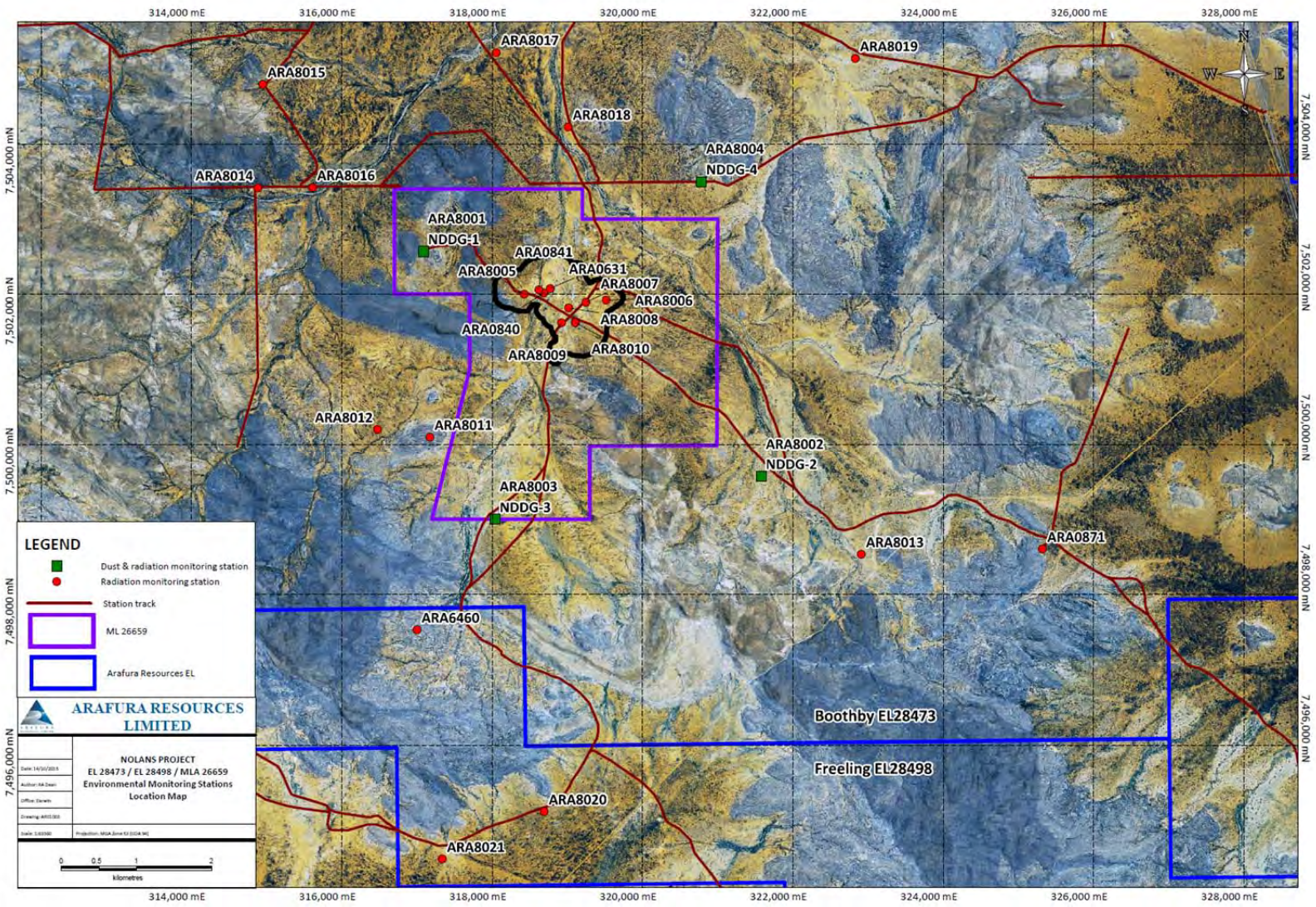
(iv) passive radon and thoron via 'Raduet' track-etch badges; and

(v) real time instrumental runs observing atmospheric Rn and Tn.

These have been collated in Hussey 2016 and Dean & Grose, 2016. A summary of the results is provided in this section.

Figure 7.1 shows the location of various environmental radiation monitors and tasks, namely, environmental gamma radiation via TLD badges; passive radon/thoron (etch-track) monitors (PR/TMs), passive dust deposition gauges (DDGs), and soil sampling locations. The outline of the Nolans open pit is shown by the black line.

Figure 7.1: Location of TLDs, PR/TMs, DDGs, and Soil Sampling Sites



6.3.2 Soil Sampling

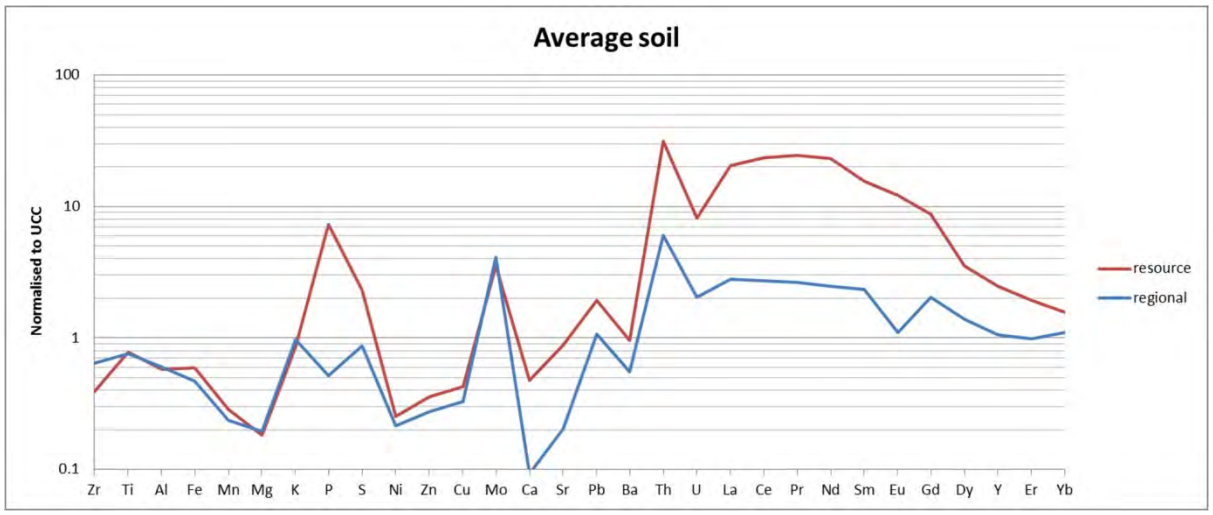
Arafura has conducted extensive soil sampling, taking samples at each of the long term TLD sites, as part of its geological and radiological characterisation of the region. Uranium and thorium concentrations for a range of samples have been determined and show that:

(i) general assays were 'as expected' (Hussey, 2016);

(ii) U and Th contents correlated reasonably with both TLD and aerial radiometric data; and

(iii) the samples on-deposit were enhanced in P, Ca, U, Th and lanthanides c.f. regional soils.

Figure 7.2: Average Composition of Regional and Resource Area Soils



6.3.3 Gamma Surveys

There have been multiple ground gamma surveys performed over the Nolans Bore deposit, and into the surrounding area, over a number of years. They have been followed up by a major crossed transects TLD badge survey, and by aerial radiometrics (two surveys commissioned by Arafura, one by the Northern Territory DME). The results are quite consistent, when taking different coverage and areal resolution into account. They show off-deposit averages which are close to but marginally above continental average (being in the order of 0.25 µSv/h, due to general regional slight radionuclide enhancement in soils), and on-deposit dose rates which average about 0.8 µSv/h but range up to and above 10 µSv/h (Hussey, 2016). The ground TLD results correlate reasonably well with local soil assay at TLD location.

The gamma radiation levels in the region have been extensively studied through a number of surveys, including:

- Aerial radiometrics surveys;
- Hand held gamma surveys; and
- Longer term gamma monitoring using stationary monitors (i.e. TLDs).

The location of the hand held and TLD monitoring can be seen in Figure 7.1. A summary of the results is shown in Table 7.5.

Table 7.5: Summary of Gamma Monitoring Results

Sample Program and Method	Results (average and range; µSv/h)	Reference
Nolans Bore (on deposit)	0.8 (highs to > 10)	Hussey (2016)
Nolans Bore (off deposit)	0.25	ANSTO (2007)

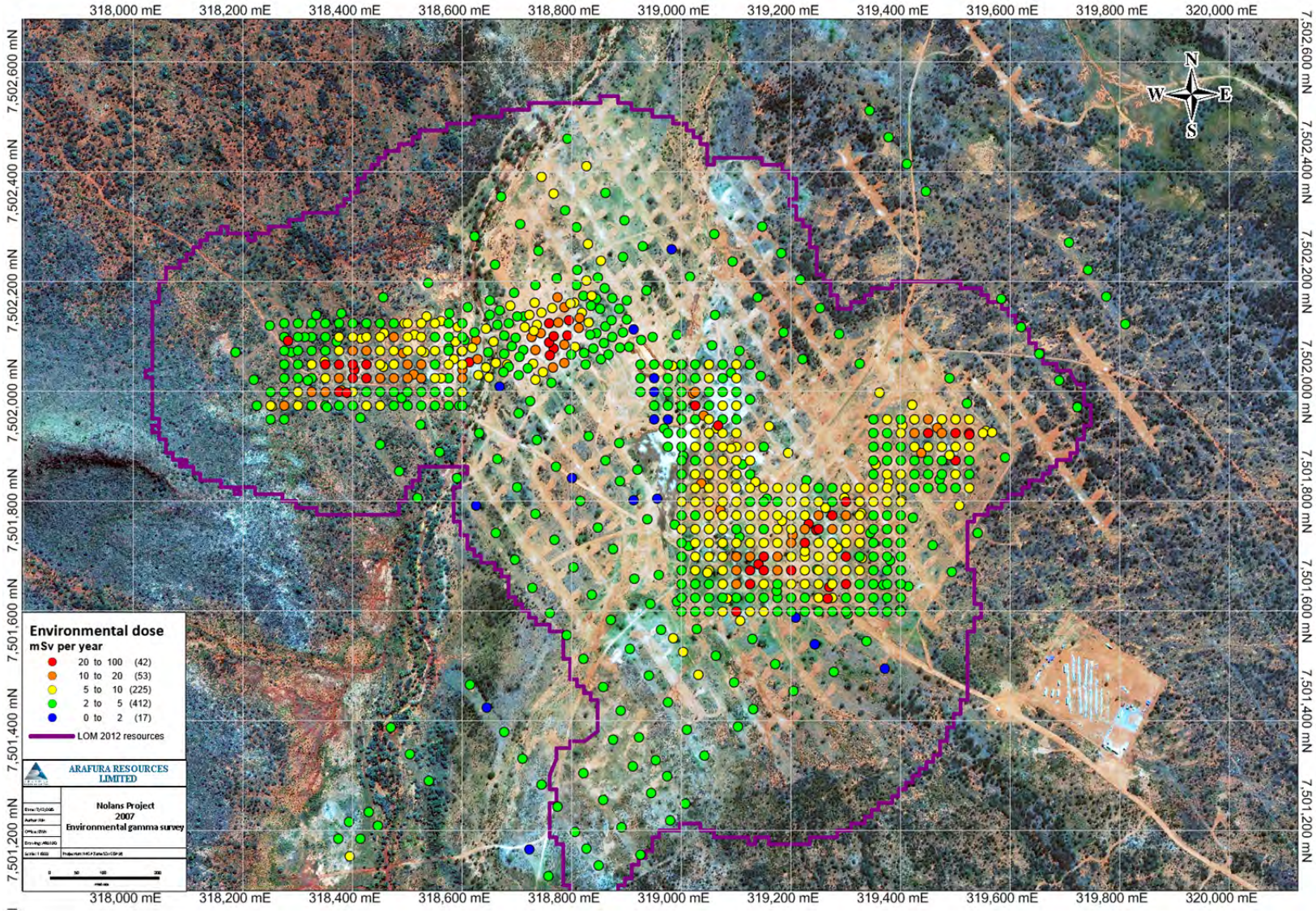
In general, the surveys provide consistent results and clearly show the gamma signature of the mineralised material and the wide regional variation in gamma radiation levels. The results show off-mineralisation averages of approximately 0.25µSv/h, with on-deposit dose rates averaging approximately 0.8 µSv/h, but ranging up to and above 10 µSv/h (Hussey, 2016).

The levels of background gamma radiation depend primarily on the concentrations of natural radionuclides in the soil, namely U238 and Th232 and their daughters, and K40. Typical gamma background levels across Australia are shown in Table 7.6. The average environmental TLD results for the Nolans Project area are also shown for comparison.

Table 7.6: Environmental Gamma Results elsewhere in Australia

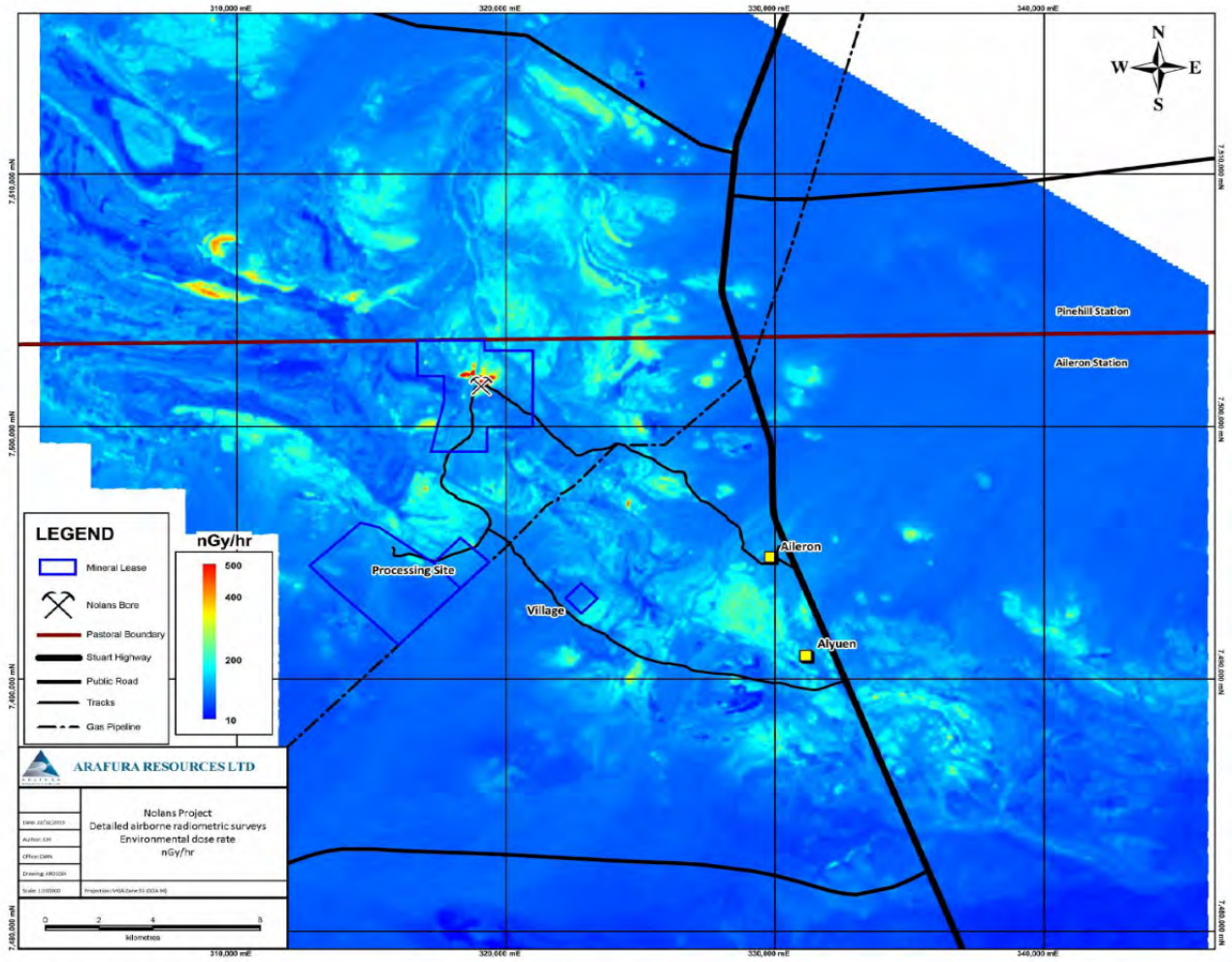
Locality	Average Environmental Gamma (µSv/h)	Reference
Australian average	0.07	Inferred from ARPANSA (2005)
Central South Australia	0.1	BHP Billiton (2009)
Honeymoon, SA	0.1 (no surface outcrop)	Southern Cross Resources (2006)
Kintyre, WA	0.09 (no surface outcrop)	Cameco (2013)
Lake Way, WA (on deposit)	0.9	Toro Energy (2015)
Lake Way, WA (off deposit)	0.1	Toro Energy (2015)
Yeelirrie, WA (on deposit)	0.9	Cameco (2015)
Yeelirrie, WA (off deposit)	0.09	Cameco (2015)
Mulga Rock, WA	0.06 (no surface outcrop)	Vimy Resources (2016)
Nolans Bore (on deposit)	0.8 (highs to > 10)	Hussey (2016)
Nolans Bore (off deposit)	0.25	ANSTO (2007)

Figure 7.3: Arafura Ground Gamma Survey 2007



Arafura has flown aerial radiometric surveys of the Nolans region, specifically to obtain information for environmental baseline purposes, and results are displayed in Figure 7.4.

Figure 7.4: Aerial Gamma Survey Results



6.3.4 Dust Deposition

Passive sampling using dust deposition gauges (DDGs) measures the rate at which airborne dust (and its contained radionuclides) deposits out on the ground (measured in g/m^2/month). Samples can then subsequently be assayed for radionuclide concentrations.

Dust deposition gauges were placed at four locations approximately 2 to 3 km 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 (Figure 8.2). This data set is reported in Dean and Grose (2015). A summary of the results is presented in Table 7.7.

Table 7.7: Dust Deposition Gauge (DDG) Results (averaged over total time)

	Total Dust Deposition (g/m^2/day)	Thorium Deposition (µg/m^2/day)	Uranium Deposition (µg/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 average results also show a marked seasonal variation (Table 7.8), with lower deposition occurring in the winter months.

Table 7.8: DDG Results, Seasonal and by Sector

Site	Average Total Dust Deposition (g/m^2/d)			
	Spring	Summer	Autumn	Winter
NDDG-1 (NW)	0.061	0.084	0.075	0.006
NDDG-2 (SE)	0.026	0.031	0.015	0.003
NDDG-3 (SW)	0.039	0.029	0.081	0.006
NDDG-4 (NE)	0.041	0.024	0.031	0.003

The uranium and thorium concentrations in the deposited dust are relatively consistent at approximately 6 ppm and 10 ppm respectively. These figures are very close to those quoted for worldwide background level of radionuclides in soils, being about 3 ppm U (or approx. 40 BqU/kg) and about 10 ppm Th (or about 40 BqTh/kg), with associated decay daughters. (Eisenbud and Gesell, 1997; UNSCEAR, 2000)[2]

[2] Environmental Radioactivity, 4 ed, Table 6-6 gives global average for U in 'all rock' as 7-60 Bq/kg, and 7-40 Bq/kg for Th232. UNSCEAR (2000) quotes global average soil U238 and Ra226 levels as 35 Bq/kg.

6.3.5 Dust Concentrations in Air

Between September 2010 and March 2011, dust concentration sampling was conducted using a DustTrak monitor. This device measures sub 10µm particles in air (also referred to as PM10 dust).

The results show daily average PM10 dust concentrations varying between 1 and 35 µg/m^3 over the sampling period. Highest results were observed in late summer. The average dust concentration over the sampling period was 16 µg/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 3 ppm and 10 ppm 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 and 1.2 mBq/m^3 for uranium and thorium, respectively.

Worldwide airborne radionuclide concentrations (UNSCEAR, 2000) are estimated to be in the order of 1 µBq/m^3, based on soil concentrations and assumed airborne dust loading (Toro Energy, 2015).

In an arid environment and with outcropping mineralization such as at Nolans, one can assume significantly higher dust loadings averaged over time and hence higher airborne activities.

6.3.6 Background Radon and Thoron in Ambient Atmosphere

Radon (both Rn222 and Rn220, also called 'thoron') occurs naturally in the atmosphere, being generated from the radioactive decay of parent radium (Ra226 and Ra224 respectively) in soil and rock. Some proportion of the radon, after its formation, will diffuse through the soil and escape into the air.

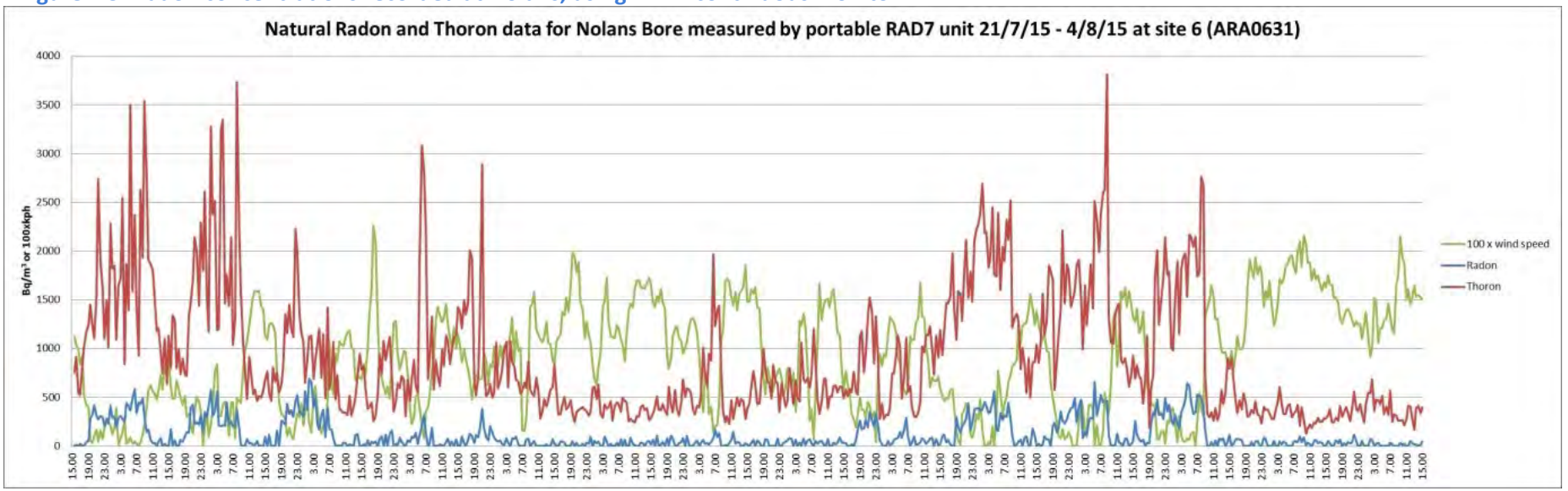
There is a pronounced *diurnal* cycle in near-surface atmospheric radon concentration, particularly evident during winter, when night-time temperature inversions create a very stable atmosphere and mixing of the surface air layer is almost completely inhibited. In these circumstances, near surface radon concentration can build to levels that are an order of magnitude more than average daytime levels, which are kept low by convective mixing (note anti-correlation with windspeed) which begins shortly after dawn due to solar heating (Figure 7.5).

Natural airborne radon concentrations are extraordinarily variable, ranging well over an order of magnitude in a typical 24 hour cycle, possibly from 1 Bq/m^3 to 1,000 Bq/m^3. UNSCEAR (2000) reports the worldwide average as 10 Bq/m^3.

These variations are well documented and have been observed in baseline monitoring undertaken on other projects (Olympic Dam, Yeelirrie, Beverley and Wiluna).

During 2015, Arafura Resources used a Durridge Rad 7 real time radon and thoron monitor to carry out a campaign of monitoring on site at Nolans Bore (Hussey, 2016; Sonter and Hondros, 2015). The results indicated a high level of variability in both radon and thoron concentrations, up to two orders of magnitude, consistent with variations observed elsewhere (see Figure 8.3).

Figure 7.5: Radon concentrations recorded at Nolans, using RAD7 continuous monitor



During the sampling period, the naturally occurring average radon concentrations were found to be approximately 80 Bq/m^3, with thoron concentrations on average about 800 Bq/m^3 (Sonter and Hondros, 2015).

The thoron (Tn) concentrations shown here are significantly higher than the radon concentration, and it should be noted that (a) this is both quantitatively and qualitatively 'as expected', and (b) this does not represent a health risk. The reasons for this relate to the consistently very low Equilibrium Factor for TnDP observed in ambient air.

Time-integrating track-etch radon and thoron detectors were supplied by Radosys Ltd, Hungary. These detectors were exposed, for a period of 118 days, at locations shown in Figure 8.2. Long term average results (on-deposit and off-deposit) are given in Table 7.9. As expected, on-deposit detectors gave noticeably higher average readings.

Table 7.9: Passive Radon and Thoron averages reported by Raduet track-etch badges.

Location	Average Concentration (Bq/m^3)	
	Radon	Thoron
Within pit footprint	43.7	470.2
Outside pit footprint (regional)	28.9	120.3

Comparison with radon data from uranium projects in Australia are shown in Table 7.10:

Table 7.10: Reported Average Environmental Radon Concentrations.

Location	Airborne Radon Concentrations (Bq/m^3)	Reference
Lake Way	27	Toro Energy (2015)
Beverley	36 (no surface ore)	Heathgate Resources (1998)
Honeymoon	28 (no surface ore)	Southern Cross Resources (2006)
Olympic Dam	20 (no surface ore)	BHP Billiton (2009)
Kintyre	16 (no surface ore)	Cameco (2013)
Mulga Rock	24.5 (no surface ore)	Vimy Resources (2015)
Nolans (regional)	28.9 Rn; 120.3 Tn	This report
Nolans (on deposit)	43.7 Rn; 470.2 Tn	This report

This shows that the local regional radon figures are consistent with the rest of outback Australia. In addition, the 'on-deposit' radon levels at Nolans Bore are only slightly above the figures for projects with no surface ore expression at all. The thoron levels are noteworthy as they do show a significant 'signal' over the deposit, as would be expected, given the very short half-life of 55 seconds.

6.3.7 Radon and Thoron Decay Product Concentrations

Radon Decay Product (RnDP) Concentrations

Historically, manual (Environmental Rolle) grab sample counts of radon decay product (RnDP) concentrations were performed at Nolans Bore during radiation monitoring campaigns in June/July 2005 (11 daytime readings averaging 0.27 µJ/m^3) and Feb 2008 (27 daytime readings giving average

0.02 µJ/m^3). Note that these are midwinter and midsummer readings and thus do 'make sense' despite the order of magnitude difference (Sonter, 2016a).

Thoron Decay Product (TnDP) Concentrations

More recently, manual thoron decay product (TnDP) readings have been taken, in two campaigns during 2015, the second simultaneously with the Rn/Tn instrumental survey described above. Very large day-night variations were observed, similar to the variations shown in Rn and Tn concentrations in Figure 8.3.

Between 28 September and 6 October 2015, daily TnDP concentrations were measured, using the Rock Procedure on the Nolans Bore deposit at 0640 and 1600 on each day. Average concentrations (excluding negative results) were:

- Morning – 0.166 µJ/m^3; maxima about 0.3 µJ/m^3;
- Afternoon – 0.039 µJ/m^3;
- All average – 0.085 µJ/m^3.

Since the Derived Air Concentration (DAC) for TnDPs is 20 µJ/m^3 (RPS #9 ARPANSA, 2005) these levels imply low inhalation doses from TnDPs, even for extended exposure times.

Most importantly, ***because the mineralization is outcropping***, these readings can be taken as generally indicative of what is likely to be experienced in at least the early stage development of the Nolans open pit.

Equilibrium Factors

During the 2015 campaign, Tn levels were measured continuously using a RAD-7. Comparison of simultaneous Tn and TnDP concentrations as measured via the Rock Procedure gave Equilibrium Factors ranging from 0.001 to 0.004 (Sonter and Hondros, 2016).

6.3.8 Radon and Thoron emanation from ores

Emanation studies were carried out in July 2015 on two drums of ore from Nolans (one apatite, one calc-silicate, both grading about 6,000 ppm Th and 500 ppm U). The measurement methods were: (i) use of charcoal cans with subsequent gamma counting ('Countess method'); and (ii) sealing the drum and sampling of headspace air via Durridge RAD-7 radon monitor to watch Rn and Tn increase over time. These two quite different techniques gave reassuringly similar results, with both dry crushed ore types giving about 1 Bq/m^2/s for Rn222 and about 300 Bq/m^2/s for Rn220 (Sonter, 2016b). As noted above, these readings for thoron are a close match with theory (IAEA TR472).

The emanation rates which can be inferred for the life of mine average exposed ore (200 ppm U and 2,700 ppm Th) is thus 0.4 BqRn/m^2/s and 150 BqTn/m^2/s.

6.4 Summary

The baseline monitoring shows that:

(i) there is enhanced regional distribution of thorium and uranium; and
(ii) notwithstanding (i), local gamma radiation and airborne radioactivity are small.

7 Radiation Overview of Proposed Project

The Nolans Project will comprise an open pit, an adjacent concentrator, and a nearby processing plant. There will be a beneficiation tailings storage facility (TSF) adjacent to the concentrator, and processing plant residue storage facilities (RSFs). For a more complete Project Description, see Chapter 3 of the Nolans Project EIS.

The mine will extract approximately 1 Mtpa of ore, with a total material mined of 10 Mtpa. The 9 Mtpa of waste will be sent to waste rock stockpiles which will ultimately approach 600 hectares. The radon release from these stockpiles is however specifically discounted as a project contribution, because Arafura has determined that there is sufficient inert material in the waste rock stream to ensure that mineralized waste will be encapsulated by non-radioactive material, which will be of 'continental' radionuclide content.

The ROM ore contains on average about 200 ppm U and 2,700ppm Th, and is in approximate secular equilibrium, in both the U238 and Th232 chains.

The concentrator upgrades the ROM ore by a factor of about two to produce a mineral (or beneficiation) concentrate. This is the feed material to the processing plant. The material rejected by the upgrading process at the concentrator (i.e. the beneficiation tailings) will be pumped to the TSF. The tailings will grade 1 Bq/g (80 ppm) U and 5 Bq/g (1,000 ppm) Th (Table 8.6).

The mineral concentrate (at 4.5 Bq/g U (= 360 ppm U) and 19 Bq/g Th (= 4750 ppm Th) is then pumped to the processing plant where *essentially all radionuclides are rejected into the process residue stream which reports to the RSFs.*

At cessation of processing, the TSF and RSFs will be capped with a nominal 1 metre of unmineralised waste rock to prevent water erosion and deter burrowing by wildlife. This will also prevent dust resuspension and attenuate radon release.

After operations cease, the pit will be allowed to flood, and there will be no continuing radiation emissions, as the TSF and RSFs (where all radionuclides will be sequestrated) will be covered, and mineralized waste rock will be encapsulated in non-mineralized waste rock; and the pit will have been depleted of ore.

The radiation emissions (gamma, dust, radon and thoron) associated with the project are thus driven by the following physical factors:

- Mining pit (final size approx. 180 ha, of which approx. 40 ha maximum ore exposure (including bench faces));
- Pit volume (final) 160 x 10^6 m^3;
- Waste rock dumps (final area 600 ha, but no emissions as capped by inert (<1 Bq) waste rocks);
- Concentrator footprint (500 m x 500 m = 25 ha nominal);
- TSF (40 ha uncapped at any time);
- Processing plant footprint (25 ha nominal); and
- RSFs (80 ha uncapped at any time).

The criteria in Table 8.1 are also relevant to the radiological impact assessment.

Table 8.1: Physical factors

Factor	Ore	> 1 Bq waste	< 1 Bq waste
Average mining rate (Mtpa)	1	4.5*	4.5*
Grade U (ppm)	200	80	5
Grade Th (ppm)	2,700	480	20

*The quantities of waste rocks in these categories will vary on an annual basis and is dependent on where mining is taking place in the pit. Over the life-of-mine, approximately 50% of the waste rocks fall into each category.

7.1 Radionuclide Analyses

Table 8.2 is a summary of the radionuclide testwork undertaken by ANSTO (ANSTO, 2015).

Table 8.2: Radionuclide Analysis of Metallurgical Streams

Radio Nuclide	Ore	Beneficiation Tailings		Beneficiation Concentrate	Process Residues		Cerium Carbonate Product	Rare Earth Chloride Product
	Bq/g	Solids (Bq/g)	Liquids (Bq/l)	Solids (Bq/g)	Solids (Bq/g)	Liquids (Bq/l)	Solids (Bq/g)	Solids (Bq/g)
Th232	9.6	5.0	0	19.0	8.3	92.4	0.35	0.00
Ra228	9.6	5.5	0	18.0	10.1	145.4	0.10	0.46
Th228	9.6	5.0	0	19.0	9.5	93.5	0.29	0.08
U238	2.1	1.0	0	4.5	2.8	17.3	0.05	0.00
U234	2.1	0.9	0	4.6	3.0	16.3	0.06	0.00
Th230	2.1	0.5	0	5.5	4.7	34.7	0.19	0.00
Ra226	2.1	0.8	0	4.8	2.2	12.9	0.04	0.04
Pb210	2.1	0.7	0	5.1	2.6	0.2	0.06	0.00
Po210	2.1	1.0	0	4.5	2.0	0.3	0.02	0.00
Ac227	0.0	0.0	0	0.0	0.0	0.0	0.03	0.35
Mass(t)	**920,000**	**618,000**	**0**	**301,500**	**602,000**	**1,625,333**	**17,000**	**26,000**

Radio Nuclide	Ore	Beneficiation Tailings		Beneficiation Concentrate	Process Residues		Cerium Carbonate Product	Rare Earth Chloride Product
	%	Solids %	Liquids %	Solids %	Solids %	Liquids %	Solids %	Solids %
Th232	100	35.1	0	64.9	62.9	1.9	0.07	0.00
Ra228	100	38.5	0	61.5	59.0	2.3	0.02	0.12
Th228	100	35.1	0	64.9	63.1	1.7	0.05	0.02
U238	100	30.8	0	69.2	68.1	1.1	0.03	0.00
U234	100	29.2	0	70.8	69.7	1.0	0.04	0.00
Th230	100	15.4	0	84.6	82.9	1.7	0.09	0.00

Ra226	100	26.1	0	73.9	72.6	1.1	0.04	0.06
Pb210	100	21.5	0	78.5	78.4	0.0	0.05	0.00
Po210	100	30.8	0	69.2	69.2	0.0	0.02	0.00
Ac227	100	30.8	0	69.2			3.46	65.79
Mass(t)	**920,000**	**618,000**	**0**	**301,500**	**602,000**	**1,625,333**	**17,000**	**26,000**

7.2 Gamma Radiation Sources Quantification

Gamma radiation on pit ore exposures, ROM pad, and tailings and residue surfaces can be modelled based on a general 2π steradian (infinite flat plane) emissions factor derived from the literature (see Sonter and Carter, 2015) as follows:

γ doserate = (0.3 μSv/h per BqU/g) + (0.45 μSv/h per BqTh/g).

7.3 Predictions of Source Terms for Radon and Thoron

Radon and thoron will be emitted from ore surfaces, ore stockpiles, exposed tailings and residues, releases from ore in process in and the concentrator and processing plants, and from pit dewatering.

Recent testwork has been performed to measure experimentally the radon and thoron emanation (flux) from packed drums of compacted crushed apatite and calc-silicate ores containing 6,000 ppm Th and 500 ppm U. These tests were performed: (i) by the Countess Method using charcoal cans; and (ii) also using Durridge Rad-7 continuous radon monitors. They showed results which agreed in general and indicated around 1 Bq/m^2/s for radon, and very scattered figures but in the order of 200-500 Bq/m^2/s for thoron.

The figure of 1 Bq/m^2/s for Rn is generally consistent with other measurements and estimates reported in the literature, when scaled for U grade (e.g. Mason, Elliot and Gan, 1982). The range of Tn flux readings is in line with a flux figure calculated from first principles of 300 BqTn/m^2/s (for 500 ppm Th content).

For the 'global' grades of 2,700 ppm Th and 200 ppm U we therefore infer Rn flux factor of 0.4 BqRn/m^2/s, and for Tn flux, a figure conservatively set at 200 BqTn/m^2/s.

7.3.1 Radon from pit and pit dewatering

It is assumed that ultimate ore exposure will be about 40 ha. We apply Rn and Tn flux factors of 0.4 Bq/m^2/s and 200 Bq/m^2/s respectively, giving 160 kBq/s of Rn and 80 MBq/s of Tn.

Radon release from pit dewatering has been estimated and found to be very minor (some kBq/s).

7.3.2 Radon and Thoron from Beneficiation Tailings

Radon release from tailings is substantially mitigated due to the material being deposited as a slurry. For modelling purposes a notional radon emanation rate for this material of 10% of the flux for crushed material has been assigned, based on results from testwork on saturated crushed ore (Sonter, 2016b). For the beneficiation tailings, with U and Th grades of 1 and 5 Bq/g respectively (i.e.

80 ppm U and 1,250 ppm Th), this corresponds to 0.16 and 60 Bq/m2/s for Rn and Tn respectively, and hence totals of 64 kBq/s of Rn and 24 MBq/s of Tn.

7.3.3 Radon and Thoron from Processing Plant

Radon and thoron releases from the concentrator are assumed to be negligible because no leaching takes place. Releases from the processing plant as result of leaching are calculated from activity throughput of ore, conservatively assuming the complete release of the total activity of contained radon and thoron from the ore *during processing*.

The concentrate feed grade is quoted as 19 and 4.5 Bq/g Th and U respectively, and the feed rate is 0.3 Mtpa. On this basis the Tn and Rn release from leaching is found to be 0.2 MBq/s of Rn220, and 0.04 MBq/s of Rn222.

There will also be thoron release in the processing plant from ingrowth from thorium in transit through the plant (assuming an ore residence time in-plant of 24 hours). This has been calculated to be 195 MBq/s. The Tn emission will not be an impact to distant receptors due to the rapid decay of thoron, being 55 seconds, but prompts consideration as an occupational exposure in the plant (see later discussion, and Sonter and Hondros (2016)).

Emanation from the RSFs is assessed to be negligible, based on the wet and clayey nature of the process waste residues.

7.3.4 Radon source terms total

The radon source terms for various project elements, based on the above, are provided in Table 8.3.

Table 8.3: Radon and Thoron Source Terms

Source	Area or throughput	Rn total	Tn Total
Ore benches	40 ha ore (final pit)	160 kBq/s	80 MBq/s
Concentrator	0.34 MBqTh/s; 80 kBqU/s	minor - no leach	minor - no leach
Beneficiation Tailings	40 ha	64 kBq/s	24 MBq/s
Processing Plant	0.18 MBqTh/s; 43 kBqU/s	43 kBq/s	195 MBq/s
Process Residues	80 ha	minor: wet, clayey	minor: wet, clayey
Waste Rock Dumps	600 ha max	** not assessed	** not assessed
Total		approx 0.3 MBq/s	approx 300 MBq/s

**Rn release from WRD is assumed to be same as underlying unmineralised soils.

As discussed above, and based on measurements, a radon emission rate (or flux) applicable to ore benches of 0.4 Bq/m^2/s, and a thoron flux of 200 Bq/m^2/s, were used. TSF figures were estimated as the product of one tenth of the ore flux values, and its area. RSF fluxes were assessed as zero.

These source terms are the figures used as input to meteorological modelling for calculation of doses to offsite receptors.

7.3.5 Airborne Dusts containing long-lived alpha emitters

Ore, concentrate, tailings, and process residue dusts contain long-lived alpha emitting radionuclides, namely U, Th, Ra, and Po. These radionuclide bearing dusts can potentially arise from:

- fugitive suspended ore dust from mining operations, haul roads and spillages; and

- dried and resuspended process or tailings dust (eliminated by being kept wet).

In the absence of robust data from elsewhere, a pessimistic average fulltime dust concentration in workplaces of 1 mg/m^3 inhalable fraction has been nominated as a blanket assumption. Applying the ROM assays for U and Th, this concentration is equivalent to 0.06 αdps/m^3, which is low compared with the Derived Air Concentration of 1 αdps/m^3.

8 Predicted Workplace Radiation Doses

The following sections give results of estimations and calculations of various radiation parameters.

It is considered that the overall radiation environment, both in the Nolans pit and in the Nolans concentrator and processing plant, will be broadly similar to the radiation environments found in similar workplaces at the Ranger Uranium operation. The reason for this belief lies in the similar gamma, dust activity, and RnDP readings which have been found during the exploration works at Nolans, and in the similar activity concentrations in the ore and concentrate (albeit of thorium rather than uranium). First-principles estimations support this prediction.

8.1 Gamma doserate and dose predictions

As a general statement, the in-pit gamma doserates will be low, because the level of contained thorium is low. There will be limited gamma shine from process material in the concentrator. There will be more significant gamma shine from higher specific activity thorium hydroxide waste in the relevant section of the processing plant.

In-pit gamma doserate assessments were carried out using the rule given in 8.2.1 above. For global average ore of 200 ppm U and 2,700 ppm Th, this equates to about 5 µSv/h for 'infinite flat plane' geometry, without shielding. If the ore-to-waste ratio of 1:5 is then applied to reflect the proportion of area of waste exposed to area of ore exposed, this results in a reduction to about 1 µSv/h.

Internal (Arafura) historical reports describe instrumental gamma surveys over the central part of the deposit which gave a 'global' doserate figure in the order of 0.8 µSv/h (Hussey, 2016). This is in general conformity with the above estimate and supports the belief that the present surface data is indicative of the future radiation environment of the initial open pit.

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

Note that shielding by their equipment will reduce this for blasthole drillers, by perhaps 50%, but they will spend essentially full time in-pit so that total doses will still be about 1 mSv/y.

Since these are likely 'worst case' assessments, there will be no necessity to implement any specific gamma dose controls, for pedestrian workers such as pit surveyors, geologists, drillers, or grade control technicians (noting however that ongoing monitoring via EPDs and TLDs will provide ongoing real time and cumulative checking of this assessment).

In-pit heavy equipment operators will have their gamma doses attenuated by approximately 50% to 70%, due to the mass of equipment between them and the surrounding ground, and so despite higher in-pit hours, they also will also receive about 1 mSv/y.

Gamma doses in the concentrator and processing plant will be low, as ore will be in slurry form and in vessels, and hence (a) diluted and (b) adventitiously shielded. Experience at uranium operations (i.e. Olympic Dam, Ranger, Beverley) shows that metallurgical plant workers habitually receive gamma doses of about 1 mSv/y, and the gamma radiation from the Nolans ore slurry will be similar in intensity to that from a medium grade U treatment plant grinding / leach section (see for example the doses reported in the Olympic Dam EIS (BHP Billiton, 2009), and ARPANSA National Dose Register for 'hydrometallurgical' workers). As a result, and in line with historical data from elsewhere, Nolans concentrator and processing plant workers' gamma doses is expected to be about 1 mSv/y.

The single area of greater potential gamma dose rate will be the area within the processing plant which is producing and handling double sulphate precipitation (DSP) barren liquor acid neutralization residue. This residue comprises an iron-thorium hydroxide, and will be of significant (but as-yet undetermined) specific activity. The equipment surface dose rates in this area will depend on total mass and contained activity, and ingrowth time.

In this area, it is envisaged that there will be emplaced shielding, with access restriction as a Controlled Area, and all work under Radiation Work Permit conditions specific to the task (similar to design and procedures for Yellowcake Packing Areas in uranium plants). Spillage will be rigorously contained with washdown via concrete sloped flooring and sump and thence returned to general residue stream. Maintenance workers when working in this area will be issued with EPDs for real time gamma monitoring.

Table 9.1: Estimated annual gamma doses for Nolans workers

Worker Type	Estimated annual gamma dose[3]
Geologists, Pit Technicians	1 mSv
Blasthole drillers	1 mSv
Mine heavy equipment operators	1 mSv
Concentrator and processing plant operators	1 mSv

8.2 Predictions of concentrations of radon & thoron & their decay products

Radon and thoron decay product concentrations will vary depending on a number of conditions. Surface conditions can be predicted from existing background monitoring results and project impacts are likely to be minor compared to natural background levels.

However concentrations in the mine may vary significantly, with temperature inversions leading to higher concentrations.

[3] Work-related, see details in Appendix 6.

Open Pit: Radon and RnDP:

It is recognised that winter-time early morning still air conditions are conducive to stable air and near-surface inversions. These inversions can trap radon and thoron and give periods of relatively high RnDP and TnDP concentrations (see Sonter and Grose 2016 for discussion of on-site measurements at Nolans Bore). These occurrences are identified as the most likely radiation exposure situations requiring active controls. The timeline generally shows a build-up of RnDP and TnDP during the pre-dawn period with rapid drop in concentration coinciding with breakup of the temperature inversion soon after solar heating commences, and thus thermal convection.

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

Radon in pit: At 160 kBq/s into a pit volume of 160 x 10^6 m^3, the resultant is 7.2 BqRn/m^3 after 2 hrs and thus PAEC for RnDP of about 0.04 µJ/m^3. This resultant RnDP concentration is under 1% of the DAC (which is 7 µJ/m^3).

Thoron in pit: Similarly, at 80 MBq Tn/s, and completely still air, one finds ultimate Tn concentration (which occurs after about 10 minutes) of about 40 BqTn/m^3.

These concentrations are low despite still air simply because volume of pit is 140 million m^3, thus there is very significant dilution, even in still air conditions.

Processing Plant: Thoron release at the processing plant occurs primarily from ingrowth from thorium dissolved in process. The thoron generation rate in the processing plant is conservatively calculated to be 195 MBq/s.

In zero windspeed conditions, and assuming total release of this generated thoron into a plant 'pizza box' air volume of 500m x 500m x 50m, and in the absence of any design feature to aid dispersion, this would give equilibrium airborne thoron concentration in plant air of 1.3 kBq/m^3. Note however that *any air movement at all* will significantly reduce this by inducing vertical mixing and dilution.

Note in addition, that that even in still-air conditions, Nolans measurements showed an Equilibrium Factor for TnDP in the range 0.001 to 0.004, for a variety of times and weather conditions. Wasiolek & James reports EF = 0.03; if we use conservatively EF = 0.01, then 1.3 kBqTn/m^3 equates to a doserate of a little under 0.5 µSv/h[4]

As a 'reality check', note that actual measured average Tn PAEC at Nolans of 0.1 µJ/m^3 equates to a doserate of 0.05 µSv/h.

[4] The DCF for thoron given in RPS #9.1 is 0.036 µSv/h per Bq/m^3, at EF =1. However, there is strong evidence that EF for TnDP/Tn never gets much above 0.01 and will generally be in the order of a tenth of that.

The DCF for TnDP is 0.48 µSv per uJ.hr/m^3.

Nevertheless, this result points to the necessity to retain the option to install exhaust stacks on vessels in the processing plant that may release thoron.

8.3 Predictions of airborne Long Lived alpha-emitters (LLα) in dust

Dusts containing long-lived alpha emitting radionuclides comprise ore, tailings, or product dusts. The contained alpha-radiation-emitting radionuclides will be U, Th, Ra and Po. Airborne radionuclide-bearing dusts arise from:

- fugitive suspended dust from ore handling and movement in-pit and from ROM pad;
- dried and resuspended plant spillage, controlled by prompt washing to sumps (ITP area in processing plant to be strictly segregated); and
- dried and resuspended tailings dust.

For assessment of occupational dose from inhalation of airborne ore dust, it was decided to take a suitably conservative, indeed pessimistic, approach to estimation of dust doses as follows:

- We assign (pessimistically) an inhalable dust concentration in the pit of 1 mg/m^3;
- At 10 BqTh/g activity in the ore dust, the 'global average' for Nolans ore, this mass concentration equates to 0.06 αdps/m^3, which is low compared with the DAC of 1 αdps/m^3;
- Applying a 1:5 ore to waste ratio to this in-pit dust, and assuming 2,000 hrs/y, will then amount to about 0.25 mSv/y, *without* controls (either PPE or active management).

8.4 Environmental radiation sources

Dust suspension source terms for calculation of off-site environmental impacts were estimated by reference to NPI Emissions Estimation Manual for Mining (see Appendix 3).

In-pit dust control will be provided primarily by wetting down stockpiles and haul roads. In-plant, all operations are wet and therefore the only fugitive dust will be that produced by allowing spillages to dry. This will be avoided by requiring all spills to be washed promptly to allow return to leach circuit for processing. This is very consistent with world's best practice as currently applied across multiple operations in Australia.

8.5 Resultant predicted doses

Nolans concentrator and processing plant workers are likely to get doses similar to those reported for Ranger Uranium and Olympic Dam hydrometallurgical plant workers, namely about 1 mSv/y.

Concentrations from radon and thoron progeny from in-plant sources will be monitored and managed and various controls and mitigations measures discussed in Section 10. With mitigation such as (for example) exhaust stacks on vessels in the processing plant, doses from RnDP and TnDP concentrations in plant should not exceed 0.3 mSv/y.

For mine workers, the generally wet or moist condition of the ore, together with application of water on haul roads, will adequately address the dust dose delivery pathway.

Concentrations of radon and thoron progeny from in-pit and in-plant sources have been estimated as above, and will be monitored and managed using controls as discussed in Section 11.

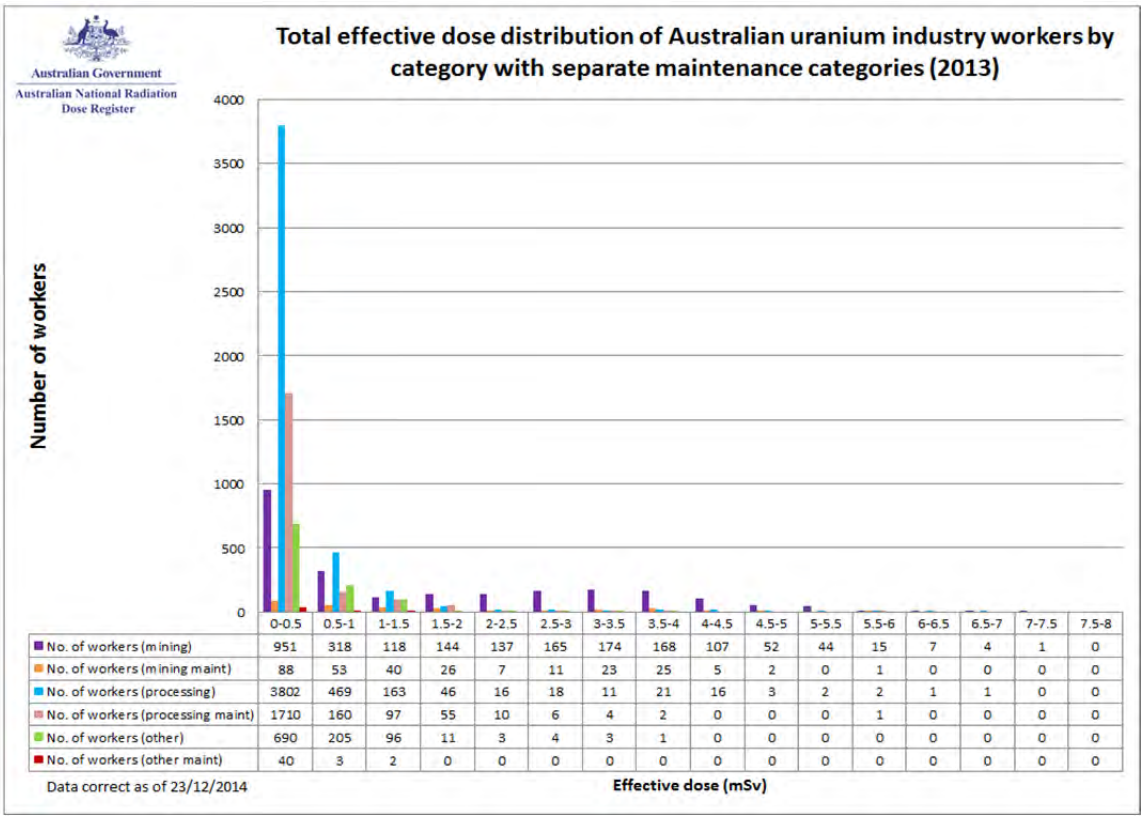
Table 9.2: Mine workers' predicted doses

Worker Category	Radiation Dose (mSv/y)			
	Gamma	Dust (LLa)	RnDP/TnDP	Total
Mine on-foot	1.0	0.25	< 0.3	1.5-3
Mine heavy equipment	1.0	0	0	2
Concentrator or processing plant	1.0	0	< 0.3	1.3

Mine workers at the Ranger Uranium operation were reported (BHP Billiton, 2009) to have an average annual dose of 1 mSv and maximum about 4.8 mSv. Gamma and dust pathways were more significant than radon.

Total predicted doses for Nolans workers are thus expected to be in line with actual doses observed throughout the Australian uranium mining and processing industry (Figure 10.1).

Figure 10.1: Doses in Australian Uranium Industry



	0-0.5	0.5-1	1-1.5	1.5-2	2-2.5	2.5-3	3-3.5	3.5-4	4-4.5	4.5-5	5-5.5	5.5-6	6-6.5	6.5-7	7-7.5	7.5-8
No. of workers (mining)	951	318	118	144	137	165	174	168	107	52	44	15	7	4	1	0
No. of workers (mining maint)	88	53	40	26	7	11	23	25	5	2	0	1	0	0	0	0
No. of workers (processing)	3802	469	163	46	16	18	11	21	16	3	2	2	1	1	0	0
No. of workers (processing maint)	1710	160	97	55	10	6	4	2	0	0	0	1	0	0	0	0
No. of workers (other)	690	205	96	11	3	4	3	1	0	0	0	0	0	0	0	0
No. of workers (other maint)	40	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0

8.5.1 Processing plant workers doses elsewhere

At Ranger, average workers' doses recorded in the processing plant are 1.3 mSv/y, with the maximum being 4.1 mSv/y. For both the mine and plant, on average, gamma made up approximately 50% of the total dose, with approximately 40% of the dose coming from radionuclides in dust for the plant workers. (Cameco 2013).

The Olympic Dam EIS (BHP Billiton, 2009) reported average total dose to workers in the Olympic Dam hydrometallurgical plant of 1.5mSv/y, broken down as follows (converted from percentages):

- Dust: 0.75 mSv/y
- Gamma Radiation: 0.60 mSv/y
- Radon Decay Products: 0.15 mSv/y

Construction and administration workers' doses are assessed to be well below 1 mSv/y. This is based on observations of doses to workers at Nolans during historical drilling operations. Other than drillers' assistants and geological field assistants, who manually handled bulk quantities of mineralised materials daily, all other workers were found to have low or <MDL TLD badge results, and all workers other than those involved in bulk on-deposit earthworks were found to have negligible dust doses.

8.6 Conclusions

As stated above, doses to workers at Nolans will be very similar to those which have historically been experienced at Australian uranium mines.

9 Controls and Mitigation

Radiation control aspects of the Nolans Project are not expected to be highly onerous, provided adequate consideration is given during design and development of operational procedures.

Essential to radiation management is ensuring review of radiation control features at early stages of project and operational design studies. Design for radiation dose control and radioactive waste management will follow a risk management approach. This means that design and proposed operation will be reviewed to determine likely radiation sources and levels, and options for control will be identified for these sources. Options will 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 PPE.

The approach will be iterative, with input from the regulator agencies from an early stage.

ALARA (the principle that doses be kept 'As Low As Reasonably Achievable, social and economic circumstances being taken into account'), will be followed, both in design and in operations.

This will be achieved by implementing and resourcing a robust Radiation Management Plan (RMP), and by regular senior management review of, and response to, the data generated by on-going monitoring.

9.1 Radiation Control in Design and Operation

Mine

The doses to mine workers are expected to be low (see above), and Arafura will implement standard management controls to ensure that doses remain low. These 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 (wetting of materials before handling, wetting of roadways, provision of dust collection systems on drills, etc.) and protective measures to reduce subsequent exposure (use of respiratory protection, etc.);
- monitoring the levels of dust generated during tipping of material onto stockpiles and implementing standard dust control techniques as necessary; and
- separate wash-down pad within the site area for vehicles that have exited the mine area.

Concentrator and Processing Plant

The material will 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 at least the volume of the tank in the event of a catastrophic failure;
- tailings pipeline corridor bunded to control spillage from tailings 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.

10 Environmental Radiation Impact Assessment

This section discusses the potential for radiation impacts on the environment from project emissions. Airborne and surface concentrations associated with emissions from the project are estimated via dispersion modelling. Results are discussed below.

10.1 Dust

Source terms have been developed by GHD, based on mining rates, pit sizes and scheduling, haul road distances, tailing disposal areas, etc., as supplied by Arafura Resources, and using standard dust

re-suspension factors as quoted in National Pollution Inventory Emissions Estimation Techniques Manual for Mining.

These source terms were then modelled for dispersion using site specific weather and atmospheric data, from the site weather station which has been operational at Nolans since 2009.

The outputs of significance for environmental impact are:

(i) airborne dust (PM_{10}) concentration contours. These are relevant to assessment of dust doses to members of the public residing at Aileron and Alyuen; and

(ii) dust deposition contours. These allow estimation of end-of-mine surface soil project increment radionuclide concentration, and thus potential for impact on non-human biota (NHB), and they also provide necessary input to calculations of radionuclide uptake and hence incurred dose from ingestion of local 'bushtucker' food .

10.2 Radon

Radon source terms for the mining pit, ore and waste rock stockpiles, and TSF/RSF areas, were calculated by Radiation Advice & Solutions Pty Ltd (RAS), based on literature review of other projects, general guidance from UNSCEAR and ARL, first-principles calculations, and on-site measurements.

These source terms were applied as point sources as input to the atmospheric dispersion model developed by GHD from the site weather data, to give airborne concentration contours, from which RAS calculated annual member of the public (MoP) doses from inhalation of the resulting radon decay products.

The dust and radon doses to members of the public residing at Aileron and Alyuen are shown to be far below the MoP limit of 1 mSv/y (see Section 12).

11 Member of Public Dose Calculations, and NHB Assessment

This section of the radiation report provides a summary of the potential doses to the public and the environment. Further detail is provided in JRHC (2016).

This section provides:

- Assessment of the public dose;
- Assessment of potential doses from bush tucker; and
- Radiological impact assessment for non-human biota (NHB).

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

The locations of interest for public dose have been identified for the project and are:

- The accommodation village, located approximately 5km from the processing plant;
- Aileron, located approximately 12km from the project area; and
- Alyuen, located approximately 12-15km from the project area.

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

11.1 Methods of Impact Assessment

The potential exposure pathways for members of the public are:

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

Table 12.1 provides a summary of the dose assessment methods for the different exposure pathways.

Table 12.1: Exposure Estimation Methods

Exposure Pathway	Assessment Method
Gamma Radiation	Estimated from first principles
Inhalation of radionuclides in dust	Based on air quality modelling
Inhalation of radon decay products[1]	Based on air quality modelling
Ingestion of radionuclides	Based on air quality modelling

Note 1: The impacts of the decay products of both radon222 and radon220 are determined.

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

11.2 Dust Concentrations and Deposition

The air quality modelling provided an estimate of the dust concentrations and dust deposition rates at the sensitive receptor locations.

A summary of the dust results can be seen in Table 12.2.

Table 12.2: Air Quality Modelling Results for Dust

Location	TSP Concentration ($\mu g/m^3$)	Dust Deposition (g/m^2/month)
Accommodation Village	1.90	0.37
Aileron	0.52	0.12
Alyuen	0.52	0.12

11.3 Radon and Thoron

The estimated radon and thoron emission rates from the proposed project are described earlier in this report. For the purposes of public dose assessment, the radon emission rates have been conservatively assumed to be 2MBq/s. The thoron emissions are as described earlier.

The air quality modelling provides the radon and thoron concentrations at the sensitive receptor locations (Table 12.3

Table 12.3: Modelled Radon and Thoron Concentrations

Location	Incremental Ground Level Radon Concentrations Annual Average (Bq/m^3)	Incremental Ground Level Thoron Concentrations Annual Average (Bq/m^3)
Accommodation Village	0.05	8.3
Aileron	0.02	2.6
Alyuen	0.02	2.3

11.4 Public Doses

Background

The potential exposure pathways for members of the public are:

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

Gamma Radiation

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

Using the WISE radiation gamma dose calculator software (WISE, 2015), the gamma dose rates can be calculated at distances from a 1,000,000m^3 ore stockpile containing uranium and thorium. At one metre from this stockpile, the gamma dose rate is approximately 7 µSv/h. At one kilometre, the gamma dose rate is calculated to be less than 0.1 nSv/h. For a member of the public at this location, for a full year, the gamma dose is calculated to be less than 1µSv/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 can be seen in Table 12.4.

Table 12.4: Public Inhalation Dose Estimates

Location	TSP Dust (mSv/y)		RnDP/ThDP* (mSv/y)	
	U in Dust Dose	Th in Dust Dose	RnDP Dose	TnDP Dose
Accommodation Village (workers)	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	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 conducted for representative persons living at each of the locations of interest. The conservative 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.

On a more realistic level, the Nolans region is sparse with minimal plants and animals in the region due to the lack of surface water. Consuming food solely generated in-region for a full year is therefore highly unlikely.

The assessment method assumes that dust emissions from the mining 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.

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).

Published concentration ratio values are available from a number of sources, including ARPANSA (2014) and the IAEA TSR 472.

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 12.5.

Table 12.5: Data for Ingestion Dose Assessment

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

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

11.5 Total Dose Estimates

The total dose estimates at the sensitive receptors are shown in Table 12.6. Note that the doses are based on 100% occupancy (that is 8,760 hours per year) at Aileron, Alyuen and Alice Springs. Occupancy at the accommodation village has been assumed to be 4,000 hours per year.

Table 12.6: 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	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).

11.6 Flora and Fauna Impact

The ERICA assessment was conducted using the changes in soil concentrations shown in Table 12.7.

Table 12.7: Change in Soil Concentration Due to Deposition from Project (42 years of operation)

	Change in Soil Radionuclide Concentration (Bq/kg)	
Location	**Uranium series radionuclides**	**Thorium series radionuclides**
Accommodation Village	6.3	18
Aileron	2.1	5.9
Alyuen	2.1	5.9

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

- Wallaby (mass: 15 kg, height: 0.7 m, width: 0.2 m, length: 0.2 m); and
- Kangaroo (mass 50 kg, height 1.5 m, width 0.75 m and depth 0.75 m),

The output of Tier 2 level assessment is presented in Table 12.8 which shows that after 42 years of dust deposition, the 10 µGy/h screening level is not exceeded for any species.

Table 12.8: Output of ERICA Assessment

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
Reptile	0.10
Shrub	0.62
Tree	0.04
Wallaby (user defined)	0.07
Kangaroo (user defined)	0.48

It can be concluded that the ERICA assessment indicates no radiological risk to reference plants and animals from emissions from the Nolans Project.

12 Monitoring Plan and Responses

12.1 Occupational and Environmental Radiation Monitoring

There are several reasons for carrying out workplace monitoring programs, depending on the details of what is to be measured and how the data are to be handled:

- provide *day-to-day engineering feedback and operational control* - this requires rapid reporting of high readings to foremen and senior management;
- in *fulfilment of operating licence conditions* – regulators will generally require periodic workplace monitoring data that gives them an ongoing auditing capability;
- provide *input for personal dose assessments* - these are required under the Code of Practice and also tend to set the agenda for long-term dose control actions including strategic changes in engineering, procedures, and personal protective measures;
- for *input to future epidemiological studies* – note that it is essential to retain raw data, so that dose calculations can be reworked if conversion factors, internal dosimetry models, etc. are changed. This is facilitated by the required hand-on of dose data to the ANRDR; and
- To *manage legal liability*, prove duty of care etc. This requires good record keeping.

Thus, the monitoring program is shaped by the pathways to be monitored, the purpose to be accomplished, and the associated data handling and reporting requirements, and the methods and technologies available.

Monitoring is quite demanding not only in terms of technician man hours expended gathering data, but also in terms of clerical time manipulating data, and required management review.

Table 13.1 gives a broad summary of the occupational radiation monitoring plan with indicative instrumentation but other or newer technologies may be adopted.

Table 12.11: Occupational Radiation Monitoring Plan

Radiation type	Measurement methods & frequency	Application; Purpose
Gamma shine	Thermoluminescent dosimeter (TLD) badges: quarterly issue	All plant and pit personnel; dose data
	Electronic Personal Dosimeters (EPDs): daily issue as required to potential high doserate workers	Specific in-pit and maintenance tasks; operational control
	Gamma survey with meter: monthly	Routine surveys, pit and plant; controls effectiveness
Inhalation LLα dust	Personal Air Samplers (PAS) plus drawer assembly count: weekly to representative personnel	Issue to personnel in each SEG; dose estimation
	Locational: investigative	For investigative purposes

Inhalation RnDPs & TnDPs	Grab samples (Borak, Rolle)	For investigative purposes
	Continuous Rn, Tn, & RnDP monitors	Continuous in-pit, in-plant, for control and investigation; E.F. determinations
	Track-etch personal badges	Dose calculations
Surface alpha contamination	Large-area alpha probe surveys: monthly	Workplace and crib-room checks; controls effectiveness
		Equipment and outgoing checks; 'gatehouse' control

* Further discussion will be presented in Draft RMP, including frequency / coverage

12.2 Action levels

In conformity with good ALARA practice, and as a management tool, there will 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.

12.3 Environmental Radiation Monitoring

Environmental radiation monitoring aims to characterise natural background radiation, and hence provide baseline and ongoing data for identification of any project-origin increments. This is a difficult task, because it involves identifying small signals which are additive to a spatially and temporally variable natural background.

The keys to success are to focus on time-integrated data, as such data signals accumulate over time, and also inherently smooth out short-term variability. It is also important to ensure the areal extent of the baseline and ongoing surveys extend well beyond the immediate footprint of the project, to capture clearly 'non-impact' area data.

Thus Arafura has been collecting the following environmental data sets:

(i) an array of environmental TLD badges for long-term gamma dose data;
(ii) wide area instrumental gamma survey information and aerial radiometrics;
(iii) an array of passive radon track etch monitors, for time-averaged airborne radon;
(iv) passive dust deposition collectors;
(v) a suite of surface soil samples for radionuclide assay; and
(vi) a suite of groundwater samples.

These data accurately characterise the regional radiation environment and its variability.

All these monitoring tasks will continue into operation.

12.4 Incident, Accident and Emergency Response

Radiological accidents or emergencies are extremely uncommon in mining or mineral processing operations, but plans will be prepared to identify response requirements for unexpected loss-of-control situations. These will include:

- Advice to first aid / fire fighting /emergency responders;
- Evacuation of non-essential personnel and boundary control;
- Stabilisation of 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.

The main likely radiation accident situation which can be envisaged is an in-plant high activity material spill. In this case, the potential for significant dose is small, but it is crucial to provide very full and clear information and briefings, as apprehension can otherwise grow and create psychological flow-on effects. Keeping exposed persons fully briefed is an absolutely critical part of the response.

All unplanned in-plant spillage possibilities will be taken into account in planning, by providing for bunding to hold the contents of a tank which has lost integrity (such as for example the Ranger leach tank collapse), or of a tank which may require emergency or planned draining. There should be adequate space for access by clean-up equipment. Concrete flooring and wash to sump pits for pump back to process are design fixes which normalize the response requirement for spill occurrences.

13 Draft Radiation Management Plan

A draft Radiation Management Plan (RMP) has been developed which is structured so as to follow closely the headings given in RPS#9, Section 2.7, where the requirements for information to be supplied in an RMP are specified.

For an RMP to conform with the requirements of the Code, the following information is required:

- Description (of operations, and of measures for control);
- Demonstrated access to expertise;
- Monitoring Plan and method for dose assessment;
- Provision of appropriate / 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 so as to achieve continual improvement.

Some additions and clarifications will be added where they seem to fit best.

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

It will specify the monitoring processes, and their purposes and timelines, and hence frequency, and the consequent equipment, staffing, and facilities, together with Arafura's access to expertise.

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

In accordance with the requirements of the Code of Practice (RPS #9), there will also be developed a Radioactive Waste Management Plan (RWMP), in close consultation with the regulator. It is likely that the RWMP will be written to sit as a component of the RMP in a single document, because aspects of monitoring and reporting requirements will overlap, and will best be captured in the one document.

The RWMP, in conformity with Code requirements, will cover:

- Outline of the process(es) generating the waste(s);
- Description of the environment including baseline radiological characteristics;
- Description of the proposed system for waste management including details of facilities etc.;
- Predictions of environmental concentrations and doses;
- Program for monitoring;
- Contingency plans for dealing with accidental releases;
- Schedule for reporting;
- Plan for decommissioning; and
- Commitment to periodic assessment and review.

Some of the requirements are already addressed, in part, in the present document. Advice will be sought from the regulators in developing the RWMP for submission for approval.

14 References

AAEC, 1985	Australian Atomic Energy Commission Research Establishment Lucas Heights Research Laboratories, Options for clean-up of the Maralinga test site, Environmental Science Division, June 1985
ANSTO, 2007	Report to Arafura Resources Limited: Baseline Radiological Survey Of the Nolans Project Site, ANSTO Minerals Report C950, June 2007
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15 Glossary

Absorbed dose – the amount of energy (in joules) deposited by radiation in a kg of matter; one Gray of absorbed dose = 1 J/kg

Activity – amount of radioactive material in a sample, measured in Becquerels, where 1 Bq = 1 atomic decay per second

ALARA – As Low As Reasonably Achievable, social and economic circumstances being taken into account

Alpha – high energy, high speed particle radiation, actually a double-ionized helium nucleus, emitted from a decaying atom

ARPANSA – Australian Radiation Protection and Nuclear Safety Agency

Becquerel – Unit of Activity: 1 atomic decay per second; named after the discoverer of natural radioactivity

Beta – energetic particle radiation, actually a high speed electron emitted from a decaying atom

Committed dose – dose which you are 'committed to' following inhalation or ingestion of radionuclides; once incorporated into the body, these may continue giving a dose for many years

Contamination – unwanted radioactive material, on surfaces or in air or water

Controlled Area – area within which there must be specific procedures for ensuring control of worker doses below the limit; also, area within which the worker may get more than 3/10 of the limit.

Decay chain – sequence of transformations that a radioactive 'parent' atom passes through as it decays, giving out alpha, beta, and gamma radiation; see uranium and thorium decay chains.

Dose – may be absorbed dose, committed dose, equivalent dose, or effective dose

DDG - Dust Deposition Gauge

EIS - Environmental Impact Statement

E.F. - Equilibrium Factor, ratio of radon daughters to parent radon in air, or of thoron daughters to parent thoron in air

EPDs - Electronic Personal Dosemeters

Effective dose – dose to human body, taking into account the radiation weighting factor for effectiveness of different radiation types, and the organ/ tissue weighting factor for differing radiosensitivities for cancer induction of the target organs - expressed in Sieverts or millisieverts

Epidemiology – study of disease incidence in large groups of people

Exposure – used in various contexts: may refer to the existence of an exposure pathway for delivery of internal or external dose; or sometimes may be inaccurately used meaning 'dose'; may mean period of time in a radiation field.

Gamma radiation – electromagnetic radiation like x-rays but emitted from nucleus of atom

HEPA - High Efficiency Particulate Air (filter)

Hi-Vol - High volume air sampler, (usually runs at 70 m^3/h) for collection of environmental airborne dust

Half-life – time for a radionuclide to decay to half its original amount

Half Value Layer – the thickness of shielding which reduces the strength of a penetrating gamma beam by half.

IAEA – International Atomic Energy Agency

ICRP – International Commission on Radiological Protection

ITP - iron-thorium precipitate

Joule – unit of energy (1 watt of power for 1 second)

Kerma – kinetic energy delivered from radiation into air: essentially same as absorbed dose in air

LNT - Linear No Threshold hypothesis

LLα – Long lived alpha emitters (see decay chains)

Member of Public – MoP, person not occupationally exposed to radiation

Monazite – mineral, a rare earth-thorium phosphate, very resistant to leaching

Millisievert - mSv, unit of (effective) dose (one thousandth of a Sievert)

NORM – Naturally Occurring Radioactive Materials

NHB - Non-Human Biota

PAS – Personal Air Sampler, for sampling airborne dust onto a filter paper

PPE – personal protective equipment eg dust masks

PRM - Passive Radon Monitor

Quality Factor – old terminology for Radiation Weighting Factor

RE, REEs, REO, $RECl_2$ - Rare Earths, Rare Earth Elements, Rare Earth Oxide, Rare Earth Chloride

RMP - Radiation Management Plan

RWMP - Radioactive Waste Management Plan

Radiation – transfer of energy through space

Radionuclide – also radioisotope, a radioactive element

Radium – radium226 was discovered by Marie Curie, 88^{th} element in the Periodic Table, the only source of intense radiation other than x-rays, until the development of nuclear reactors and artificial radioisotopes in the 1940s and 1950s

Radon – Rn222, decay product of radium-226, inert gas, similar to argon, neon, xenon etc.

Radon progeny / radon daughters / radon decay products - Po218, Pb214, Bi214, Po214, short lived radionuclide breakdown products of the decay of Rn222

RnDP - acronym for radon decay products, see above

Secular Equilibrium – the state in a decay chain when all nuclides are decaying at the same rate, i.e., all have the same activity, i.e., in each 'species', new atoms are being generated by breakdown of the parent just as fast as they are being removed by decaying to form the daughter….

Sievert Sv– Unit of effective dose

Supervised Area – workers outside supervised area will not need to be regarded as occupationally exposed and will not get more than Member of Public limit; within supervised area, worker dose is most unlikely to exceed 3/10 of the limit, and specific procedures to avoid going over the limit are not necessary

TLD Badge – Thermo-luminescent Dosimeter, personal radiation badge, records time-integrated gamma dose

Thorium – Th232, 90^{th} element in the Periodic Table

Thoron – Rn220, decay product of Ra224, a member of the thorium decay chain, another isotope of radon.

TnDP - thoron decay products (see thorium decay chain):

UNSCEAR – United Nations Scientific Committee on the Effects of Atomic Radiation

Uranium – 92^{nd} element in the Periodic Table: three natural isotopes: U238, U234, and U235

Working Level – old unit for radon daughter concentration, equal to 1.35 x 10^7 MeV of ultimately delivered alpha energy per litre of air, also equals (new units) 20.7 μJ/m^3; originally defined as the alpha energy equivalent to 100 pCi/l of radon in equilibrium with its four shortlived daughters……

X-rays - high energy, short wavelength electromagnetic radiation, discovered by Wilhelm Roentgen in 1895

ARAFURA RESOURCES

NOLANS RARE EARTHS PROJECT: ENVIRONMENTAL AND PUBLIC RADIATION TECHNICAL REPORT

FINAL

1st March, 2016

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INDEX

1. INTRODUCTION

The aim of this technical report is to provide an assessment of the radiation related impacts to the public and to the environment for the Nolans Rare Earths Project.

This report consists of the following:

- an outline of the relevant radiological characteristics of the project;
- description of the methods for the assessments;
- the results of the assessments and comparisons with relevant standards;
- an ERICA assessment for non-human biota;
- estimates of public and environmental impacts post closure; and
- description of the environmental monitoring program.

A description of the proposed project is not provided in this report.

2. RADIOLOGICAL CONSIDERATIONS OF THE NOLANS PROJECT

2.1 OVERVIEW

This section provides an overview of the methods and parameters used to assess the public and environmental radiological impacts for the proposed Nolans Project.

In general, it is usual for radiation related impacts to be quantified by determining the potential radiation doses to members of the public and by calculating the dose rate for non-human biota.

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

The locations of interest for public dose assessment that have been identified for the Nolans Project are:

- Aileron (includes Aileron Roadhouse, campground and houses, and the Aileron Station Homestead and workers' accommodation);
- Alyuen Aboriginal Community; and
- Workers at the operation's accommodation village (note that for this assessment, the accommodation village workers, for example cleaners and cooks, are considered to be members of the public).

A conservative assessment will also be 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 (TSP) dust concentrations at Aileron and the accommodation village location.

2.2 Methods of Impact Assessment

The potential exposure pathways for members of the public are:

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

Table 1 provides a summary of the dose assessment methods for the different exposure pathways.

Table 1: 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

* The impacts of the decay products of both radon-222 and radon-220 are determined.

For environment, the assessment method is via the ERICA assessment software (http://www.erica-tool.com/) which uses changes in the radionuclide concentration of media (such as soil and water) as a result of the operation, to determine a dose rate and radiological risk quotient. The method for determining the change in media concentration is via modelled dust deposition results.

2.3 Dose Assessment Criteria

The following criteria have been used in the radiological impact assessment. Note that the actual project characteristics may vary from the figures used in the assessment; however, the conclusions are expected to remain valid.

Production Factors

- Average total mining rate – 10Mtpa (ore and waste rock)
- Average ore (mineralised material) mining rate – 1Mtpa
- Average uranium grade of mined ore –160ppm
- Average thorium grade of mined ore – 2400ppm
- Average uranium grade of radioactive waste rock – 80ppm
- Average thorium grade of radioactive waste rock – 480ppm
- Average uranium grade of inert waste rock – 5ppm
- Average thorium grade of inert waste rock – 20ppm
- Average uranium grade of all material mined – 54ppm (approximately and calculated as a weighted average)
- Average thorium grade of all material mined – 465ppm (approximately and calculated as a weighted average)
- Average annual tailings production rate – 1Mtpa
- Mine operating life is 42 years

Exposure Factors

- member of the public exposure hours – 8,670h/y
- member of the public breathing rate – 1.0m^3/h
- accommodation village worker exposure hours (working year) – 4,000h/y (assumes 2,000h/y working and 2,000h/y residing)

Physical Property Factors:

- relationship between uranium grade and radionuclide activity is
  1ppm U = 12.3mBq U^{238}/g
- relationship between thorium grade and radionuclide activity is
  1ppm Th = 4.0mBq Th^{232}/g
- uranium and thorium in ore is in approximate secular equilibrium when mined
- the vast majority of radionuclides report to tailings and residue
- deposited dust will mix in the top 10mm of soil
- specific gravity (density) of soil in the environment is 1m^3 = 2.0 tonne
- radon; Rn^{222} (referred to as radon in this report) and Rn^{220} (referred to as thoron in this report) emission rates are shown in Section 2.5.

Radon and Thoron factors:

- The relationship between for radon and radon decay products (RnDP) is expressed by the following equation (UNSCEAR, 2000):
  - F = PAEC(nJ/m^3) / (5.56 x C(Rn^{222}) (Bq/m^3)) where:
    - F is Equilibrium Factor;
    - PAEC is potential alpha energy concentration of the RnDPs; and
    - C(Rn^{222}) is the concentration of radon.
- The relationship between thoron and thoron decay products (TnDP) is expressed by the following equation (UNSCEAR, 2000):
  - F = PAEC(nJ/m^3) / (75.7 x C(Rn^{220}) (Bq/m^3)) where:
    - F is Equilibrium Factor;
    - PAEC is potential alpha energy concentration of the TnDPs; and
    - C(Rn^{220}) is the concentration of thoron.

- The dust inhalation dose conversion factor is derived from figures in ICRP (1995), using AMAD of 1 micron and most restrictive lung solubility class and assuming secular equilibrium for the decay chain radionuclides

2.4 RADIONUCLIDE ANALYSIS OF MATERIALS

Appendix 1 provides a summary of the radionuclide testwork undertaken by ANSTO (2015). A summary is presented in Table 2. The summary shows that the majority of radionuclides report to the beneficiation tailings and the process residues. Table 3 shows the percentage deportment of radionuclides.

Table 2: Radionuclide Deportment Through Process

Radio-nuclide	Ore	Beneficiation Tailings		Beneficiation Concentrate	Process Residues*		Cerium Carbonate Product*	Rare Earth Chloride Product*
	Bq/g	Solids (Bq/g)	Liquids (Bq/L)	Solids (Bq/g)	Solids (Bq/g)	Liquids (Bq/L)	Solids (Bq/g)	Solids (Bq/g)
Th^{232}	9.6	5.0	0	19.0	8.3	92.4	0.35	0.00
Ra^{228}	9.6	5.5	0	18.0	10.1	145.4	0.10	0.46
Th^{228}	9.6	5.0	0	19.0	9.5	93.5	0.29	0.08
U^{238}	2.1	1.0	0	4.5	2.8	17.3	0.05	0.00
U^{234}	2.1	0.9	0	4.6	3.0	16.3	0.06	0.00
Th^{230}	2.1	0.5	0	5.5	4.7	34.7	0.19	0.00
Ra^{226}	2.1	0.8	0	4.8	2.2	12.9	0.04	0.04
Pb^{210}	2.1	0.7	0	5.1	2.6	0.2	0.06	0.00
Po^{210}	2.1	1.0	0	4.5	2.0	0.3	0.02	0.00
Ac^{227}	0.0	0.0	0	0.0	0.0	0.0	0.03	0.35
Mass(t)	920,000	618,000	0	301,500	602,000	1,625,333	17,000	26,000

* The Benefication Concentrate is processed to produce Process Residues, Cerium Carbonate Product and Rare Earth Chloride Product

Table 3: Percentage Radionuclide Deportment Through Process

Radio-nuclide	Ore	Beneficiation Tailings		Beneficiation Concentrate	Process Residues		Cerium Carbonate Product	Rare Earth Chloride Product
	%	Solids %	Liquids %	Solids %	Solids %	Liquids %	Solids %	Solids %
Th^{232}	100	35.1	0	64.9	62.9	1.9	0.07	0.00
Ra^{228}	100	38.5	0	61.5	59.0	2.3	0.02	0.12
Th^{228}	100	35.1	0	64.9	63.1	1.7	0.05	0.02
U^{238}	100	30.8	0	69.2	68.1	1.1	0.03	0.00
U^{234}	100	29.2	0	70.8	69.7	1.0	0.04	0.00
Th^{230}	100	15.4	0	84.6	82.9	1.7	0.09	0.00
Ra^{226}	100	26.1	0	73.9	72.6	1.1	0.04	0.06
Pb^{210}	100	21.5	0	78.5	78.4	0.0	0.05	0.00
Po^{210}	100	30.8	0	69.2	69.2	0.0	0.02	0.00
Ac^{227}	100	30.8	0	69.2			3.46	65.79
Mass(t)	920,000	618,000	0	301,500	602,000	1,625,333	17,000	26,000

2.5 PROJECT RADON AND THORON EMISSIONS

For radon and thoron emissions from the project, the following criteria are used:

- Ore and waste rock, both broken and unbroken:
  - The radon emission rates is 30Bq/m^2.s per %U
  - The thoron emission rate is 200Bq/m^2.s per %Th
- Tailings and process residues,
  - The radon emission rates is 10Bq/m^2.s per %U
  - The thoron emission rate is 20Bq/m^2.s per %Th
- Release rates dependent upon throughput and residence time of process materials.

The emission rate figures for ore and tailings are based on testwork conducted by Arafura Resources on actual material and they are presented in Table 4.

Table 4: Estimated Radon Emission Rates (year 5 of operations)

Source	Radon (MBq/s)	Thoron (MBq/s)
Mine	0.8	40
Beneficiation Plant	0.1	0.1
Beneficiation Tailings	0.1	25
Processing Plant	0.1	175
Process Residues*	minor	minor
Stockpiles †	0.9	60
Total	2	300

* Arafura Resources testwork indicates that emissions from process residues will be minor (<0.1MBa/s)

† Stockpiles refer to the various stockpile configurations that will occur on site

Note that the release rate of thoron is seemingly high. This is partially due to the higher original grade of thorium in the feed material, but is more due to the decay constant of thoron. Thoron has a very short half-life, therefore its relative activity rate is high compared to the number of thoron atoms.

Note also that the relatively high thoron emission rate from the processing plant is due to the assumed residence time of the process material in the plant.

2.6 DUST EMISSION RATES

The dust sources for the air quality assessment are based on project characteristics (such as stockpile sizes and areas of exposed materials) and standard emission factors for equipment and processes. The air quality modelling calculates an increase in dust concentration at the selected locations for TSP in units of $\mu g/m^3$ and a project originated dust deposition in units of g/m^2.month as a result of an emission rate from the operation. (Note that the air quality modelling consultant's report was incomplete at the time of completion of this report, however, the actual modelling results were available for use in this report).

Air quality modelling was conducted for various stages of the project, representing different mining areas (pit stages) and the maximum rates were used to provide a worst case assessment of emissions. The dust emission rates are used in the air quality modelling.

Potential emissions of dust containing higher concentrations of radionuclides from the processing plant are unlikely to occur and therefore not considered for long-term modelling. This is because once the ore is crushed and ground it becomes a slurry with very little chance of dusting.

2.7 AIR QUALITY MODELLING OUTPUTS

2.7.1 BACKGROUND

Air quality modelling was conducted to determine the potential increments in airborne concentrations of dust as a result of airborne emissions from the Nolans Project. The modelling utilises the radon and thoron emission rates described in Section 2.5 to calculate radon and thoron concentrations at sensitive receptor locations. For dust, emission factors are used to provide dust concentrations (as total suspended solids) and dust deposition rates at sensitive receptor locations.

2.7.2 RADON AND THORON

When modelling radon, it is usual to assume that there is no decay of the original emitted radon over the modelled spatial domain. This is a reasonable assumption because the half-life of radon is approximately 3.5 days and in that time, the radon concentration is unlikely to decrease significantly across the modelled spatial domain. However, for thoron the situation is very different. The very short half-life (approximately one minute) means that much of the thoron would have decayed before dispersing any distance from the emission point.

Because the dispersion modelling assumes no decay of the thoron, it provides a gross overestimate of modelled thoron concentrations at various locations.

The modelled annual average ground level concentrations at each of the areas of interest can be seen in Table 5. It should be noted that the baseline monitoring gives average naturally occurring radon concentrations of approximately 60 Bq/m^3 and average thoron concentrations of approximately 750 Bq/m^3.

Table 5: Annual Average Radon Ground Level Concentrations

Location	Incremental Ground Level Radon Concentrations Annual Average (Bq/m^3)	Incremental Ground Level Thoron Concentrations Annual Average (Bq/m^3)
Accommodation Village	0.05	8.3
Aileron	0.02	2.6
Alyuen Community	0.02	2.3

2.7.3 AIRBORNE DUST CONCENTRATIONS

Table 6 provides the modelled TSP dust concentrations.

As noted in Section 2.3, the weighted average uranium and thorium concentrations of all material mined is approximately 54ppm U and 465ppm Th. This gives specific activity levels of 0.68Bq/g for U^{238} decay chain radionuclides and 1.9Bq/g for Th^{232} decay chain radionuclides.

The dust concentration is multiplied by the weighted specific activity to give an activity concentration and these are also shown in Table 6.

Table 6: Annual Ground Level Concentrations

Location	Ground Level Concentrations Total Dust ($\mu g/m^3$)	Equivalent Uranium Chain Radionuclide Concentration ($\mu Bq/m^3$)	Equivalent Thorium Chain Radionuclide Concentration ($\mu Bq/m^3$)
Accommodation Village	1.9	1.3	2.5
Aileron	0.52	0.35	1.0
Alyuen Community	0.52	0.35	1.0

2.7.4 DUST DEPOSITION

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 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 non-human biota assessment.

The air quality modelling has calculated the cumulative dust deposition for the life of the project and can be seen in Table 7, together with the calculated radionuclide deposition rates.

Table 7: Dust Deposition

Location	Average Dust Deposition Rate (g/m^2.month)	Cumulative Deposition after 42 years		
		Dust (g/m^2)	Uranium Chain Radionuclides (Bq/m^2)	Thorium Chain Radionuclides (Bq/m^2)
Accommodation Village	0.369	185	125	360
Aileron	0.121	61	41	118
Alyuen Community	0.121	61	41	118

3. PUBLIC DOSES

3.1 BACKGROUND

The potential exposure pathways for members of the public are:

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

3.2 GAMMA RADIATION

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

Using the WISE radiation gamma dose calculator software (WISE, 2015), the gamma dose rates can be calculated at distances from a 1,000,000m^3 ore stockpile containing uranium and thorium. At 1m from this stockpile, the gamma dose rate is approximately 7µSv/h. At 1km, the gamma dose rate is calculated to be less than 0.1nSv/h. For a member of the public at this location, for a full year, the gamma dose is calculated to be less than 1µSv/y.

3.3 AIRBORNE DOSE ESTIMATES

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

3.3.1 DUST

The dust dose is based on the modelled average radionuclide concentrations in air and is calculated for an exposure time of 8,760h/y (full time occupancy), a breathing rate of 1m^3/h and individual radionuclide inhalation dust factors as outlined in ICRP Publication 68 (ICRP, 1995). The formula is:

Dose from U^{238} Radionuclides (mSv/y) =
Uranium Series Dust activity concentration (Bq/m^3) x
Breathing rate (1.0m^3/h) ×
Hours per year (8,760h/y) ×
Dose Conversion Factor for each radionuclide (mSv/Bq)

Dose from Th^{232} Radionuclides (mSv/y) =
Thorium Series Dust activity concentration (Bq/m^3) x
Breathing rate (1.0m^3/h) ×
Hours per year (8,760h/y) ×
Dose Conversion Factor for each radionuclide (mSv/Bq)

Total Dust Inhalation Dose (mSv/y) = U Dose (mSv/y) + Th Dose (mSv/y)

3.3.2 RADON DECAY PRODUCTS

The radon decay product dose is calculated from the modelled radon concentrations at the locations of interest.

The first step is to convert the modelled radon concentration to a radon decay product (RnDP) concentration using the equation in Section 2.3 as follows:

RnDP Concentration (μJ/m^3) = Equilibrium factor x 0.00556 x Rn concentration Bq/m^3

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

The RnDP dose is then calculated using the following formula:

Dose (mSv/y) = RnDP Conc (mJ/m^3) x
Exposure hours (8,760h/y) x
Dose Conversion Factor (1.4mSv.m^3/mJ.h) (ARPANSA, 2005)

3.3.3 THORON DECAY PRODUCTS

The dose from thoron decay product dose is calculated in a similar manner to radon decay products; however, the values in the equations are different.

The modelled thoron concentration is converted to a thoron decay product (TnDP) concentration using the following formula (formula from IAEA (2004)):

TnDP Concentration (μJ/m^3) = Equilibrium factor x 0.0757 x Tn concentration Bq/m^3

For this assessment, an equilibrium factor of 0.005 has been used. This is based on information provided in Sonter (2015).

The TnDP dose is then calculated using the following formula:

Dose (mSv/y) = TnDP Conc (mJ/m^3) x
Exposure hours (8,760h/y) x
Dose Conversion Factor (0.48mSv.m^3/mJ.h) (ARPANSA, 2005)

A summary of the inhalation dose estimates can be seen in Table 8.

Table 8: Public Inhalation Dose Estimates

Location	TSP Dust		RnDP &ThDP*	
	U in Dust Dose (mSv/y)	Th in Dust Dose (mSv/y)	RnDP Dose (mSv/y)	TnDP Dose (mSv/y)
Accommodation Village (workers)	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 doses using the new recommended dose conversion factor can be seen in parentheses in the table.

3.4 INGESTION DOSE ESTIMATES

The estimate of the potential annual dose from the ingestion exposure pathway has been conducted for representative persons living at each of the locations of interest. The conservative 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.

On a more realistic level, the Nolans Project site is sparse with minimal plants and animals in the region due to the lack of surface water. Consuming food solely generated in-region for a full year is highly unlikely.

The assessment method assumes that dust emissions from the mining 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 rates and characteristics;
- Uptake factors into foods; and
- Incremental concentrations of radionuclides from the project.

Consumption Rates

The ingestion dose assessment is based on the following consumption rates:

- Vegetation
    - 30kg/y of non-leafy vegetables
    - 30kg/y of leafy vegetables
    - 30kg/y of root vegetables
- 100kg/y of beef that has been grazing in the area.

Concentration Ratios

Published uptake factors are available in IAEA 2010 and the Compendium of Transfer Factors (2003). For this assessment, the uptake factors used can be seen in Table 9.

Table 9: Uptake Factors

Element	Vegetation Bq/kg(dry veg weight) / Bq/kg(dry soil weight)			Beef Bq/kg / Bq/d*
	Non-Leafy	Leafy	Root	Whole Body
Uranium	0.053	0.020	0.028	0.0003
Thorium	0.0022	0.0012	0.0087	0.00004
Radium	0.061	0.091	0.071	0.0009
Polonium	0.00019	0.0074	0.077	0.005
Lead	0.015	0.080	0.063	0.0004

* Bq/d refers to the Bq in vegetation the cow consumes in one day

Incremental Radionuclide Concentrations

The calculated change in soil radionuclide concentrations at each of the locations of interest is based on the air quality deposition modelling (see Table 10). Table 10 shows the calculated change in soil concentration based on soil density of $2t/m^3$ and a mixing depth of 10mm. It is also assumed that the uranium and thorium decay chains are in secular equilibrium.

Table 10: Change in Soil Radionuclide Concentration (after 42 years of operations)

Location	Uranium Radionuclide Deposition (Bq/m^2)	Thorium Radionuclide Deposition (Bq/m^2)	Change in Soil Radionuclide Concentration (Bq/kg) (for Uranium series radionuclides)	Change in Soil Radionuclide Concentration (Bq/kg) (for Thorium series radionuclides)
Accommodation Village (full time)	125	360	6.3	18
Aileron	41	118	2.1	5.9
Alyuen Community	41	118	2.1	5.9

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 11.

Table 11: Data for Ingestion Dose Assessment

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

3.5 TOTAL DOSE ESTIMATES

The total dose estimates at the sensitive receptors can be seen in Table 12. Note that the doses are based on 100% occupancy (that is 8,760 hours per year) at these locations.

Table 12: Public Total Dose Estimates

Location	Exposure Pathway Dose (mSv/y)*					
	Dust (U)	Dust (Th)	RnDP+	TnDP†	Ingestion	Total Dose+
Accommodation Village (full time)	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)

* As noted in Section 3.2, the gamma dose is negligible (<0.001mSv/y).

† As per explanation under Table 8, the doses using the new recommended dose conversion factor for RnDP and TnDPcan be seen in parentheses in the table.

3.6 BUSH TUCKER ASSESSMENT

Introduction

An estimate of the potential dose from the ingestion of bush tucker has been made for people living at the sensitive receptor locations and consuming bush tucker from that immediate location. It is relevant to note that that plants and animals in the Nolans Project site are sparse, mainly due to the lack of surface water. Therefore, it is unlikely that inhabitants of the region would take their entire annual food intake as bush tucker from the region. This has been factored into the assessment.

Approach

The assessment method assumes that dust emissions from the mining operation deposit in the surrounding environment and are taken up by plants and animals. The rate of uptake by plants and animals is known as the 'uptake factor', also known as the 'concentration ratio'. Exposure to people occurs when the plants and animals are consumed. It should be noted that all plants and animals already contain naturally occurring radionuclides and this assessment is for the effects of additional radionuclides from the project.

To determine the potential doses from the consumption of bush foods, an estimate of the amount of food consumed needs to be made. AAEC (AAEC, 1985) assumed a diet that consists of an intake of 155kg/y of plant material and 125kg/y of animal material for traditional owners of the Maralinga lands. These estimates have been used in this assessment and factored for likely bush tucker consumption rates.

Concentration ratios for specific species are difficult to obtain and consideration has been given to a number of sources of data, including:

- Analysis results provided in ANSTO (2007);
- Arafura Resources exploration data (Hussey, 2016);
- Published concentration ratios from ARPANSA (2014);
- Published uptake factors from IAEA (2010); and
- ERICA software databases (ERICA, 2016).

It should be noted that the concentration ratios are likely to overestimate the eventual ingestion of radionuclides. This is because concentration ratios usually apply to a whole animal or plant. When consuming animals or plants it is usual that it is not eaten in its entirety (for example, bones and offal are not generally consumed).

Even though this is a human dose assessment and not a non-human biota assessment, the ERICA concentration ratios have been considered because they provide a wealth of information.

Assessment Parameters – Annual Food Consumption

Due to the lack of native foods in the area, the following assumptions have been made:

- Locally sourced bush tucker makes up 10% of the diet. This is based on 3 days a month when bush tucker makes up the entire diet;
- The composition of the meat portion of the bush tucker consists of:
  - 90% kangaroo and/or wallaby; and
  - 10% goanna
- The composition of the vegetation portion of the bush tucker consists of:
  - 60% leafy and non-leafy vegetation; and
  - 40% root vegetation.

Therefore the total annual bush tucker consumption assumptions for this assessment are as follows:

- 11.25kg of kangaroo;
- 1.25kg of goanna;
- 9.3kg of leafy and non-leafy vegetation; and
- 6.2kg of root vegetables.

Assessment Parameters – Uptake Factors

The relevant calculated and published factors from the various sources are shown in Table 13.

Table 13: Summary of Concentration Ratios

Species	Elemental Concentration Ratio (Bq/kg (species))/(Bq/kg (soil))					Source
	Uranium	Thorium	Radium	Lead	Polonium	
Green Vegetation Tissue	0.028	0.031	0.217	0.796	0.401	ANSTO (2007)
Regional Grasses	0.002	0.0015				Hussey (2016)
Tree leaves	0.002	0.0005				Hussey (2016)
Mulga phyllodes	0.001	0.0007				Hussey (2016)
Kangaroo	0.007		0.41	0.022	0.55	ARPANSA (2014)
Reptile (Goanna)	2.5	0.027		1.2	11	ARPANSA (2014)
Non leafy	0.0265	0.0011	0.0305	0.0075	0.000095	IAEA (2010)
Leafy	0.01	0.0006	0.0455	0.04	0.0037	IAEA (2010)
Root	0.014	0.00435	0.0355	0.0315	0.0385	IAEA (2010)
Large Mammal	0.0044	0.00016	0.044	0.037	0.089	ERICA Default
Reptile	0.0052	0.0022	0.0044	0.039	0.13	ERICA Default
Shrub	0.061	0.061	0.33	0.32	0.33	ERICA Default
Tree	0.0066	0.00126	0.0116	0.0697	0.0733	ERICA Default
Grasses	0.128	0.16	0.18	0.12	0.28	ERICA Default

For this assessment, the factors for the closest species types have been used and these can be seen in Table 14.

Table 14: Summary of Concentration Ratios for Closest Species Types

Species	Elemental Uptake Factors Ratio (Bq/kg (species))/(Bq/kg (soil))					Source
	Uranium	Thorium	Radium	Lead	Polonium	
Kangaroo	0.007	0.00016*	0.41	0.022	0.55	ARPANSA (2014)
Reptile (Goanna)	2.5	0.027	0.0044†	1.2	11	ARPANSA (2014)
Green Vegetation Tissue	0.002‡	0.009‡	0.217	0.796	0.401	ANSTO (2007) Hussey (2016)
Root Vegetables	0.014	0.00435	0.0355	0.0315	0.0385	IAEA (2010)

* No APRANSA data, therefore the large mammal ERICA values have been used

† No APRANSA data, therefore the reptile ERICA values have been used

‡ From Hussey (2016)

Assessment

An overall summary of the method is as follows:

- Determine the change in soil radionuclide concentration due to deposition of radionuclides in dust from the operation for a nominal period (assumed to be for the full life of operation ie 42 years). This gives a project contributed radionuclide in soil concentration at the receptor locations (Bq/kg).
- Use the concentration ratios to determine the concentration of radionuclides in plants and animals from the soil (Table 14).
- Determine the human intake from the consumption of plants and animals (multiply the consumption rate (kg/y) by the radionuclide concentration (Bq/kg) to give the Bq/y intake).
- Use the ingestion dose factors from ICRP (1995) to determine the dose that is received by the consumption of plants and animals.

The calculated change in soil radionuclide concentrations at each of the sensitive receptor locations can be seen in Table 15 and is based on soil density of $2t/m^3$ and a mixing depth of 10mm.

Table 15: Change in Soil Radionuclide Concentration (after 42 years of operations)

Location	Increase in Soil Concentration (Bq/kg)	
	U	Th
Accommodation Village	6.3	18.0
Aileron	2.1	5.9
Alyuen Community	2.1	5.9

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 16.

Table 16: Data for Ingestion Dose Assessment from Bush Tucker

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

Summary

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.

An estimate of the potential dose as a result of consuming bush tucker has been made using conservative assumptions and the doses have been shown to be approximately 0.1mSv/y at the two closest non-operational receptors.

4. ENVIRONMENTAL IMPACTS

4.1 BACKGROUND

This section discusses the potential environmental radiological impacts of the operation. The assessment has been conducted based on the potential airborne emissions from the project which leads to the deposition of radioactive dust on surrounding soils.

The protection of the natural environment from emissions from nearby operations has historically been based solely on the protection of humans. This approach was outlined by the ICRP which stated that "if man is protected then it can be assumed that the environment is protected" (ICRP, 1991).

It is now generally accepted, however, that there is a need to demonstrate that the flora and fauna are protected from emissions from operations.

This has been addressed by the ICRP in more recent publications (ICRP, 2014) in which it is recommended that assessments be made of the impact of radiation on NHB (plants and animals). An important aspect is that protection of plants and animals is at the species level rather than the individual level. On the other hand, for humans, the protection systems are established to protect individuals.

4.2 THE ERICA TOOL

ARPANSA notes that the ERICA Software Tool (where ERICA is short for Environmental Risk from Ionising Contaminants: Assessment and Management) is applicable for use in Australia (ARPANSA, 2010) for assessing radiological impacts to plants and animals. The software uses changes in media radionuclide concentrations and concentration ratios in species, derived from studies, to provide a measure of radiological impact to a number of reference species.

An ERICA assessment is a tiered assessment. This means that the level of assessment depends on the level of impact (i.e. the higher the potential impacts, the higher the level of scrutiny) (ARPANSA, 2010). Tier 1 is the simplest assessment level, requiring the minimum input data. Where more data is available, or the potential impacts are higher, then a Tier 2 assessment

can be conducted. The final level is Tier 3 which is occurs when the likely impacts need to be better defined. The aim of the tiered approach is to ensure that the level of assessment is commensurate with the actual risk.

The overall approach defined a 'screening level' which is the calculated radiation dose rate below which no effects would be observed and the ERICA default level is set at 10 µGy/h (ARPANSA, 2010).

The two important inputs for an ERICA assessment are:

- Operationally derived changes in media concentration, which is the additional radionuclide concentration in either soils or waters attributable to the operation and is in units of Bq/kg or Bq/L; and
- The radionuclide concentration ratios, which is the ratio of radionuclide concentrations in the media and the concentrations in the flora and fauna.

The latest version of the ERICA software was released in February 2016 (version 1.2.1).

4.3 ASSESSMENT APPROACH

A Tier 2 ERICA assessment was conducted because some additional concentration ratio data was available and two user defined species were used.

The assessment was also conducted for the full set of default terrestrial flora and fauna.

The user defined species were as follows:

- The 'Black Footed Wallaby' which is associated with the Nolans region:
  - mass: 15kg, height: 0.7m, width: 0.2m, length: 0.2m;
  - based on the adult Agile Wallaby (*Macropus agilis*) (Doering, 2016).
- The 'Kangaroo' which is generic to Australia:
  - mass 50kg, height 1.5m, width 0.75m and depth 0.75m:
  - based on best estimates.

4.4 ERICA CONCENTRATION RATIOS

The key factors in an ERICA assessment are concentration ratios (CR). These are the ratio of the whole body average radionuclide concentrations in the specific species to the concentration of the radionuclides in the media (e.g. soil and water). ERICA provides a series of default values, however there is some recent published information that can complement the default set of CR values.

ARPANSA (2014) provides a number of CR values and an additional source of data was found in the Toro Energy impact assessment (Toro Energy, 2011). The data from Toro Energy consists of radionuclide in soil samples and species of shrubs (longer lived *Acacia aneura* and shorter lived *Tecticornia*).

The additional CR values used in this assessment are shown in Table 17.

Table 17: Additional Published Concentration Ratios (note that ERICA CR values are provided for comparison)

Species	Elemental Concentration Ratio (Bq/kg (species))/(Bq/kg (soil))					Source
	Uranium	Thorium	Radium	Lead	Polonium	
Red Kangaroo*	0.007	No data	0.41	0.022	0.55	ARPANSA (2014)
Large Mammal	*0.0044*	*0.000136*	*0.044*	*0.037*	*0.089*	*ERICA Default*
Long lived Vegetation†	0.21	0.02	0.05	1.06	0.58	Toro Energy (2011)
Short Lived Vegetation†	0.23	0.17	0.09	0.33	0.34	Toro Energy (2011)
Vegetation Average	0.22	0.10	0.07	0.70	0.46	Average of above
Shrub	*0.061*	*0.061*	*0.33*	*0.32*	*0.33*	*ERICA Default*

* ARPANSA 2014 figures are reported as concentration ratios – average of two sample sets used

† 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.

4.5 MEDIA CONCENTRATIONS

The media concentrations used in the assessment are seen in Table 18.

Table 18: Change in Soil Concentration Due to Deposition from Project (42 years of operation)

Location	Change in Soil Concentration (Bq/kg)	
	Uranium series radionuclides	Thorium series radionuclides
Accommodation Village (full time)	6.3	18
Aileron	2.1	5.9
Alyuen Community	2.1	5.9

4.6 ERICA ASSESSMENT OUTPUTS

The output of the assessment can be seen in Table 19 which shows that 10 µGy/h screening level is not exceeded at a Tier 2 level, using the default values.

The species with the highest level of exposure is lichen and bryophytes, however the exposure level remains well below the trigger level for further assessment.

Table 19: Output of ERICA Assessment

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
Reptile	0.10
Shrub*	0.62
Tree	0.04
Wallaby (user defined)	0.07
Kangaroo (user defined)	0.48

* The CR values used for "shrub" are the average of the short and long lived vegetation types shown in Table 17.

It can be concluded that the ERICA assessment indicates that there is no radiological risk to reference plants and animals, kangaroos or wallabies from emissions from the proposed project.

5. POST CLOSURE EXPOSURE SCENARIOS

Arafura Resources has indicated that 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 will be no long-term radiological impacts of the project following closure.

To consider future scenarios, Arafura conducted an assessment to determine future exposure scenarios (including possible failures scenarios in the tailings storage facility (TSF) and residue storage facilities (RSF)). The assessment utilised the FEPs methodology (IAEA, 2011) which 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.

Radiological assessments of the possible exposure scenarios were conducted (JRHC, 2015) and a summary of the potential doses is shown in Table 20.

Table 20: 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 0.016mSv/y.	Radiological impact is negligible
Large schist zones beneath RSF and liner failure leading to groundwater contamination		Ingestion of 1,000 litres per year of groundwater at Aileron gives an incremental annual dose of approximately 0.053mSv/y.	Radiological impact is negligible
Erosion of TSF or RSF wall due to excessive rainfall leading to overtopping and loss of containment		Loss of containment will result in doses to flora and fauna exceeding the ERICA default screening level of 10uGy/h. Full time occupation may result in human doses up to 2.7mSv/y.	Radiological impacts are likely to be minor compared to other impacts of a failure
Future drilling into TSF or RSF following closure while conducting exploration		Total occupational dose from gamma and dust for 1 year is estimated to be 4.1 mSv/y (for RSF drilling) and 3.2mSv/y (for TSF drilling).	It is unlikely that exploratory drilling would continue for an extended period without workers becoming radiation workers and being monitored.
Occupation of rehabilitated RSF and TSF with following cover materials:	Regional surface material (natural background)	Human dose < 0.5mSv/y	Considered to be consistent with existing natural background levels
	Mine waste rock and regional material (conservative average of 3Bq/g)	Human dose approximately 2mSv/y	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 exposure occur.

6. ENVIRONMENTAL MONITORING PROGRAM

In addition to the occupational monitoring program, an environmental radiation monitoring program will occur during operations. The aims of this program are 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 radiation monitoring program will be prepared for approval prior to construction commencing and an outline of the elements of such a program is shown Table 21.

Table 21: Outline environmental radiation management programme

Radiation Parameter	Measurement Method	Location and Frequency
Direct (external) gamma	Handheld environmental gamma monitor	Annual survey at perimeter of operational area.
	Passive environmental monitors	Monitors placed at environmental monitoring sites quarterly
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 will rotate between off-site locations.
Dispersion of dust containing long-lived radionuclides	High volume samplers	Sampler will rotate between approved off-site locations.
Dispersion of dust containing long-lived, alpha-emitting radionuclides	Dust deposition gauges	Sampling at identified locations. Samples composited for one year analysed for radionuclides.
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 will occur following significant rainfall events.

7. SUMMARY

The assessment has shown that the Nolans operation will result in negligible or minor radiological impacts to the public and the environment.

Post closure doses are expected to be negligible based on the closure criteria commitment and would be minor in the event of exposure scenarios.

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Appendix 1:

Metallurgical Processing Radiological Considerations - A Review of Arafura Resources Nolans ANSTO Related Reports

Metallurgical Processing Radiological Considerations - A Review of Arafura Resources Nolans ANSTO Related Reports

Overview

The final processing plant design is dependent on detailed engineering studies that are yet to be completed by Arafura Resources. However, the basic metallurgical processes are well established and are based on extensive testwork on Nolans ore by ANSTO Minerals.

Overall, the processing of Nolans ore will involve two main steps. The first step is a beneficiation process and the second step involves chemical treatment of the beneficiation concentrate.

The ANSTO testwork was conducted on ore containing approximately 2,500ppm of Th and 170ppm of uranium, which is equivalent to approximately 10Bq/g of thorium 232 and its decay products and 2Bq/g of uranium 238 and its decay products. Materials containing radionuclide concentrations above 1Bq/g are generally considered to be radioactive, requiring management controls for radiation protection. For unrestricted sales of final product, it is usual to aim to have radionuclide activity concentrations below 1Bq/g, although this can be subject to customer requirements.

For Nolans material, it was shown that generally all radionuclides report to both the beneficiation and processing solid waste streams and this note provides details on the deportment of radionuclides through the processing.

Beneficiation

Beneficiation involves crushing and grinding of ore with water to produce a slurry. A magnetic separation step occurs and then a flotation agent is added to the slurry which chemically attaches to the fine mineralised ore particles. Using the flotation separation method, the mineralised and non-mineralised particles are then separated. The mineralised portion of the slurry is known as the concentrate and remainder is known as the beneficiation tailings. The concentrate is sent for further processing and the tailings are sent for disposal.

The beneficiation process rejects approximately two thirds of the input material, with rare earths and metals upgrading into the concentrate stream. The beneficiation tailings are to be stored in a dedicated tailings storage facility (TSF).

The testwork has shown that no discernible leaching of radionuclides into liquid occurs during the beneficiation process. As well as concentrating the rare earths, the flotation process also concentrates the uranium and thorium radionuclides. The testwork shows that radionuclide concentrations are upgraded by a factor of approximately two into the metal concentrate stream. On the other hand, the radionuclide concentrations in tailings are approximately half of the ore radionuclide concentrations. The predicted radionuclide concentrations and relative proportions can be seen in Tables 1 and 2.

Table 1: Predicted Radionuclide Concentrations in Beneficiation Process

Radionuclide	Ore	Beneficiation Tailings		Beneficiation Concentrate
	Bq/g	Solids (Bq/g)	Liquids (Bq/L)	Solids (Bq/g)
Th^{232}	9.6	5.0	0	19.0
Ra^{228}	9.6	5.5	0	18.0
Th^{228}	9.6	5.0	0	19.0
U^{238}	2.1	1.0	0	4.5
U^{234}	2.1	0.9	0	4.6
Th^{230}	2.1	0.5	0	5.5
Ra^{226}	2.1	0.8	0	4.8
Pb^{210}	2.1	0.7	0	5.1
Po^{210}	2.1	1.0	0	4.5
U^{235}	0.0	0.0	0	0.0
Ac^{227}	0.0	0.0	0	0.0
Mass(t)	920,000	618,000		302,000

Table 2: Predicted Percentage Radionuclide Deportment in Beneficiation Process

Radionuclide	Ore	Beneficiation Tailings		Beneficiation Concentrate
	%	Solids %	Liquids %	Solids %
Th^{232}	100	35.1	0	64.9
Ra^{228}	100	38.5	0	61.5
Th^{228}	100	35.1	0	64.9
U^{238}	100	30.8	0	69.2
U^{234}	100	29.2	0	70.8
Th^{230}	100	15.4	0	84.6
Ra^{226}	100	26.1	0	73.9
Pb^{210}	100	21.5	0	78.5
Po^{210}	100	30.8	0	69.2
U^{235}	100	30.8	0	69.2
Ac^{227}	100	30.8	0	69.2
Mass(t)	920,000	618,000	0	302,000

Chemical Processing

The concentrate slurry from the beneficiation process is pumped to the processing plant. The concentrate is firstly filtered and then undergoes a low temperature sulphuric acid bake process to liberate the rare earths for subsequent processing and extraction.

The baked material is then leached with a mixture of leach liquor, filtration wash filtrates and water to recover rare earths to produce a pregnant liquor solution.

The pregnant liquor contains rare earths and impurities, including uranium, thorium and some radium. A sulphate precipitation process is used to precipitate rare earths from the liquor stream, which is subsequently filtered and washed for further processing. The barren liquor stream is then neutralised to remove the impurities resulting in a precipitate which is disposed in the dedicated residue storage facility (RSF).

The rare earth precipitate is then converted to a hydroxide and washed and dried and further processed to remove residual thorium and radium.

The residue from each of the processes is neutralised, which results in precipitation of impurities and this material is disposed in the RSF. Liquor is recycled where appropriate.

Final products are cerium carbonate and a rare earth chloride for export.

The ANSTO testwork shows that the majority of radionuclides in the original beneficiation concentrate are successively removed from the product stream and report to the residue streams. Neutralisation of the residue streams acts to precipitate the radionuclides into the solids phase of the residues.

The predicted radionuclide concentrations and relative proportions can be seen in Tables 3 and 4 and are based on material used in ANSTO testwork.

Table 3: Predicted Radionuclide Concentrations in Beneficiation Process

Radio Nuclide	Beneficiation Concentrate	Process Residues		Cerium Carbonate Product	Rare Earth Chloride Product
	Solids (Bq/g)	Solids (Bq/g)	Liquids (Bq/L)	Solids (Bq/g)	Solids (Bq/g)
Th^{232}	19.0	8.3	92.4	0.35	0.00
Ra^{228}	18.0	10.5	20.1	0.10	0.46
Th^{228}	19.0	9.5	73.0	0.29	0.08
U^{238}	4.5	2.8	17.3	0.05	0.00
U^{234}	4.6	3.0	16.3	0.06	0.00
Th^{230}	5.5	4.7	34.7	0.19	0.00
Ra^{226}	4.8	2.3	1.5	0.04	0.04
Pb^{210}	5.1	2.6	0.2	0.06	0.00
Po^{210}	4.5	2.0	0.3	0.02	0.00
Ac^{227}	N/A*	0.0	0.0	0.03	0.35
Mass(t)	302,000	602,000	1,625,333	17,000	26,000

* The Ac^{227} results are based on comparison with Lanthanum results

Table 4: Predicted Percentage Radionuclide Concentrations in Beneficiation Process

Radio Nuclide	Beneficiation Concentrate*1	Process Residues		Cerium Carbonate Product	Rare Earth Chloride Product
	Solids %	Solids %	Liquids %	Solids %	Liquids %
Th^{232}	64.9	62.9	1.9	0.07	0.00
Ra^{228}	61.5	61.0	0.3	0.02	0.12
Th^{228}	64.9	63.5	1.3	0.05	0.02
U^{238}	69.2	68.1	1.1	0.03	0.00
U^{234}	70.8	69.7	1.0	0.04	0.00
Th^{230}	84.6	82.9	1.7	0.09	0.00
Ra^{226}	73.9	73.6	0.1	0.04	0.06
Pb^{210}	78.5	78.4	0.0	0.05	0.00
Po^{210}	69.2	69.2	0.0	0.02	0.00
Ac^{227}	69.2†			3.46	65.79
Mass(t)	302,000	602,000	1,625,333	17,000	26,000

* The remnant proportions of radionuclides are present in the beneficiation tailings

† The Ac^{227} results are based on comparison with Lanthanum results

ABN 22 080 933 455

Report ARU-15/008

ENVIRONMENTAL RADIATION AND GEOCHEMICAL STUDIES ASSOCIATED WITH THE NOLANS PROJECT EIS, DISCUSSION AND ANALYSIS OF SOME RESULTS

By

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SUMMARY

Arafura Resources has completed a number of detailed geochemical and radiation studies to document the baseline levels of uranium and thorium and the naturally occurring radioactivity around the Nolans Rare Earth Elements (REE) Project. These studies provide background information to the Nolans project EIS and demonstrate an understanding of baseline data for Nolans Bore placing it in a regional and global context.

This report summarises background data collected at Nolans Bore, mostly by Arafura, since 1999 and provides an analysis of the natural environment in its current state prior to any substantial mining related development. The report also provides an outline of historic exploration which led to the discovery of Nolans Bore and demonstrates that there have been no substantial changes to the natural environment by exploration activities commenced. The report also clearly demonstrates significant variability in the natural environment.

The area around Nolans Bore is a not a pristine environment and has been subject to pastoral activities for about 100 years or more. The stock bore (Nolan Bore or more commonly Nolans Bore) was drilled in 1978 and was used continuously as a stock bore until about 2011. Cattle operations are still in operation today in the area around Nolans Bore. Exploration by Arafura has demonstrated that the original stock bore was drilled directly into mineralisation. Like most bores in the Aileron-Reynolds Range region, the water from Nolans Bores contains elevated U, but it is not the highest in the region.

PNC discovered and mapped outcropping mineralisation within the cattle yards and elsewhere around Nolans Bore in 1995. Arafura has undertaken and completed exploration activities and resource definition drilling at Nolans Bore since late 1999. All exploration activities have been approved and monitored by NT DME and all drilling-related ground disturbances have been rehabilitated in accordance with approved NT DME guidelines. The Nolans Bore area has been radiometrically surveyed several times with the effective gamma dose rates measured pre- and post-ground disturbing activities. The background radiation in the Nolans Bore project area is currently consistent with the pre-exploration state.

Arafura"s exploration team has developed a large in-house database that significantly contributes to the wealth of our geological and environmental understanding of U and Th at Nolans Bore and throughout the region. The database includes detailed low-level airborne radiometric surveys and extensive on-ground reconnaissance exploration mapping, sampling and radiometric measurements. Arafura"s radiation instruments are routinely calibrated and the data from airborne radiometric surveys has been confirmed using whole rock and soil assays and thermo-luminescence dosemeters as area monitors. In addition to this Arafura has drilled and radiometrically logged about 1150 exploration and resource definition holes within several kilometres of Nolans Bore. Arafura has assayed about 30,000 samples from these drill holes. Arafura has also visited about 5200 locations in the general region and has sampled and assayed rocks, soils, streams and vegetation from more than 2100 of these sites. Arafura has also measured the natural dust deposition in the Nolans project area and established a baseline understanding of the natural dust composition, composition of the soils and the environmental uptake of various plant species throughout the region.

The area around Nolans Bore has the highest natural background gamma radiation levels in the project area. However there are number of other locations in the Aileron-Reynolds region where similarly anomalous radioactive rocks and soils are also exposed at the surface, although their aerial extent is much less. The natural environmental background gamma dose rates measured at the Nolans Bore deposit are similar to other places on Australian continent and in the rest of the world.

Arafura has managed radiation exposures to its workers and the environment through monitoring programs and by adopting work practices to minimise the amount of dust and movement of material as per Arafura"s Radiation Management Plan. Arafura routinely measures the average background gamma dose rates at each drill site prior to drilling and also measures the dose rates of all material brought of the surface. This ensures our understanding of radiation remains sound and under-control with no surprises. Arafura"s onsite radiation clearances and inspection protocols also limits the spread of radioactive material and ensures that only material required for test work leaves site.

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INTRODUCTION

Arafura Resources has completed a number of detailed studies to document the baseline levels of naturally occurring uranium (U) and thorium (Th) around the Nolans Rare Earth Elements (REE) Project. Some of the geochemical and radiation studies mentioned in this report are likely to be part of ongoing investigative programs. This report specifically focuses on the amount of U and Th, and the gamma radioactivity measured in the natural environment around the Nolans project area. It documents and investigates the natural baseline characteristics and variability inherent within the rocks, soils, sediments and vegetation in the project area. The report also outlines the habitation of the area and places some of these results into a regional and global context. While this study is in not exhaustive it provides a comprehensive benchmark assessment of the area and compares favourably with other environmental studies that also only use a limited number a study sites and samples. Finally this report and a companion report by Dean and Grose (2015) provides detailed background information to the Environmental Impact Statement (EIS) being prepared by GHD and radiation consultants Jim Hondros and Mark Sonter.

General background

Arafura Resources is planning to develop, process and recover REE from the Nolans Bore REE deposit in the Aileron-Reynolds Project area about 140km NNW of Alice Springs in the Northern Territory, Australia. Exploration and resource definition drilling, and geological modelling, has demonstrated that Nolans Bore is a world-class REE deposit which remains open at depth. For the purposes of the EIS, Arafura has adopted the Mineral Resources (Table 1) and mining plans in the Nolans Development Report (NDR) which was publically released by Arafura in September 2014 (Arafura Resources 2014).

Table 1: Statement of Mineral Resources for the Nolans Bore REE deposit at March 2012, using a 1% REO cut-off. This estimate is compliant with the 2004 JORC Code and has been faithfully reproduced as calculated by Mr John Tyrell of AMC Consultants (AMC) Pty Ltd and publically released to the ASX on 12/3/2012.

Resources	Tonnes	Rare Earths	Phosphate	Uranium
	(million)	**REO (%)**	**P_2O_5 (%)**	**U_3O_8 (lb/t)**
Measured	4.3	3.3	13	0.57
Indicated	21	2.6	12	0.42
Inferred	22	2.4	10	0.37
Total	**47**	**2.6**	**11**	**0.41**

Yttrium is not included as a rare earth for this estimate. Numbers in this Table may not compute due to rounding. One lb/t U_3O_8 = 0.0454% U_3O_8.

The Mineral Resources in Table 1 were used to estimate a 2004 JORC Mineral Reserve in 2012 however this no longer applies as some of the modifying factors and assumptions have changed. The Mineral Resources in Table 1 have been used for mine planning purposes in the NDR (Arafura Resources 2014). However as is often the case, the Mineral Resources for the Nolans Bore REE deposit have recently been updated based on a new geological interpretation and remodelling of the deposit (Table 2). It is anticipated that a new JORC 2012 Mineral Reserve will be estimated based on the Mineral Resources shown in Table 2.

Table 2: Statement of Mineral Resources for the Nolans Bore REE deposit at 30 October 2015 using a 1% TREO cut-off. This estimate is compliant with the 2012 JORC Code and was computed by the author and publically released to the ASX on 30/10/2015.

Resources	Tonnes	Rare Earths	Phosphate	Uranium
	(million)	**TREO %**	**P_2O_5 (%)**	**U_3O_8 (lb/t)**
Measured	4.9	3.2	13	0.54
Indicated	30	2.7	12	0.44
Inferred	21	2.3	10	0.36
Total	**56**	**2.6**	**12**	**0.42**

Numbers in this Table may not compute due to rounding. One lb/t U_3O_8 = 0.0454% U_3O_8.

Table 2 shows there is about a 20% increase in total resources over the previous resource estimate. This

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increase is largely due to a revision of the geological model and the inclusion of additional mineralised bodies that were not included in the former statement. Most importantly the new geological model provides an equal representation of waste rock and mineralisation. This geological revision and remodelling was driven by a need to better understand the waste rocks and their characteristics for the EIS. Both Mineral Resource estimates are based on material coming from the same area and it is expected that the open pit is likely to be similar to that proposed in the NDR case, although the mining schedule and development of the pit may differ with further analysis.

In this report, the rare earth elements include the 14 naturally occurring stable or very long-lived isotopes of the lanthanoid series plus Yttrium (Y). The lanthanoids are in increasing atomic number Lanthanum, Cerium, Praseodymium, Neodymium, Samarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Thulium, Ytterbium and Lutetium (La, Ce, Pr, Nd, Sm, Eu, Gd, Tb, Dy, Ho, Er, Tm, Yb and Lu, respectively). Yttrium is chemically similar to Ho and typically included together with the lanthanoids as a rare earth element in economic geology because this suite of elements forms a coherent group with similar chemical properties. Furthermore they all typically occur together in nature. Promethium (Pm) is a member of the lanthanoid series occurring between Nd and Sm but Pm has no stable or long-lived naturally occurring isotopes making it one of the rarest naturally occurring elements in the earth. A total of about 572 g of Pm^{147} has been estimated in the total Earth‟s crust; about 560g comes from the spontaneous fission of U^{238} and it has recently been shown that a small component, about 12g, is derived from the decay of Eu^{151} (Belli *et al* 2007). Pm^{147} has been measured in pure pitchblende ores but the amount is miniscule. Pm is essentially a temporary product and the amount of Pm in most rocks would be extremely difficult measure, if present. It is also worth stating here that like many other elements, the rare earths have naturally occurring radioactive isotopes however these isotopes are extremely long-lived with half-lives that are about 10 to a billion times the age of the earth itself. This means that the radioactive breakdown of the parent isotope is a rare event. Consequently the dose rate from exposure to extremely long-lived isotopes is miniscule and they not discussed in this report.

The amount of the aforementioned group of elements, excluding Pm, is used to determine the Total Rare Earth Oxides (TREO). The reporting of TREO is standard industry practice when reporting rare earth geochemical analyses, Mineral Resources or Reserves where:

$TREO = La_2O_3 + CeO_2 + Pr_6O_{11} + Nd_2O_3 + Sm_2O_3 + Eu_2O_3 + Gd_2O_3 + Tb_4O_7 + Dy_2O_3 + Ho_2O_3 + Er_2O_3 + Tm_2O_3 + Yb_2O_3 + Lu_2O_3 + Y_2O_3$. (Equation 1)

Unfortunately the inclusion of Y as a rare earth element contrasts with a typical geochemist‟s viewpoint where only the lanthanoids themselves are referred to as the rare earth elements (REE) in the published geochemical literature. This distinction is realistic because there are conditions and situations where Y does not behave like a REE and the Y/Ho ratio can diverge from typical primordial values. For example, this often occurs in alteration systems and the author has also observed it in biogeochemistry. Parts of the mining industry also include Scandium (Sc) as a light rare earth element, but Sc has notably different chemical properties and in my view should not be included as a rare earth. To avoid any confusion from here on, and to be consistent with industry reporting practice which uses Equation 1 above, TREE or TREO and REE or REO respectively will be considered interchangeable and the same, unless otherwise stated.

Individual or mixed amalgams of REE metals are not known to occur in nature. There is however a very large number of mineral species that may contain at least some REE. The REE are in fact not rare; the amount of La and Nd in the average upper continental crust closely matches that of Cu, and the amount of Ce in the crust is similar to Zn. The REE are more abundant in the upper continental crust than Au and Ag. However in nature REE deposits of economic interest are typically elusive and nowhere near as abundant as deposits of Cu, Zn, Au and Ag. This is because very few minerals contain enough REE which are sufficiently concentrated and localised to form an economic deposit. In addition the extraction, recovery and separation of individual REE are expensive. To further complicate matters Nolans Bore is a unique style of mineralisation and its mineralogy is unusual. This is also the first instance where someone is trying to recover significant REE from an apatite-dominated deposit and means that Arafura has had to explore and develop methods to treat and recover the REE.

Because of strong chemical similarities between the elements of the lanthanoid and actinoid series, U and Th typically substitute for REE in nature. Hence most REE-enriched minerals and deposits typically contain at least some U and Th (*eg*. Mariano 1989; Orris and Grauch 2002; Hussey 2003; Linnen and Samson 2004; Hoatson *et al* 2011) and vice versa.

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Historical occupation of the area and radiation exposure.

This section outlines the habitation and occupation of the Nolans project area and clearly demonstrates minor and infrequent site occupancy by most, except for Arafura Resources, and perhaps Aileron Station.

The Anmatjere people have lived in the area for many years and a description of the aboriginal heritage is documented in Gunn (2006). In addition Anmatjere workers employed by Arafura have indicated that nobody lived near Nolans Bore because there was no bush tucker or permanent water (*pers comm*). This is highlighted in a traditional dot painting that was commissioned by Arafura to depict Nolans Bore (Figure 1). The painting portrays Kerosene Camp Creek and the surrounding mulga plain with an eagle nest, skeletons and tracks. The story behind the painting is summarised as "*people walked through area but there was no food or water so they died and then the eagle came down, ate them and scattered their bones*". This painting suggests there is no reason to be in this area although it is acknowledged that people traversed across the area. It is clear that this story has nothing to do with specific rocks, landforms or radiation in the project area, and the location of the Nolans Bore deposit is not recognised in their cultural heritage.

The aboriginal occupancy of the area would have been focussed on areas of reliable water and food, and radiated out from there (Gunn 2006). The nearest reliable source of water is at Angerle (Anna‟s Reservoir), about 10 km due west of Nolans Bore, previously documented by Gunn in a separate uncited report to AAPA referenced in Gunn (2006). Water is also locally trapped along creeks following substantial rain events however these sources quickly dry out. In addition there are significant natural drainage discharge points (*eg* Figure 2). A number of natural soaks also occur near many of the larger orthogneiss hills in the general area and would have provided water, but again none of these hold permanent water supplies.

There is considerable archaeological evidence that people have quarried chalcedony and quartz for stone tools in the area around Nolans Bore (Gunn 2006). The largest working occurs about 1500m north of Nolans Bore where chalcedony has been quarried (Figure 3). The chalcedony at this location is associated with calcrete however the workings are small and there appears to have been limited amounts of suitable material. These rocks have not been sampled or assayed because they are a Registered Sacred Site. However it seems logical that they might contain a small amount of uranium (possibly up to 100ppm U or more) given a coincident low-level airborne uranium anomaly and geological similarities to Arafura‟s Goanna U prospect which occurs in calcrete about 1-2km SW of Nolans Bore. There is also a number of worked quartz vein outcrops and flaked quartz scatter around Nolans Bore, but these are essentially insignificant and the author has observed numerous similar occurrences throughout the region.

Gunn (2006) also pointed out that a number of large trees were scarred in such a fashion that they were probably used to obtain small quantities of water via natural transpiration. Similar examples have been observed elsewhere in the region by the author. Gunn also identified petrogylphs and grinding patches about 5km SE of Nolans Bore however the lack of permanent water means only short term occupancy at that area.

Figure 1: Photograph of a traditional dot painting depicting the Nolans Bore area by Wayne Jungarryi Scrutton. This painting is about 1800mm x 900mm and was commissioned by Arafura through the Aileron Outback Gallery in 2007.

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Figure 2: Example of a typical drainage discharge point about 3km northeast of Nolans Bore. The jointed and blocky hills of orthogneiss in this general area hold water for short periods of time following major rainfall events. These hills produce a significant number of natural springs and drainages as shown here. The water storage capacity is limited and these discharges eventually dry up.

Figure 3: Example of a stone tool manufacturing site of about 1500m north of Nolans Bore showing worked and flaked chalcedony. This and other archaeological evidence demonstrates that aboriginal people have been here (Gunn 2006).

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Nolans Bore is clearly part of the natural environment for the traditional aboriginal peoples of the region. Radiological doses from the natural environment are variable and reflect one"s living area; however they are essentially irrelevant as they are considered to be your normal background dose. Nevertheless radiological exposures and doses to the traditional aboriginal people from Nolans Bore would have been very low because the period of occupation in this area was limited.

The explorer John McDouall Stuart discovered and named the rockhole Anna"s Reservoir in April 1860, and from that moment onwards Anna"s Reservoir played an important historic role in the European development of region and the NT (Milgate 2002). Milgate (2002) provides basic historical information about Anna"s Reservoir Conservation Reserve. It is well known that Stuart and his fellow explorers visited Anna"s Reservoir on the forward and return journeys of each of his three attempts to reach the north coast of Australia. In 1879-80 Alfred Giles drove 8000 sheep and 4000 cattle in an epic journey to Springvale Station near Katherine and watered them at Anna"s Reservoir; it therefore seems high likely that this large group would have also passed through the open valleys near Nolans Bore on its way north. A homestead was built near Anna"s Reservoir by the ambitious Barrow Creek Pastoral Company in 1884. This homestead was to be focus of a very large land holding in this area however it was abandoned because the Anmatjere people attacked and set fire to it. Anna"s Reservoir was also significant to the linesman on the Overland Telegraph Line. Jeremiah Ryan and his well sinking team established Ryan Well as a stock bore in 1889 and the nearby Glenn Maggie homestead was established as a sheep and cattle station in 1914 (Milgate 1999). Ryan Well and Glenn Maggie are about 21 km SE of Nolans Bore but it is likely that there was some "traffic" between them and Anna"s Reservoir and that grazing may have occurred in the Nolans project area, particularly as "Blue Bush Swamp" often holds a reasonable volume of water after major rain events and it is only 11km SSE of Nolans Bore and between Ryans Well and Anna"s Reservoir.

Given the location of natural water sources and the lay of the land, it is therefore possible that at least some of the early European explorers, pastoralists and travellers passed through the Nolans project area in the past. However exposures to these people would also be extremely small due to the brief occupancy of the Nolans project area, if at all.

It was not until the establishment of the stock bore (Nolans Bore) that the pastoralists would have occupied the area for any significant period of time. The development of the stock bore in 1978 and surrounding yards implies that there has been considerable use and occupancy of the area immediately around Nolans Bore since 1978. The author has observed a number of station hands camping at Nolans Bore for short periods. This is sometimes common practice when cattle are yarded for short periods. However in most instances the pastoralists and their workers typically only visit a stock bore every second day or so for a short period of time between yarding and mustering events. Yarding and mustering events on the other hand can last for a day or two and they are often dusty. Based on Arafura"s experience at Nolans Bore, the gamma doses from these activities in the yards is likely to be measurable however the dusty nature of the yard in this area is of more concern and suggests that some may receive modest longer term doses from inhaled dust.

The Bureau of Mineral Resources (BMR) commenced second edition geological mapping of the Reynolds Range Region in 1971 and worked throughout the region until 1976. As part of this work program, detailed 1:25,000 colour aerial photography was acquired over the entire project area by the Commonwealth Government, capturing the Nolans area on 20 April 1971. The aerial photography shows a vehicle track heading south from the old wooden cattle yards about 1.4km north of the current Nolans Bore location. This track crosses North Zone mineralisation and stops on the eastern side of the creek just south of Arafura"s discovery area. The track loops around and does not appear to head further south, suggesting the track might have been used to access a camp site near shade trees. The darker colour tones inside the wooden yard indicate there is no grass, suggesting the yard was recently used in 1971. The use of this wooden yard is strange given the absence of a stock bore near this locality at that time. The evidence suggests that cattle would have grazed across the project area and that the pastoralists may have infrequently traversed this area before 20 April 1971. However the occupation of the area is probably limited because there was no stock bore in the area before 1978 and the main the station track of the time was on the NE side of Nolans Creek linking Aileron Station to Kerosene Well on Pinehill Station.

The data presented on the published geological maps clearly indicates that BMR geologists mapped in the hills around Nolans Bore in 1972 and 1973 (Stewart and Pillinger 1981; 1982). Based on the location of their data points, it appears that a geologist may have walked across, or very close to, the Steinerts prospect. The BMR mapping team did not recognise or make note of what we now know as Nolans Bore-type mineralisation or alteration (Stewart *et al* 1980). The BMR mapping teams probably spent no more than a day or two in the area in 1972 and 1973. The BMR would have camped in the general area for a brief period. The BMR appear to have simply photo-interpreted the Cainozoic geology of the valley floor

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where most of the outcropping mineralisation occurs and concentrated their investigations and field work in the surrounding hills where the radioactivity is generally lower. There was only limited geological and exploration interest in this region prior to 1971 however the BMR"s geological findings sparked considerable academic and exploration interest in rocks of the area, with periodic and more focussed geological investigations since that time.

The BMR mapping and energy interests sparked uranium exploration in the region, which included exploration for sediment-hosted uranium deposits in the peripheral Cainozoic basins. This exploration also included the assaying of ground water from numerous stock and domestic bores throughout the region in 1972 by CRAE (Hughes and O"Sullivan 1973). CRAE"s groundwater uranium and radium data has been publically available for many years, although the report was only electronically scanned in 2000 (NTGS *pers comm*). This groundwater data shows that the area has elevated uranium and radium concentrations.

A number of PhD and post-Doctoral studies have focussed on the geology of this region, and at least one of these geologists (Paul Dirks) would have camped near Nolans Bore as he mapped in the hills to the south of Nolans Bore. In fact the author also drove past Nolans Bore in early 1995 while accompanying a PhD student. This was before the discovery of Nolans Bore.

Outcrops of Nolans Bore type mineralisation were first discovered and mapped by PNC in 1995. PNC spent some time in the area exploring, surveying, sampling and documenting the area but ultimately they relinquished their exploration licence because the uranium results were too low to be of economic interest. NT DME consequently released PNC"s exploration data as open file reports. The NTGS also included PNC"s airborne radiometric survey of the Nolans area in their regional airborne survey data published in 1997.

Arafura was the next entity to explore the geology and mineral potential of the Nolans Bore deposit and first ventured into the area 20 May 1999 (John Goulevitch *pers comm*). Arafura has completed numerous exploration campaigns at Nolans Bore over the years and have occupied and worked around the Nolans Bore deposit for periods of a few days to 11 months every year since 1999. Clearly, Arafura has occupied and worked around Nolans Bore more than anyone else, especially from 2004 onwards.

Both PNC and Arafura stayed at the Aileron Roadhouse and neither has camped at Nolans Bore. One of Arafura"s drilling contractor"s camped near Nolans Bore for three months, however Arafura ensured the radiation levels at the camp were low and typical of regional background levels. Arafura has a Radiation Management Plan and has routinely inducted and monitored worker"s doses and exposure for all significant exploration programs since 2005.

In the past Arafura has routinely contracted Aileron Station to complete earthworks at the Nolans Bore REE deposit and surrounds on it"s behalf. All of these workers have been inducted in radiation OH&S matters and operational procedures. Work-related gamma and dust exposures have been monitored and reported to workers by Arafura"s Radiation Safety Officer, as appropriate. For example, Anthony Pooley (a station hand working on Aileron Station) was inducted by the author in February 2011, and completed all earthworks and site rehabilitation at Nolans Bore as directed by Arafura throughout 2011. Pooley and Aileron station were also aware of and conformed to Arafura"s radiation management and clearance procedures at site. The former landowner (Garry Dann) was inducted in 2005 by John Goulevitch (*pers comm*) prior to his work activities at Nolans Bore for Arafura Resources. Aileron Station changed ownership in mid-2015. As such the current pastoralists and their workers on Aileron Station have not worked for Arafura Resources nor has any of them been inducted.

Anmatjere workers have also been employed at Nolans Bore and all have been inducted in radiation OH&S matters and operational procedures by John Goulevitch or Arafura personnel, with exposures from work-related gamma and dust monitored as appropriate. As part of community awareness the author also demonstrated the natural background radioactivity during early on-ground meetings held in 2006 and 2007. Arafura"s radiation monitoring programs indicate workers exposures are in-line with other radiation workers (Mark Sonter *pers comm*).

The nearest inhabited communities are located about 13-14km southeast at Aileron Station, Aileron Roadhouse and campground, and Alyuen. The nearest downwind communities are at Pinehill Station about 28km northwest, and Laramba and Napperby Station, about 50km slightly north of west.

Hence based on the above, there has only ever been short term and temporary occupancy of the area around Nolans Bore, except for Arafura who have occupied the area for extended periods during its exploration activities. The area has been used as a cattle mustering and water point for about 38 years with evidence of grazing in the area since before 1971.This implies that Aileron Station has also occupied the area for a considerable period but the amount of time and doses are less than Arafura"s.

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Arafura's tenure over the Nolans Bore REE deposit.

Arafura and its predecessor have maintained continuous exploration interest and mineral title rights over Nolans Bore deposit since 25 November 1996. The original title over the area was initially explored for gold by Homestake Gold of Australia Ltd under a farm-in arrangement but most of this activity was NW of Nolans Bore. The exploration focus shifted to Nolans Bore in 1999 after a literature review of the project area by Exploremin Pty Ltd for Norsk Hydro identified a hard-rock phosphate potential at Nolans Bore. Since 1999 most of Arafura"s exploration activity has been concentrated on the Nolans Bore deposit itself or more regionally in exploration for additional near surface Nolans Bore-type deposits.

Exploration Licence 9762 was granted to McCleary Investments PL (ACN 009 627 132) on 25 November 1996 for a period of 6 years, and was transferred to Arafura Resources NL (ACN 080 933 455) on 2 May 2001. Substitution Exploration Licence 23671 was granted to Arafura Resources NL on 8 December 2003 for a period of 4 years in substitution for the combination of pre-existing licences EL 9762 and EL 22384. SEL 23671 was renewed for two two-year periods on the anniversary date in 2007 and again 2009. The Nolans Bore deposit is now covered by EL 28473 which was granted to Arafura Resource Ltd on 5 October 2011 for a period of four years following an exercise agreed between Arafura and the Department of Resources to eliminate a small slither of ground left vacant as a result of the datum shift in 2000. EL 28473 was renewed for a further two year period on 5 October 2015.

Arafura Resources NL split off its uranium exploration assets to form NuPower Resources Ltd with Arafura Resources Ltd (ACN 080 933 455) retaining all mineral rights at Nolans Bore and its immediate surrounds, and retaining non-uranium rights elsewhere. With the demise of NuPower Resources Arafura re-acquired all mineral rights in the project area. The Nolans project area is also covered by parts of the former EL 23571, some of which was used to form the current EL 28498, and EL 29509.

Arafura Rare Earths Pty Ltd (ACN 118 158 893) is a wholly owned subsidiary of Arafura Resources and currently holds four Mineral Lease applications (ML 26659, ML 30702, ML 30704 and ML 30705) over the Nolans project area. These MLs cover the proposed mine site, processing and storage areas and the accommodation village.

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Evolution of Nolans Bore landforms and its current exposure.

The landscape expression around the deposit is subdued and mostly corresponds to a low-lying broad open valley in an area dominated by alluvial sediments and colluvial sheet flow fan sediments of the Kerosene Camp Creek drainage system (Figure 4 and Figure 5). Hill (2009) documented the regolith and landscape evolution of the Nolans Bore area describing a range of regolith materials and landforms associated with the evolution of the region since at least possibly the Mesozoic. Hill (2009) points out that the low-lying setting of the area has persisted since at least the mid-Tertiary, and is largely due to the extensive development of weathering. Hill (2009) indicated that the ferruginous weathered rocks on the nearby bevelled rise summit remnants possibly defines a mid-Tertiary palaeosurface in the area that was stripped and incised by a south to north palaeo-drainage system. This palaeo-drainage system has since been incised and many of its remnants have been topographically inverted by contemporary lateral drainage channels. The observations of Hill (2009) imply that Nolans Bore and its surrounds have been weathering and eroding since the Mesozoic and that this eroded material has been ultimately deposited in the Ti Tree Basin to the north. This regolith assessment was done to determine if there was any potential for downstream secondary deposits.

The basement rocks underlying these regolith units do outcrop in the area but they are typically sparse and limited to isolated occurrences on the valley floor. There is however a reasonable amount of regolith calcrete adjacent to the palaeochannels in this area. There are enough basement outcrops throughout the general area to build up a basic geological framework of the area. However most of the detailed geological understanding of the basement rocks and the deposit has come from detailed observations of material derived from costeans and drilling at Nolans Bore.

Figure 4: Aerial view looking northwards and showing most of the Nolans Bore deposit on March 2011. The image is unusual because the region is not usually this green and it was captured during a major resource definition drilling program with six active drill rigs on site. Drilling data demonstrates that the brighter green areas in the central part of the image have significantly thicker soil cover and conceal underlying palaeochannels that join at the cross roads in the centre of the image. Note the sumps dug beside each drill hole are part of Arafura"s approved Radiation Management Program and are purposely dug to trap and bury drilling returns thereby minimising the spread of potentially radioactive material. All excess RC drill samples (white bags) are collected, irrespective of their radioactivity, and buried in trenches in the palaeochannel on top of the deposit in accordance with Arafura"s approved MMP. Areas of outcropping mineralisation occur on either side of the palaeochannel. Mineralisation also occurs beneath the palaeochannel.

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Figure 5: Image looking to the NE across the North Zone of the Nolans Bore deposit in the valley floor. This image was taken in March 2008 towards the end of a major RC drilling campaign and the arid appearance is more typical of the region than Figure 4 above.

The Nolans Bore prospect was discovered by PNC in 1995 during ground-based reconnaissance and mapping of exploration targets identified in their 1994 regional airborne radiometric survey of the region. PNC mapped and identified most of the mineralised outcrops in the vicinity of Nolans Bore and completed ground based radiometric surveys and sampling.

As noted above, Arafura first ventured into the Nolans Bore area on 20 May 1999. Examples of outcropping mineralisation at that time are shown in Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10. Arafura"s first historic photograph of the stock bore is also shown in Figure 11 and a recent example of the stock bore from a different angle is shown in Figure 12. While outcrops of mineralisation are not evident at the bore itself, small boulders of mineralisation and calcrete are present inside, and adjacent, to the original steel yards shown in Figure 11. Small outcrops of mineralisation were mapped by PNC immediately east of the bore and subsequent exploration drilling by Arafura has demonstrated that the original stock bore was drilled into a mixture of mineralisation and country rocks. The soil cover around the stock bore is mostly thin (0.15-1m) and overlies weak to anomalously radioactive calcrete.

Small outcrops of mineralisation also occur in the yards to the NE and SE of the bore. A prominent example of naturally outcropping of mineralisation occurs southeast of Nolans Bore beside the station track (Figure 13) and demonstrates the thin skeletal soil cover in this area. The amount of mineralisation exposed at this location (Figure 13) and elsewhere in the yards is not static and varies depending on the amount of sediment and dusty soil cover. This outcrop in Figure 13 occurs at the SW end of discontinuous outcrops in a 100m long NE-SW trend across the cattle yards in Arafura"s pre-2004 mapping of the deposit. Some of these outcrops are no longer visible and have since been covered by soil as part of Arafura"s rehabilitation of drilling areas.

Mineralised outcrop was discovered at the surface during exploration mapping in 2005 (Figure 14) and this is currently the western most example of Nolans Bore-type mineralisation. This outcrop is about 60m long and 1-3m wide and is referred to as the Steinerts prospect. Detailed sampling and chemistry has not be done at the Steinerts prospect but the observed mineralogy and measured dose rates of up to 18 µSv/h measured on the rock surface are similar to Nolans Bore.

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Figure 6: Arafura"s initial "discovery" outcrop area. Patchy outcrops of mineralisation occur over a 60m x 20m N-S area on the western side of the creek. Photograph taken by John Goulevitch 20 May 1999, looking WSW at 318615E 7502020N. Note this is within an area of naturally high background radioactivity on the W side of the creek.

Figure 7: Arafura"s initial "discovery" outcrop area. Patchy outcrops of mineralisation occur over a 60m x 20m N-S area on the western side of the creek. Photograph taken by John Goulevitch 20 May 1999, looking E towards 318612E 7502000N. Note this is within an area of naturally high background radioactivity on the W side of the creek.

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Figure 8: Example of poorly outcropping mineralisation (dark brown rocks near hammer and about 1m to the right) in an area dominated by colluvial red sandy soils and quartz vein detritus at 318469E 7501950N. Photograph taken by J Goulevitch 20 May 1999. Note this is within an area of naturally high background radioactivity on the W side of the creek.

Figure 9: Example of poorly outcropping mineralisation in an area dominated by thin skeletal colluvial red sandy-gravelly soils and quartz vein detritus. Photograph taken by J Goulevitch 20 May 1999, at 318535E 7502075N looking WNW. Note this is within an area of naturally high background radioactivity on the W side of the creek.

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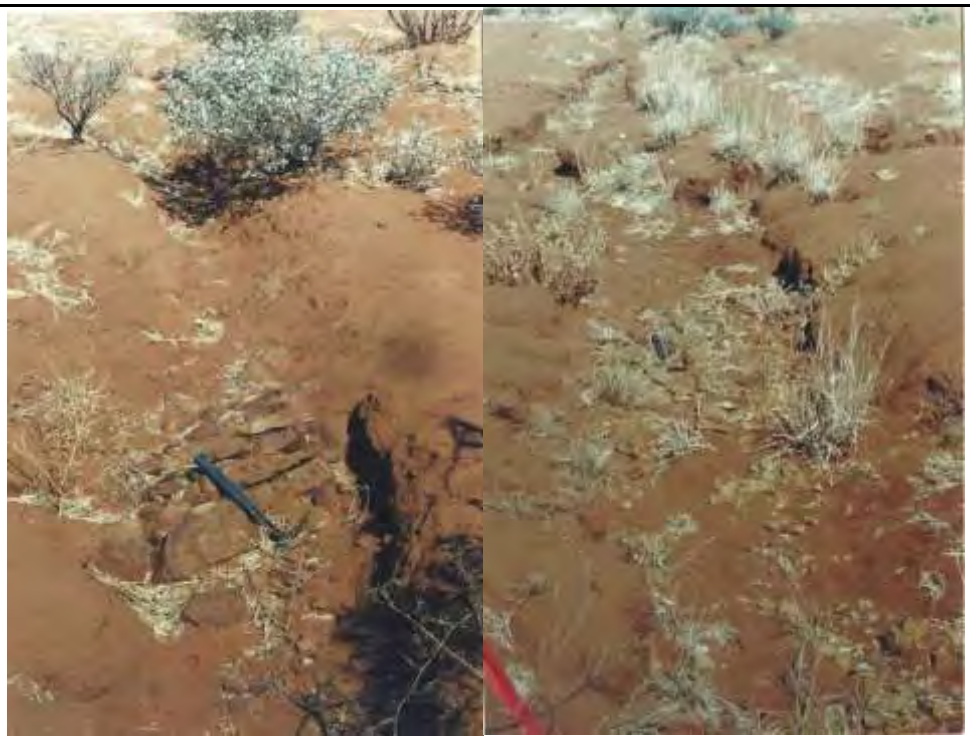

Figure 10: Outcropping mineralisation exposed in a natural erosional gutter prior to Arafura"s disturbance. Photographs taken by J Goulevitch 20 May 1999 and demonstrate a very thin colluvial soil cover at 318535E 7502075N. Note this is within an area of naturally high background radioactivity on the W side of the creek.

Figure 11: Nolans Bore and cattle yards. Photograph looking SW and taken by J Goulevitch 21 October 1999. Outcrops of mineralisation were found in the yards near this location.

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Figure 12: Nolans Bore and cattle yards. Image looking NE and taken 19 March 2016.

Figure 13: Outcropping mineralisation exposed beside the track to Nolans Bore at 319263E 7501620N, about 200m SE of the stock bore. Photograph taken in September 2008 looking N across the cattle yards. A maximum of about 10m^2 of mineralisation has been observed at this location over the past 15 years. This outcrop was not mapped by PNC in 1995 but was sampled by the author for petrology in 2000 (NTGS data). The dose rate measured at this location varies from about 10-15 µSv/h depending on the amount of transported soil cover over this outcrop.

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Figure 14: Outcropping Nolans Bore-type mineralisation at 317005E 7502527N about 2.2km NW of Nolans Bore. Photograph looking SW and taken by J Goulevitch in 2005 shortly after discovery.

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Background to Radioactivity

The Nolans Bore REE deposit occurs in a geological region known to contain rocks with elevated uranium and thorium concentrations and above average natural background radiation (published BMR/GA and NTGS data and maps). As a consequence of the above average U and Th concentrations in the rocks, the region also has soils with above average U and Th. In addition naturally high levels of uranium also occur in groundwater (*eg* Hughes and O"Sullivan 1973; unpublished NTG data; Graham Ride *pers comm;* unpublished Arafura data). These natural phenomena have all been strong drivers for uranium exploration in the region since the 1970"s. In fact Nolans Bore was discovered by following up and locating the source of an anomalous airborne radiometric signature.

While U and Th are the main focus of this report, it is acknowledged that there are other radioactive elements in the natural environment. For example, an isotope of potassium (K^{40}) and the daughter products of the U and Th decay chains are also present, but these are only briefly discussed here. This is because the amount of potassium is broadly similar to numerous other granitic terrains in the world, albeit slightly elevated and above crustal average. Although K^{40} adds to the overall radioactivity of the area, the amount of K^{40} is not unusually considered a radiological risk due to its low dose conversion factor (Jim Hondros *pers comm*), especially when compared to anomalous amounts of U and Th. With respect to other naturally occurring radio-isotopes, only a limited number of detailed radionuclide analyses for the U and Th decay chains have been done to date (*eg.* Collier *et al* 2007; plus several other unreferenced ANSTO studies on raw and processed Nolans Bore material). A number of comprehensive radionuclide analyses were originally planned to further document environmental uptake following on from the mid-2015 geochemical study (Dean and Grose 2015). However sampling did not occur due to the drought conditions and the lack of quantities of grass at most sites in late-2015, and also in early 2016 (eg Figure 12).

Secular equilibrium considerations

Secular equilibrium has been assumed and is described below. Secular equilibrium occurs when the activity concentration of all decay products are equal to the activity concentration of the head of the decay chain. As a general guide it can be assumed that the decay products of the U and Th chains are in secular equilibrium with their respective head of chain in fresh unoxidised rock. Research and numerous comprehensive radionuclide analyses has demonstrated that this is often the case in fresh "old" rocks. Hence secular equilibrium is a reasonable assumption. However geological processes can upset the decay chain equilibrium and effectively reset the clock.

Secular equilibrium occurs because the U and Th decay products remain trapped inside the host U- and Th-bearing minerals for extended periods of geological time. Hence the specific isotope decay system inside the mineral remains "closed" to external influences and the entire decay chain equilibrates with time. This is also the basis of U-Th-Pb geochronology which calculates ages based on the time it takes for the concentration of the stable daughter end-product to grow in. Hence for published age dates the "disturbance" and "concordance" must be assessed for each analysis. Furthermore the geological "meaning" of each analysis must be assessed and placed into a geological context (eg Huston *et al* in press).

There are also examples where U and Th secular equilibrium is not reached in fresh rocks. For example, U and Th secular equilibrium does not occur in "very young" igneous rocks and magmas where the daughter products have not had enough time to reach equilibrium. This phenomenon does not apply to the Nolans project area because the igneous rocks and the high temperature melting events are geologically "old" (more than about 1500 Ma). Furthermore the youngest major geological/tectonic and hydrothermal fluid event with the potential to disturb and "reset" the U and Th isotope system in this area is also "old" (more than 300 Ma, Schoneveld *et al* in press, Huston *et al* in press). Hence in most cases the U and Th bearing minerals in fresh rocks from the project area will have essentially been closed for a very long period of time. Secular equilibrium is therefore a reasonable assumption for the fresh rocks in the Nolans Project area.

An entire life time head-of-chain through to stable daughter product equilibrium should not be discounted in "fresh" rocks and disequilibria certainly occurs, even if the rock is now in secular equilibrium. For example, significant common Pb (Pb^{204}) is sometimes measured in minerals as part of Sensitive High Resolution Ion-microprobe (SHRIMP) U-Pb geochronology. This phenomenon has been measured in "fresh" rocks at Nolans Bore and surrounds (eg Worden *et al* 2008, Huston *et al* in prep) and typically occurs in a small proportion of the U- and Th- bearing minerals that have been extracted from the "fresh" rocks (zircon, monazite and allanite in these studies). The presence of significant Pb^{204} indicates these minerals have probably interacted with the external environment. Hence the isotopic system in the mineral may be partially disturbed (recently or sometime in the past) and the three radiogenic Pb isotopes (Pb^{206}, Pb^{207}, and Pb^{208}) may also have been disturbed and not be in equilibrium with their respective head of chain since they were

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formed. The tiny cracks observed in some minerals also provide a mechanism for the release of radon and thoron gas from minerals even in "fresh" rocks. The release of thoron and radon is clear evidence for non-secular equilibrium and their proven emanation from Nolans Bore-type mineralisation (*eg*. Dean and Grose 2015) and other rocks elsewhere is definitive evidence for non-secular equilibrium. However despite the above, most fresh rocks are essentially in secular equilibrium or very close to it.

U and Th decay chain disequilibria typically occurs in regolith settings (*ie*. **everything** between fresh rock and the air/land surface). This occurs because some U- and Th bearing minerals break down during weathering, and uranium and thorium or their daughter products are mobilised and re-deposited. One of the more common examples of this occurs during the formation of secondary U-bearing minerals as surface coatings on weathered rocks. This is a natural ongoing geological and weathering process which leaches uranium from oxidising rocks and re-precipitates the labile components transported by oxidised surface and ground water. The formation U-bearing minerals in regolith carbonates and also in iron and silica cements are other common examples. Because U can be mobilised by oxidised water, the ground water itself is typically not in equilibrium due to complex interactions with the rocks and regolith (and biosphere) and the short timeframes associated with migrating ground water.

The same principles also apply to plants as they take up and selectively consume or store nutrients and other elements from the environment. Biogeochemical processes can preferentially select particular elements (or chemically equivalent elements) and take them up through a number of complex biogeochemical pathways from various sources (ie. different rocks, regolith, groundwater, rain and air). The strong chemical similarities and elemental associations that exist between like-elements and the relatively "short" timeframes mean that biogeochemical processes typically lead to selective (and accidental) biogeochemical uptake. Clearly the selective biological uptake leads to non-secular equilibrium between U and Th and their daughter products. For example, Ra readily substitutes Ca and Sr and in nature. This leads to non-secular equilibrium as Ca is an essential element required for plant growth (Dunn 2007) and consequently Ra is often preferentially taken up by plants. Secondary carbonates and cements are also precipitated from oxidised ground waters also often contain significant Ra (eg Ramsar).

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Regional geology and background

The Nolans Bore deposit is hosted by Proterozoic metamorphic rock units of the Aileron Province, Arunta Region, Northern Territory. The host rocks are sedimentary and igneous rocks that have been subjected to medium pressure-high temperature metamorphism during the c1550-1600 Ma Chewings Orogeny with most of primary rock types in this area being older than about 1770 Ma. A more detailed discussion of the regional geology in provided in Stewart *et al* (1980) and Hand and Buick (2001). The geology of the Nolans Bore REE deposit is geochemically and mineralogically distinct and it is the only REE deposit of its type known in the world. The minimum age of primary mineralisation has been recently dated at about 1525 Ma and follows the emplacement of pegmatite at c1550 Ma (Huston *et al* in press). The geological history of deposit and the surrounding rocks is complex, having been partially overprinted and reworked by subsequent geological events which includes deformation and remobilisation during the Devonian-Carboniferous Alice Springs Orogeny (Schovenveld *et al* in press; Huston *et al* in press) and a prolonged period of intense weathering, oxidation and erosion since about the Mesozoic (Hill 2009).

Nolans Bore-type mineralisation is significantly enriched in U and Th as well as REE, P, Sr and F compared to the average UCC. Bodies of Nolans Bore-type mineralisation are known to occur over an area of about 3.5km by 4km. However most Nolans Bore-type mineralisation is concealed by superficial sedimentary deposits and has only been discovered by Arafura"s exploration drilling around Nolans Bore. Additional mineralisation of this type is considered highly likely in this general area. The known mineralisation is most concentrated in an area of about 1.2km by 1km referred to as the Nolans Bore REE deposit.

As noted above, the mineralisation and host rocks at the Nolans Bore deposit are poorly exposed and there is typically a thin veneer of colluvial and alluvial sediments with localised patchy surface outcrops. Consequently due the elevated U and Th in the mineralisation, the area around the Nolans Bore deposit is naturally radioactive and has the highest natural gamma radiation levels in the project area, but nhis is ionly evident in areas of very thin cover. Exploration has shown that there are also a number of other locations in the general Aileron-Reynolds region where anomalously radioactive U- and Th-rich rocks and soils are exposed at the surface with gamma dose rates similar to those measured at Nolans Bore.

It has been known for many years that the majority of Proterozoic granites in Australia have characteristically high levels of K, Th and U (*eg* Wyborn *et al* 1992, McLaren *et al* 2003). For example, many of the Proterozoic granites in the Reynolds Range region contain elevated K, Th and U (Stewart *et al* 1980). The K contents in many of the granites are high but they are not that unusual and within expected ranges for these rock types elsewhere in the world. The elevated U and Th contents on the other hand are distinct and well above average rock types (*eg*. McLaren *et al* 2003). More recent work by Arafura and others has shown that many geological units within the greater Reynolds Range region (granite, pegmatite, metamorphosed sedimentary rocks, alluvium and colluvium) exceed the average values for the Upper Continental Crust (UCC). The UCC averages about 2.7±1.2 ppm U and 10.5±2.0 ppm Th (Rudnick and Gao 2005, 2σ errors).

Arafura has explored the Aileron-Reynolds region since 1999 and the author has worked in the region since 1995. Consequently Arafura has developed a very large in-house geological knowledge base and geochemical database that significantly contributes and adds to the understanding of U and Th throughout the region. The database includes detailed closely-spaced, low-level regional airborne radiometric surveys and extensive on-ground reconnaissance exploration mapping, sampling and radiometric measurements. In addition to this Arafura has drilled and radiometrically logged about 1150 exploration and resource definition drill holes in and around the Nolans project area. This includes drilling at Nolans Bore and also at the Goanna, Steinerts and Mulga prospects and in the steralisation area to the east of the deposit. All of these drill holes are within about 3km of Nolans Bore itself. Arafura has analysed a total of about 30,000 rock samples from these drill holes and has also visited more than 5200 surface locations throughout the general Aileron-Reynolds project region. Arafura has sampled and assayed a mixture of rocks, soils, streams and vegetation samples from more than 2100 sites in the project area. Arafura has also successfully explored and drilled for water in the region and has assayed groundwater and surface run-off throughout the project area.

The amount of U and Th in any given rock varies for many geological reasons with most rock types in the Reynolds Range region typically containing less than about 25 ppm U and 100ppm Th (Stewart *et al* 1980, NTGS and GA databases; unpublished Arafura data). The mineralisation at the Nolans Bore REE deposit can have up to a maximum of about 3500 ppm U and 4.4% Th although most of the mineralisation contains less than about 700ppm U and 1% Th. However as noted above, numerous rocks and soils in the region also contain elevated U and Th. For example some of the granites, pegmatites and metamorphic rocks that crop out in the Aileron-Reynolds project area also significantly exceed the average UCC with localised individual rocks assaying up to about 1700 ppm U and 2300ppm Th (Thevisson 1995; unpublished Arafura

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exploration data). Most of these anomalous occurrences of U and Th are restricted to small localised outcropping areas but some of the more unusual geological rock units have outcrops exceeding about 1000m^2 in size.

Some of the country rocks that surround and host the REE mineralisation at Nolans Bore have naturally elevated U and Th contents and significantly exceed the average UCC values. These rock types are geologically unrelated to Nolans Bore-type REE mineralisation or its associated alteration, and they are simply typical examples of the naturally occurring metamorphic and igneous rock types found in this general area. This means that the natural background radioactivity of the host rocks also varies significantly, and in places Nolans Bore mineralisation and country rocks can have similar radioactivity. Fortunately the mineralogy and characteristics of Nolans Bore-type mineralisation and its associated alteration is typically distinct so one does not have to rely on radiometrics alone to differentiate mineralisation from country rocks.

Monazite, as well as other Th- and or U- bearing minerals such as zircon and xenotime also commonly occur as accessory or trace minerals in many igneous and metamorphic rock units throughout the Reynolds Range region. Allanite also occurs in some metamorphic and granitic rocks in this region but it is not common and its distribution is restricted to specific rock types and areas. Exploration and academic studies have demonstrated that monazite can locally be a significant component in some rocks in this region and a number of the radiometric exploration targets in the region are related to significant accumulations of monazite in rocks that are unrelated to Nolans Bore–type mineralisation.

Monazite, zircon and xenotime often concentrate in colluvial and alluvial sediments because they are heavy minerals which are more resistant to natural mechanical and chemical weathering processes than the other more labile components which are broken down and winnowed out during weathering and deposition. This is the case in the Aileron-Reynolds Range where large areas superficial sedimentary deposits yield alluvial and colluvial sheet flow sediments and soils with above crustal average Th and U contents.

Secondary uranium minerals occur throughout the region (*eg* Thevisson 1995) and a large proportion of the elevated U concentrations found by exploration companies are related to secondary uranium minerals. However with the exception of patchy U enrichment in calcretes and pedogenic carbonates most of the secondary uranium minerals occur as highly localised surficial accumulations on weathered granites and gneisses.

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Uranium and thorium at Nolans Bore

The amount of Th is always greater than the amount of U in Nolans Bore-type mineralisation, and the U and Th grades are related to REE grades (Figure 15). The highest grade REE mineralisation does not crop out at Nolans Bore but is known from Arafura"s resource definition drilling. Geological modelling has shown that the highest REE grades represent only a very small proportion of the total identified Mineral Resources at the Nolans Bore REE deposit; about 0.05% and 0.1% of the 2015 block model exceeds 10% and 8% TREO, respectively. The plus 10% TREO blocks average 527 ppm U (and about 7180 ppm Th by correlation) and the blocks above 8% TREO average less. The high grade REE mineralisation is largely localised to three small zones in the Nolans Bore deposit. A small isolated zone of moderately high grade mineralisation (assays>10% TREO, and up to 1560 ppm U and 2.74% Th) occurs at depth in the northern part of the Southeast Zone. While this material is yet to be cored, its mineralogy and whole rock chemistry is similar to the two larger, but still relatively small, zones of high grade mineralisation that have been extensively drilled in the North Zone (individual assays up to 50% TREO).

Arafura"s extensive geological and geochemical database demonstrates there is typically a good geochemical relationship between P, REE, U and Th in the mineralisation at Nolans Bore (Figure 15). Figure 15 demonstrates there is a good linear relationship between U and Th in the mineralisation although the Th/U ratio varies from about 5-40. The difference in the Th/U ratio appears to be mineralogical and is not related to the REE grade. The principal thorium and uranium minerals at Nolans Bore are in decreasing order of abundance, fluorapatite, allanite, monazite, and (thorite and thorianite) with detailed petrology and QEMSCAN studies indicating that most of the Th and U is hosted in monazite, allanite, thorite and thorianite (phosphate, silicate, silicate and oxide respectively). A number of subordinate Th and U minerals have also been identified (eg Huston *et al* in press) but these appear to be localised and not commonly observed throughout the deposit. The main REE minerals are fluorapatite, allanite and monazite, with a number of other phases also identified. For example, the oxidised high grade REE mineralisation also contains fine grained secondary crandallite group minerals and shows a distinctly different P/REE ratio (Figure 15).

There is also a very strong and consistent geochemical relationship between the individual REE in Nolans Bore-type mineralisation, and although there is some variability, Nolans Bore-type mineralisation has a remarkably similar and consistent REE fractionation pattern (Figure 16). In relative terms, the degree of Th enrichment at Nolans Bore is similar to that of the LREE (*ie* occurs because Th substitutes for Nd in nature) and the amount of U enrichment is similar to that of the middle REE. This mirrors the relationships reported by Hussey (2003) in the eastern Arunta Region REE prospects where LREE enriched prospects had chemical assays with Th>U whereas HREE prospects had U>Th. This occurs because U minerals are typically enriched in middle REE and vice versa.

Figure 16 also demonstrates that the Nolans Bore deposit is clearly enriched in the light rare earth elements La-Sm (LREE) inclusive with the average mineralised rock containing about 200 times the crustal average. Eu is also significantly enriched in Nolans Bore compared to most LREE deposits. Furthermore the REE fractionation pattern maximum occurs at Nd and Pr which is atypical of LREE-enriched deposits and prospects world-wide. This atypical relationship is due to the unique mineralogy and conditions that formed the Nolans Bore deposit. The high market demand for Nd-Pr as magnet feed and their strong enrichment and REE mix at Nolans Bore is the prime reason that Nolans Bore is being considered for development.

Exploration and resource definition drilling has shown that in most cases Nolans Bore-type REE mineralisation, and its associated U and Th, is confined to discrete veins. This means there is typically an abrupt drop in grade as one passes from the mineralisation into the adjacent country rock. This also means that it is very easy to detect where the REE mineralisation is by measuring the associated radioactivity. Extensive geochemistry has demonstrated that there is limited dispersion of REE mineralisation (and its associated U and Th) into to surrounding country rocks. While some dispersion does occur, the mineralisation as a whole is highly localised and associated with obvious and distinct mineralogy which is recognisable and typically easy to identify both visually and by radiometrics.

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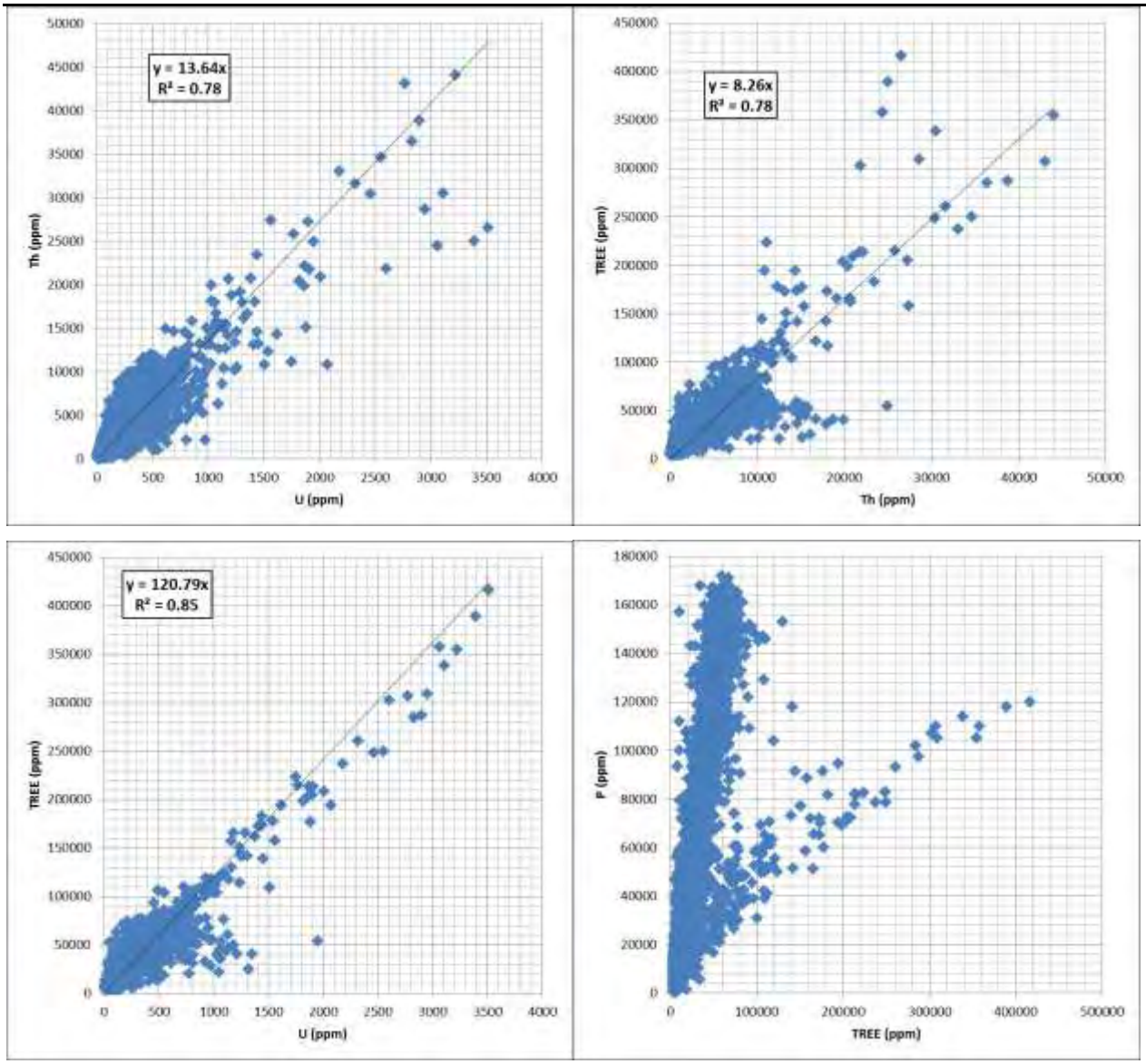

Figure 15: REE, U, Th and P relationships showing all drill core and RC chemical assays of Nolans Bore mineralisation. These plots show a good correlation between REE, U and Th. Subtle differences occurs in the various parts of the deposit but in general there is are remarkably consistent relationship despite the admixture of different rock types and a variety of minerals. The REE also strongly correlates with P grades. This is because most of the REE, Th and U are associated with phosphate minerals, although the highest REE grades (>~10% TREE) clearly have a different TREE/P ratio and reflects a different mineralogy in the localised high grade zones. Similar relationships also exist for Ca and Sr (not shown) because the dominant mineral species is apatite.

The U and Th grades of the 2012 and 2015 Mineral Resources estimates are shown in Table 3. Th has not yet been estimated into the 2015 model, however based on the linear relationship shown in Figure 15, the Measured and Indicated Resources should still be around 2800 ppm Th, or thereabouts. The differences in the two models are largely due geometric differences, the amount of waste rock included within the mineralised envelope and the estimation parameters used to populate the block model.

The modelled volumes of the various rock types at Nolan Bore are shown in Table 4.The volumes are based on the LOM pit in the NDR case and take into account all of the identified mineralisation in the 2012 Mineral Resource. Note the volume of mineralisation in the 2015 Mineral Resource is slightly bigger, about 20 Mm^3, meaning the other rock units might occupy slightly less in the next pit model. However most importantly for the EIS both Mineral Resources are encapsulated inside the all-encompassing and much bigger “Radioactive Rock” (RAD) unit which was modelled in 2015 to determine to amount of radioactive rock within the LOM pit as part of a waste characterisation study. The RAD unit was modelled conservatively to obtain the biggest possible volume and often included significant intervals of material that is below 1 Bq/g and therefore not radioactive.

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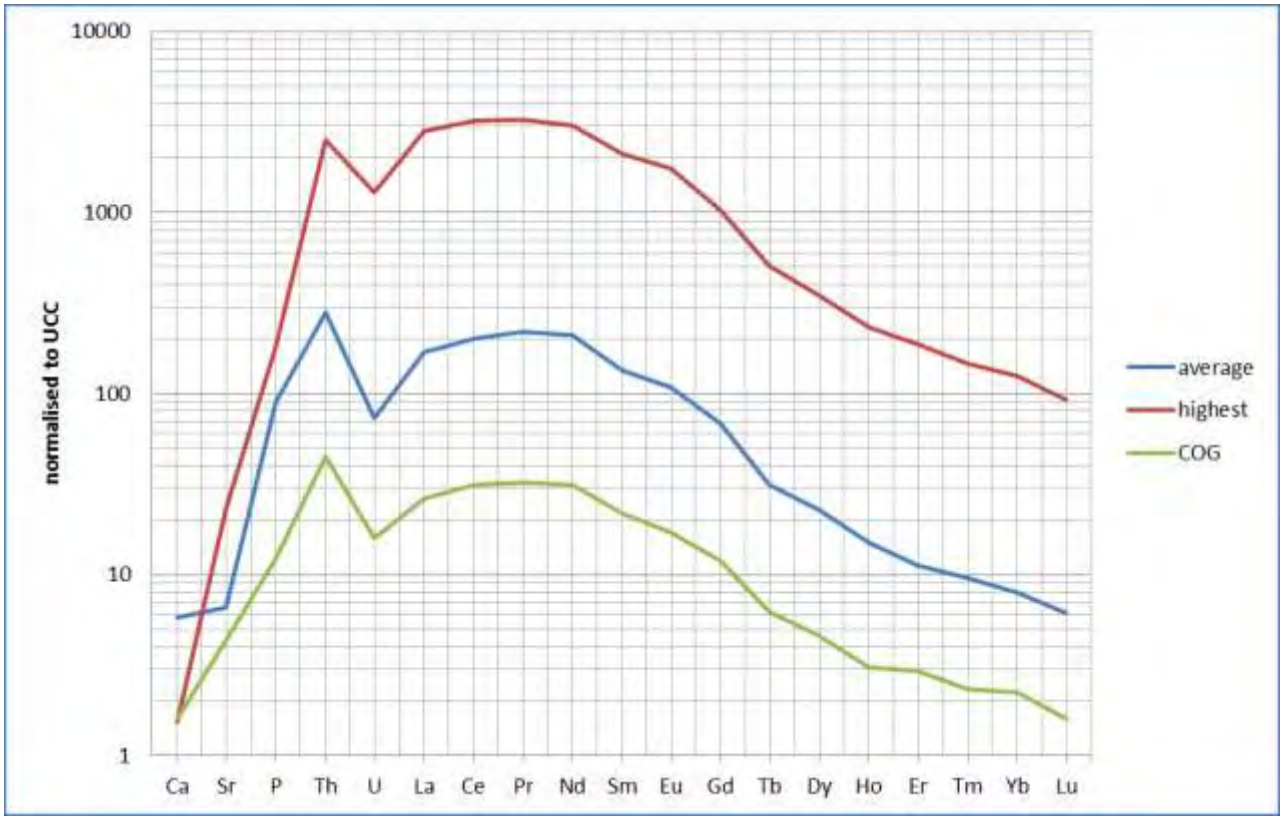

Figure 16: Composition of Nolans Bore-type mineralisation normalised to the average Upper Continental Crust, UCC (Rudnick and Gao 2003). The average of all mineralised samples is plotted in blue as well the highest REE grade sample (50% TREO) in red and a representative sample whose composition matches the 0.5%TREO cut-off grade (COG) used in the geological modelling of the deposit in green. Clearly these REE fractionation patterns closely mirror one another despite a difference of about two orders of magnitude.

Table 3: The average U and Th grades for the Nolans Bore REE deposit. The 2012 Mineral Resource estimate was done by AMC Consultants and employed a 1% REO cut-off exclusive of Y_2O_3 whereas the 2015 Mineral Resource estimate was completed in-house by the author and adopted a 1% TREO cut-off. The estimated resources are based on the same drilling and geochemical data but the geological model was updated and revised for the 2015 estimate. Note Th has not been estimated into the 2015 model.

	2012 Estimate		2015 estimate	
Resource Category	**U**	**Th**	**U**	**Th**
	ppm	ppm	ppm	ppm
Measured	221	2752	246	na
Indicated	163	2800	197	na
Inferred	142	2237	165	na
Total	159	2538	189	na
M&I	173	2792	204	na

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Table 4: Approximate volumes of various rock types in the LOM pit based on the NDR case and the 2012 Mineral Resource. The mineralisation has an average density of 2.74 t/m^3. All country rock units have been assigned an average density of 2.65 t/m^3. This is probably conservative given that some mineralisation and rock types with higher average densities are also included in each country rock unit.

Object	Upper Surface	Volume (Mm^3)	Approx Tonnes (Mt)	Percentage of LOM Pit (vol%)
LOM Pit	Base of soil	138	367	
LOM Pit	Topography	140	370	
Soil	Topography	2	3	
Mineralisation	Base of soil	17	47	12
Pegmatite	Base of soil	21	56	15
Schist	Base of soil	18	48	13
Gneiss	Base of soil	82	217	59
Radioactive Rock*	Base of soil	76	205	55

* Note the "Radioactive Rock" unit encompasses a variety of rock types and includes mineralisation.

The statistics for geochemical assays of mineralisation, waste rock as a whole, and the various major lithological subdivisions at Nolans Bore are shown in Table 5, Table 6 and Table 7, respectively. These summaries are based on the actual assay results rather than the block model values. Hence they are more likely to be representative of the entire sample population statistics because block modelling tends to average out both high- and low-grade sample populations.

The Chemically Calculated Activity (CCA) concentration values shown in the Tables below are calculated from the U and Th compositions. The CCA is an important factor to consider in potentially radioactive rocks and has been used as a guideline to assess if the material is radioactive or not. Material that exceeds 1 Bq/g is described as radioactive and needs to be managed once it is mined. Material disturbed by mining that is less than1 Bq/g is not considered radioactive. The CCA was used to model the RAD object and an overly conservative value of 0.8 was typically used to define and geologically model the object. The RAD unit is based on all available CCA values and derived correlations with gamma data from downhole surveys and activity measurements on recovered samples

Waste rock modelling indicates that about 55% of the NDR case LOM pit is likely to be above 1 Bq/g and therefore radioactive. This indicates that about 45% of the LOM pit is not radioactive (Table 4). Waste rock modelling also shows that in addition to the mineralisation, most of which is radioactive, about half of the surrounding host rocks are also radioactive. This modelling therefore shows there is ample benign material that will be mined in the LOM pit to cover and shield radioactive waste rocks and tailings storage facilities.

It should be pointed out that not all drill material has been assayed at Nolans Bore and the assay samples in Arafura"s database are especially biased towards rocks that exceeded background gamma radiation levels. Furthermore the assays are often a combination of various rock types, particularly in RC drill samples. As such localised narrow veins of mineralisation, or RC samples marginal to mineralised bodies can show up as low- to medium grade REE mineralisation. It is therefore worth noting that the rock type described in the database is in most cases the dominant unit, however in rare cases the assays suggest that the mineralisation and the country rock units might be incorrectly assigned.

Despite the assays being biased towards radioactive rocks, at least 50% of the pegmatite assays are below 1 Bq/g and not radioactive. This is an important finding because until recently it was thought that a higher proportion of the pegmatite unit would be greater than 1 Bq/g when in fact it might be even less than 50% due to Arafura"s radioactive sampling bias. Almost 80% of the gneiss is not radioactive and as anticipated less than 20% of the schist is radioactive in the LOM pit.

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Table 5: Geochemical summary of 10,098 x 2m composited assay values used in the 2015 mineral resource estimate. The 10,098 mathematically composited samples include all assay samples that occur inside the geological bodies (ALLMIN) used to estimate the grade of mineralisation at Nolans Bore. Compositing is typically done for resource estimates because it ensures an unbiased equal-length weighting of all assays across the deposit. The population statistics closely matches that of the raw assays. The CCA is strongly correlated with TREO deposit wide. Individual zones of mineralisation are often even more strongly correlated.

Summary statistics	**TREO**	**P_2O_5**	**U**	**Th**	**CCA**
	ppm	ppm	ppm	ppm	Bq/g
Mean	28547	120904	178	2643	12.80
Standard Deviation	25191	97451	181	2580	12.41
Minimum value	114	573	0.75	4.21	0.03
5.0 Percentile	1976	6107	11.8	146	0.78
10.0 Percentile	4427	15324	24.8	337	1.72
20.0 Percentile	8124	32074	45.6	653	3.24
30.0 Percentile	11958	48111	66.2	980	4.78
40.0 Percentile	16439	67636	93.0	1350	6.66
50.0 Percentile (median)	22124	93931	127	1865	9.11
60.0 Percentile	29032	123346	169	2500	12.3
70.0 Percentile	37464	163549	224	3314	16.1
80.0 Percentile	48136	212731	294	4420	21.5
90.0 Percentile	61445	280648	396	6097	29.5
95.0 Percentile	70109	315236	483	7337	34.8
97.5 Percentile	77676	334251	557	8235	38.9
99.0 Percentile	90254	351783	689	9734	45.9
Maximum value	425534	384086	3220	44000	216.25
Correlation Coefficient	**TREO**	**P_2O_5**	**U**	**Th**	**CCA**
TREO	1.000	0.822	0.948	0.913	0.932
P_2O_5	0.822	1.000	0.754	0.819	0.818
U	0.948	0.754	1.000	0.910	0.939
Th	0.913	0.819	0.910	1.000	0.997
CCA	0.932	0.818	0.939	0.997	1.000

At least some of the soils at Nolans Bore will also be radioactive however the proportion of radioactive soil has not been estimated or modelled at Nolans Bore because there are no systematic soil assays across the entire deposit area. The soils are typically skeletal and range from less than 30cm to a maximum of about 4-5m in the north-south palaeochannel across the top of the Central Zone. The average soil thickness at Nolans Bore is around 1.3m however this thickness is probably overestimated because depths have been derived from metre-based intervals and RC drilling returns. An initial estimate of the soil compositions can be made by using the environmental soils. The first drill metre assays are also informative but unfortunately many of these are RC samples and include at least some of the underlying bedrock. The regional soil compositions are reasonably close to the stream sediment compositions as the colluvial and alluvial sediments are derived from similar source areas.

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Table 6: Geochemical summary and statistics of the waste rocks showing an analysis of all assays that occur within the proposed LOM pit for NDR case and outside of the identified mineralisation in the 2015 Mineral Resource model. This summary is based on 12,913 assays of varying sample length. This dataset also contains small isolated intervals of medium- to high-grade mineralisation that were not identified as being part of a larger mineralised body.

Summary Statistics	TREO	U	Th	CCA
	ppm	ppm	ppm	Bq/g
Mean	3459	19.1	321	1.52
SD	7262	45.5	751	3.53
Minimum value	16	0.03	0.03	0.00
1%ile	149	1.05	9.35	0.06
5%ile	272	1.75	18.0	0.11
10%ile	353	2.36	23.3	0.14
20%ile	532	3.25	34.1	0.19
25%ile	642	3.75	41.5	0.23
30%ile	769	4.20	51.4	0.28
40%ile	1082	5.45	79.0	0.41
50%ile (median)	1469	7.05	121	0.60
60%ile	1992	9.41	177	0.84
70%ile	2686	13.2	247	1.16
75%ile	3132	16.0	297	1.37
80%ile	3799	20.0	353	1.65
90%ile	6169	34.8	596	2.73
95%ile	12632	66.7	1120	5.25
97.5%ile	23813	133	2290	10.5
99%ile	43992	243	4268	20.1
Maximum value	79442	1320	16100	80.9

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Table 7: Geochemical summary and statistics of the waste rock subdivided into Pegmatite (PEG, top left), gneiss (GNE, top right), schist (SCH, bottom left) and mineralisation (MIN, bottom right) in Arafura"s database. Note not all material has been assayed and assay sample lengths are variable. The data included here is not exhaustive and is based on a complex query to interrogate the database. Assays and lithological boundary overlap issues means that the assignment is not always correct in this query. For example, 8% TREO is obviously medium-high grade MIN and not gneiss. Furthermore the assays are often a combination of rock types. This dataset also contains small isolated intervals of medium- to high-grade mineralisation that were not identified as being part of a larger mineralised body.

	TREO	Th	U	CCA
	ppm	ppm	ppm	Bq/g
Mean	2501	300	8.83	1.31
SD	2894	327	14.7	1.45
Minimum value	34	1.80	0.35	0.01
1%ile	173	13.4	1.10	0.08
5%ile	390	32.9	1.7	0.17
25%ile	1052	122	3.20	0.54
50%ile (median)	1779	221	5.10	0.96
75%ile	2987	370	8.75	1.60
80%ile	3388	423	10.4	1.83
90%ile	4845	580	16.7	2.54
95%ile	6213	780	27.0	3.44
99%ile	13037	1516	69.4	7.00
Maximum value	40527	4420	248	20.8

	TREO	Th	U	CCA
	ppm	ppm	ppm	Bq/g
Mean	2010	156	12	0.78
SD	3831	361	23.9	1.71
Minimum value	34	1.35	0.35	0.01
1%ile	101	7.15	0.90	0.05
5%ile	203	14.00	1.5	0.09
25%ile	439	28.1	3.40	0.16
50%ile (median)	982	58.7	6.60	0.32
75%ile	2268	162	13.9	0.82
80%ile	2846	202	16.3	1.01
90%ile	4317	330	24.7	1.62
95%ile	5722	491	35.3	2.31
99%ile	18078	1710	101	7.71
Maximum value	80267	6960	527	34.4

	TREO	Th	U	CCA
	ppm	ppm	ppm	Bq/g
Mean	2237	200	13	0.96
SD	4842	557	27.2	2.55
Minimum value	83	3.35	0.55	0.03
1%ile	130	8.42	0.91	0.06
5%ile	253	16.00	1.52	0.09
25%ile	446	28.7	3.05	0.16
50%ile (median)	928	59.3	5.60	0.32
75%ile	2053	158	12.0	0.76
80%ile	2590	196	14.5	0.93
90%ile	4310	339	24.6	1.62
95%ile	6426	599	39.3	2.79
99%ile	32479	3435	152	15.2
Maximum value	46127	6510	413	29.1

	TREO	Th	U	CCA
	ppm	ppm	ppm	Bq/g
Mean	10086	903	57	4.33
SD	14327	1497	93.8	7.08
Minimum value	16	0.70	0.55	0.02
1%ile	141	6.29	1.50	0.06
5%ile	312	16.6	2.75	0.12
25%ile	1155	65.1	8.25	0.38
50%ile (median)	4042	283	24.0	1.48
75%ile	12542	1013	61.3	4.79
80%ile	16175	1330	79.6	6.38
90%ile	29086	2754	150	12.7
95%ile	44204	4291	239	20.0
99%ile	63656	6587	428	31.4
Maximum value	89015	16700	1350	83.7

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Perspectives on the amount of U and Th in Nolans Bore type mineralisation.

While the average grades of U and Th at Nolans Bore are well above crustal average, it is important to place these grades in a global perspective. The average amount of U in Nolans Bore is about 67 times UCC whereas the Reserves in active uranium mines can be up to 60,000 times UCC levels or more (source: Cameco website - "Uranium in Saskatchewan" fact sheet). At present about 1000ppm U_3O_8 is typically required for a stand-alone U mine although lower grades are being considered for economic development.

There is currently no economic demand or market for Th. However some are considering Th reactors meaning there may eventually be a market if this technology is developed further. Hence despite Th being much more abundant in the continental crust than U, currently there is no requirement for JORC-compliant Mineral Resource and Reserve statements to be published, and in fact Th resources and reserves are rarely if ever published. In more recent times however Th has been included by some in resource statements. This is mainly because Th has been modelled as a deleterious element and Th grades typically need to be understood as part of radiation management. Fortunately Th assays for some mineral deposits are sometimes published in the scientific literature however it is often very difficult to gauge how representative these results are.

The Steenkampskraal REE deposit in South Africa is the most Th-enriched hard-rock deposit known to the author. Steenkampskraal is a monazite-rich REE deposit that was discovered in the late 1940"s and the mine operated between 1952 and 1963. Resources are still available and recently there was considerable interest in recommencing operations. The Steenkampskraal deposit is a one-kilometre long vein which averages about 2.5% Th, almost 10 times that of Nolans Bore, with the highest grade of about 5.7% Th (Jones and Hancox 2012). The amount of U in Steenkampskraal was not published by Jones and Hancox (2012) but the average in their report is 526 ppm U and the maximum is 1480 ppm U. Additional monazite veins and extensions to the known vein system would certainly appear likely at Steenkampskraal. The levels of U and Th are much higher in the Steenkampskraal deposit meaning there would also be much higher background dose rates compared to Nolans Bore but these have not been published.

Both Nolans Bore and Steenkampskraal are vein-style REE deposits with the REE mineralisation (and its associated U and Th) confined to the mineralised vein itself. Other REE-Th-U deposit styles are known and the monazite-enriched heavy mineral sand deposits are the biggest sources of U and Th. Heavy mineral sand deposits have much larger footprints than vein-style deposits and typically form large elongate deposits along modern and ancient coastlines (Hoatson *et al* 2011; van Gosen *et al* 2014). For example, the coastal sand deposits of Brazil have some of the highest heavy mineral monazite concentrations in the world with up to 8% monazite (Van Gosen *et al* 2014). Veiga *et al* (2006) measured the natural radioactivity of the beach sands at 43 tourist resorts in Brazil with the Areia Preta beach in Guarapari yielding the highest average Th content (1.4% Th). Veiga *et al* (2006) reports an average of 70mSv/year (ie 8μSv/h) at the Areia Preta beach in Guarapari. HM sand mines span some 800km of the Guarapari coastline in Brazil and higher values might be expected at these mine sites. The eastern and western shores of southern India host one of the largest thorium and REE resources in the world and monazite is currently being recovered from mining operations on the southwest coast in the Kerala state. Similar environmental dose rates are also reported in Kerala area. Australian mineral sand deposits generally have lower Th levels because the monazite contents are lower but they are still elevated (Masters 1990, Shepherd 1990). In fact REE-enriched monazite was historically recovered from numerous sand mining operations in Australia (Hoatson *et al* 2011) and processed to recover its REE. In the current Australian HM operations the monazite is recovered and then re-blended and buried.

The airborne radiometric surveys of the Australian continent (below) shows areas with similar or higher natural environmental dose rates observed at Nolans Bore occurs at numerous locations on the Australian continent.

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Airborne Radiometric Surveys

Introduction

Airborne radiometric surveys have been used for many years because they provide a rapid remotely-sensed method to determine the radiometric (gamma) signature of large areas. Modern airborne radiometric surveys resolve spectral signatures of naturally occurring potassium, uranium and thorium with the end product typically reporting the total activity and the ground concentrations for K, U and Th. Elevation and magnetic field data are also typically recorded during most airborne radiometric surveys. Modern airborne radiometric surveys have now been acquired over most of the continental land mass of Australia (Figure 17).

In more recent times, the airborne gamma surveys have also been used to calculate the effective ground-level dose rate (Figure 18). To facilitate and calibrate this data Geoscience Australia completed the Australia-Wide Airborne Geophysical Survey (AWAGS) which allowed them to merge and accurately level out variations observed between different surveys (Minty *et al* 2009). The application of AWAGS means that for the first time all individual airborne surveys in the national database can be directly compared and accurately assessed for their ground-level gamma emissions and dose due to terrestrial sources (*ie*. surface geology). Prior to AWAGS this was not strictly possible as there were differences and artificial survey boundaries between surveys in all government regional compilations. The application of AWAGS also means that the national radioelement database is now accurately levelled to the International Atomic Energy Agency"s radioelement datum (Minty *et al* 2009). Hence the Radiometric Map of Australia (and all subsequent updates) provides a rapid method to directly compare and analyse the radioactivity and surface geology over different parts of Australia at the 100m x 100m pixel scale. The second edition of this map included an estimated cosmic radiation component for each pixel however this has been omitted from third (2015) edition. Based on the 2015 Radiometric Map of Australia data, the average dose rate in Australia from terrestrial sources is 0.37 mSv per year and the 99th percentile value is 1.26mSv per year. The data in the latest Radiometric Map of Australia indicates that 82.44km^2 exceeds 5mSv per year and some 10,632 km^2 exceeds 2mSv per year.

Airborne radiometric surveys clearly provide an excellent method to rapidly evaluate the natural environmental radioactivity. However it is important to note that the radioactivity and dose rates only relate to the terrestrial component (ie. surface geology) and not the total environmental dose. Other environmental sources of radiation such as cosmic, radon and thoron are not included. Cosmic radiation varies with solar activity, magnetic field, geographic location and latitude. Cosmic radiation increases with altitude because it is absorbed as it passes through the atmosphere. In general the cosmic radiation is higher at the poles and it increases with elevation. In Australia, annual doses from cosmic radiation are about ~300 µSv at sea level and ~500 µSv at 1000m (source: ANSTO website and fact sheets). Radon and thoron are naturally occurring radioactive gases and their relatively short half-lives prevent them from accumulating in the atmosphere. In the open environment, these gases are diluted by air currents, mixing and thermals, but these gases can accumulate in still air (*eg*. indoors or cold still outdoor conditions), ground waters and natural hydrocarbon fluids (oils and gases). In Australia, the average annual dose from radon and thoron is about 200 µSv but this can vary significantly depending on the type of construction materials used in your house, air flow and water supply (source: ANSTO website). Arafura has conducted a number of radon and thoron surveys to determine the natural environmental levels around the Nolans project area and the amount of radon and thoron emanated from typical Nolan Bore mineralisation. These are reported in Dean and Grose (2015). ANSTO has also measured radon and thoron at Nolans Bore (eg Collier *et al* 2007).

The gamma-ray spectrometers used in modern airborne radiometric surveys are calibrated against known source compositions and typically utilise large sensor crystals to minimise statistical errors and more accurately measure the gamma signature. The spectrometer performance is monitored daily to ensure the spectral data is measured correctly. Modern spectrometers typically sense and count a range of spectral activities using 256 channels to resolve the different spectral signals using the energies for the radioelement of interest. Each radiometric result is derived from the integrated activity recorded by the sensor during a one-second flight time, typically a distance of about 50-70m for a fixed wing aircraft, at a constant height above the ground level. Flying heights (*ie*. average terrane clearance), line spacing and the size of the sensor crystal used in the spectrometer are the main factors to consider when comparing the quality of different surveys over the same area. The final airborne radiometric dataset is typically levelled and gridded for display as a coloured image. The final images provide an interpolated result of ground level concentrations or dose rates over the entire survey area based on a systematic aerial survey pattern. The pixel size is usually a quarter or a fifth of the flight line spacing but for regional map scales of 1:100,000 or greater most surveys are usually gridded at 100m x100m. This is usually done because regional surveys have typically been acquired using the government"s adopted standard, maximum spacing of 500m and

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maximum height of 100m, and smaller pixels are not in perspective as the data is effectively "over-interpreted".

It is important to note that radiometric surveys only measure gamma emissions from the surface, and perhaps the topmost 30 cm at best; deeper sources are typically shielded and masked by the overlying material. This depth limitation applies to both aerial and ground-based radiometric surveys. Hence radiometric surveys mostly record on the material present at or very near the surface. It is also important to realise that the spectral signature at the surface might not be the same as the underlying parent rock due to geological processes such as weathering, erosion or deposition.

Airborne radiometric surveys effectively measure the average gamma signal emitted from the surface and typically yield robust radiometric maps and models in areas of uniform geology and surface exposure. Unfortunately there is often variability and the signature of a rock is easily masked or significantly altered by a thin layer transported material or soil of a different composition.

Ground-based geochemical sampling of surface material (rocks, stream sediments and soils) by Arafura (and numerous others) shows that a local geological context is often required when directly comparing geochemical assays to the compositions derived from airborne radiometric datasets. Exploration datasets collected by Arafura in the Aileron-Reynolds project region clearly demonstrate that the compositions of various rocks and soils are generally well correlated and the relative differences observed in K, U and Th channels are often explainable. In areas of uniform geological exposure, representative assays generally agree with an acceptable error to the compositions determined by airborne radiometric surveys. However in nature there is often some degree of geological complexity to be considered and more often than not the size of the geological unit, its internal variability and the local setting needs to be carefully considered when evaluating compositions derived from airborne radiometric data. For example, geological processes such as weathering, erosion and deposition need to be considered when interpreting the chemical compositions as intense weathering typically means lower K and U compositions compared to their fresh equivalent. In certain geological settings such as the Nolans project area both fresh and weathered geological units can be present in the same area along with other transported and deposited material and soil. Hence the airborne survey simply averages what is present at the land surface in the area. Fortunately most anomalous radioactive geological units typically stand out as prominent features in regional airborne surveys because their gamma signature strongly contrasts with their surrounds. That said it can still be difficult to detect and identify small radioactive units in regional airborne surveys however the higher resolution more detailed airborne datasets akin to those acquired by exploration companies typically highlight and resolve most radiometric features. Unfortunately the averaging effect means that the modelled concentrations and dose rates for small geological units may not be accurately portrayed in regional airborne surveys, irrespective of their composition.

In summary airborne radiometric surveys typically produce a representative radiometric average of the land surface however an accurate analysis of an airborne or surface dataset requires a geological understanding of the area concerned. One must also remember that the results of airborne and surface surveys are scale dependent and more detailed closer-spaced surveys are required to resolve small features. As such small geological units and compositional variations can be difficult to resolve and differentiate because the radiometric signatures are "averaged" in radiometric surveys. High resolution ground-based radiometric surveys are typically required to accurately locate and resolve the spatial and radiometric character of smaller features.

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Figure 17. Ternary radiometric image showing K, Th and U as red, blue and green with the colour intensity proportional to the total activity based on the radiometric map of Australia (third edition, 2015). Blank areas are not surveyed to acceptable national standards.

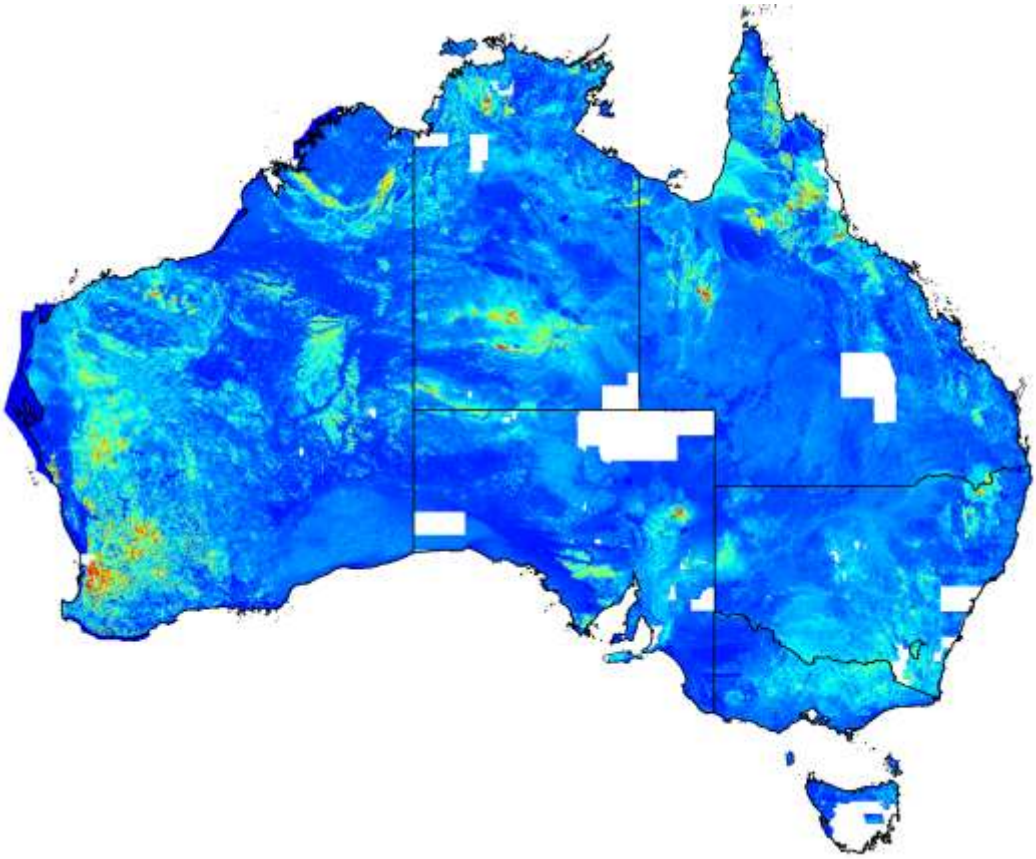

Figure 18: National terrestrial gamma dose rate derived from the Radiometric map of Australia (third edition, 2015). Linear colour stretch from low (blue) to high (red) dose rates with levels more than 2 mGv/yr shown in red. Blank areas are not surveyed to acceptable national airborne standards. The image demonstrates there is significant variability across the Australian continent. Clearly the Nolans project is within one of many naturally occurring areas with elevated radioactivity.

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Airborne radiometric surveys over the Nolans project area.

The first airborne radiometric survey over the Nolans project area was acquired by the Bureau of Mineral Resources, Geology and Geophysics (BMR) in 1958 (Carter 1960, Stewart *et al* 1980). This airborne survey covered parts of the Napperby, Mount Doreen and Mount Theo 1:250 000 map sheets and was acquired along one-mile (~1600m) spaced east-west flight lines at an average height of about 500‟ (~150m). Unfortunately the locational accuracy of this data is somewhat suspect given the navigation and location methods used at that time. Furthermore the scintillometer used in this survey was incapable of spectrally distinguishing between potassium, thorium and uranium. Hence the initial radiometric survey does not meet the minimum accepted specifications for modern airborne surveys and is not used in the national database. Despite the shortcomings of this initial survey it indicated that all major granites in the area were significant radiometric features with intensities six times or more above the standard deviation on the low side of the change (Stewart *et al* 1980). This survey has now been superseded by more recent airborne surveys.

Two detailed airborne radiometric surveys have been acquired over the Nolans Bore deposit and its immediate surrounds. Both of these surveys surpass the minimum standards for the national radiometric survey database. The first airborne survey was acquired by PNC in 1994 and led to the discovery of Nolans Bore. The second survey is a more detailed survey acquired at a much higher specifications by Arafura Resources in 2008. Arafura‟s airborne survey was specifically done to better document the natural environmental radioactivity of the project area for EIS purposes. Two additional airborne surveys have also been acquired and cover other parts of the Nolans project area. The specifications of the regional airborne geophysical surveys in the project area are shown in Table 8.

PNC‟s 1994 airborne radiometric survey meets the minimum specifications required for State- and Territory-level regional geophysical datasets. As such rather than re-acquiring a new airborne data over the same area, PNC‟s survey was incorporated into the Northern Territory Geological Survey‟s 1997 Napperby-Hermannsburg airborne geophysical dataset. PNC‟s 1994 airborne survey over Nolans Bore has therefore also been included in all publically released regional airborne datasets that cover the Napperby 1:250 000 map sheet, the NT and Australia since 1997. PNC‟s 1994 airborne survey is therefore part of the national database and has been levelled and incorporated into the Radiometric Map of Australia shown in Figure 17 and Figure 18 (Percival 2014). Arafura‟s airborne surveys over the Nolans Project area were more detailed and acquired at much higher specifications than previous airborne radiometric surveys. Arafura‟s surveys were flown one quarter of the previous line spacing and at least half the flying height to provide more detailed radiometric information.

The results from Arafura‟s detailed low-level airborne radiometric surveys are consistent with the national dataset. Arafura‟s detailed airborne datasets are not publically available but they clearly provide a greater level of radiometric detail (Figure 19, Figure 20, Figure 21, Figure 22, Figure 23, Figure 25 and Figure 26) especially when compared to an example of the original dataset derived from the Radiometric Map of Australia over the same area (Figure 24).

The airborne radiometric signatures in the Nolans project area are consistent with the published regional geology (Figure 27). Many of the anomalous radiometric features within Arafura‟s airborne datasets have been followed up by reconnaissance mapping, gamma surveys and geochemical sampling. Figure 19, Figure 20 and Figure 21 shows that the outcropping rocks and soils in the region have area of naturally elevated K, U and Th, respectively. Figure 20 and Figure 21 shows that the U and Th are elevated in most of the outcropping granites, especially when compared to the average UCC values. In general, the highest radiometric values mostly occur in the areas where the rocks crop out at the surface, however the signature and the radioactivity is clearly dependent on the rock type or regolith unit. The airborne dataset also clearly highlights the natural dispersion by highlighting erosion and deposition and relating them back to the outcropping rock units which serve as the principal source areas. Uranium and Th radiometric features are evident in drainages shedding off the granites and metamorphic rock units. Comparisons of the airborne magnetic and radiometric datasets also clearly demonstrate that the transported sheet flow deposits mask and shield the underlying radiometric signature. For example, natural erosion near creeks exposes the underlying rocks that are spectrally different to the surrounding soils (eg downstream of Nolans Bore) and isolated outcrops of granite protruding out of the sand plains are often spectrally different to their surrounds.

The strongest and most prominent airborne U and Th radiometric signatures occur at the Nolans Bore deposit itself and are associated with outcropping or sub-cropping Nolans Bore-type mineralisation or soils derived from eroded and naturally dispersed Nolans Bore-type mineralisation. Hence it is no surprise that some of the highest Th and U soil and rock assays in the region also come from this area. Consequently the highest naturally occurring environmental dose rates in the project area have been measured around Nolans Bore itself, with large areas typically showing environmental dose rates up to about 15µSv/h. The high

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results are typically only measured in areas directly above outcropping mineralisation although a number of high readings are also found where there is very thin cover over mineralisation and the soils are largely locally derived.

Table 8: Details of low level airborne radiometric survey specifications.

Survey Name	**Napperby**	**Napperby-Hermannsburg**	**Nolans**	**Aileron East**
Year	1994	1997	2008	2012
Originator	PNC	NTGS	Arafura	Arafura
Survey Company	World Geoscience	Kevron Geophysics	UTS Geophysics	UTS Geophysics
Line spacing	200m	400m	50m	100m
Line direction	180-360	180-360	180-360	180-360
Tie-line spacing	5000m approx	4000m	500m	1000m
Tie-line direction	090-270	090-270	090-270	090-270
Sensor height	80m	60m	30m	30m
Coordinate system	WGS84 Zone 53		MGA94 Zone 53	MGA94 Zone 53
General survey equipment	• Cessna U206G fixed wing aircraft • King KN525A Horizontal Situation Indicator. • Garmin 100, 5 channel autonomous GPS receiver in aircraft used for navigation. • Novatel, auto all in view, 12 channel GPS base station • post mission data verification and processing, including DGPS. • Sperry radar altimeter. • King KT76A ATC-SSR	• Rockwell Aerocommander Shrike 500S • Real time DGPS	• CRESCO-08-600 fixed wing aircraft • UTS proprietary flight planning and survey navigation system • UTS proprietary high speed digital data acquisition system. • Novatel 3951R, 12 channel precision navigation GPS. • OMNILITE 132 real time differential GPS system. • UTS LCD pilot navigation display and external track guidance display. • UTS post mission data verification and processing system. • Bendix/King KRA-405 radar altimeter.	• FU24 – 954 fixed wing aircraft • AG-NAV flight planning and survey navigation system • RMS DAARC500 high speed digital data acquisition system. • Novatel, 12 channel precision GPS. • OMNISTAR real time differential GPS system. • AG-NAV LCD pilot navigation display and external track guidance display. • UTS post mission data verification and processing system. • Bendix/King KRA-405 radar altimeter.
Radiometric data acquisition equipment	PGAM 1000 256 Channel spectrometer	• Geometrics GR-820D	• Exploranium GR-820 gamma ray spectrometer. • Exploranium gamma ray detectors. • Barometric altimeters (height and pressure measurements). • Temperature and humidity sensor.	• Exploranium GR-820 gamma ray spectrometer. • Exploranium gamma ray detectors. • Barometric altimeters (height and pressure measurements). • Temperature and humidity sensor.
Radiometric detector volume	16.5 litres	33.6 litres	32 litres	32 litres
Radiometric sample rate	1 Hz	1 Hz	1 Hz	1 Hz
Survey speed	~140 Kn	~140 Kn	140 Kn	100 Kn

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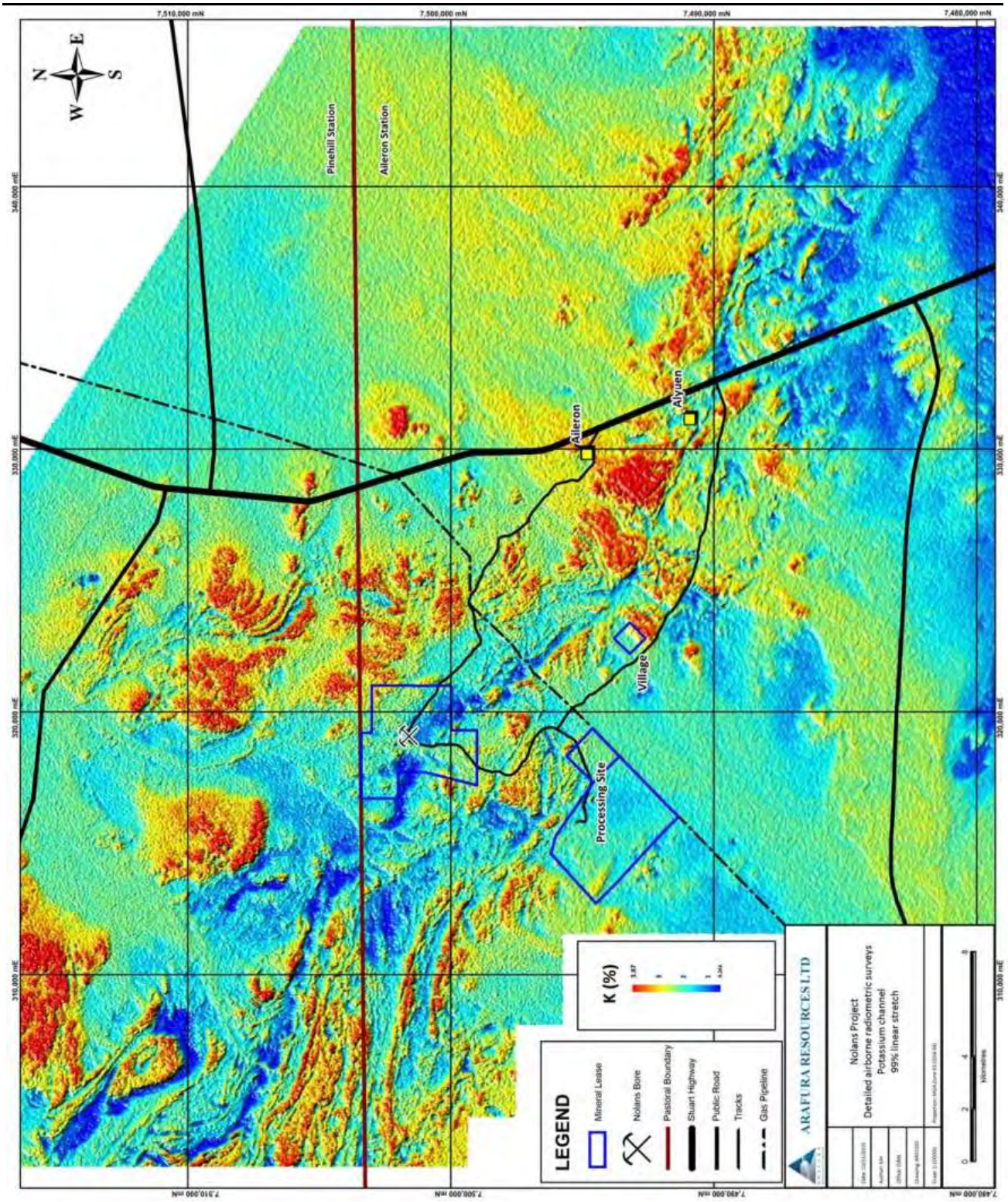

Figure 19. Average potassium content at the surface for the Nolans project area based on Arafura's detailed low-level radiometric surveys. The average UCC is estimated with a two-sigma error at 2.32 ± 0.38 %K (Rudnick and Gao 2004). The K values observed in this area are typical of an average outcropping granite-dominated crustal setting.

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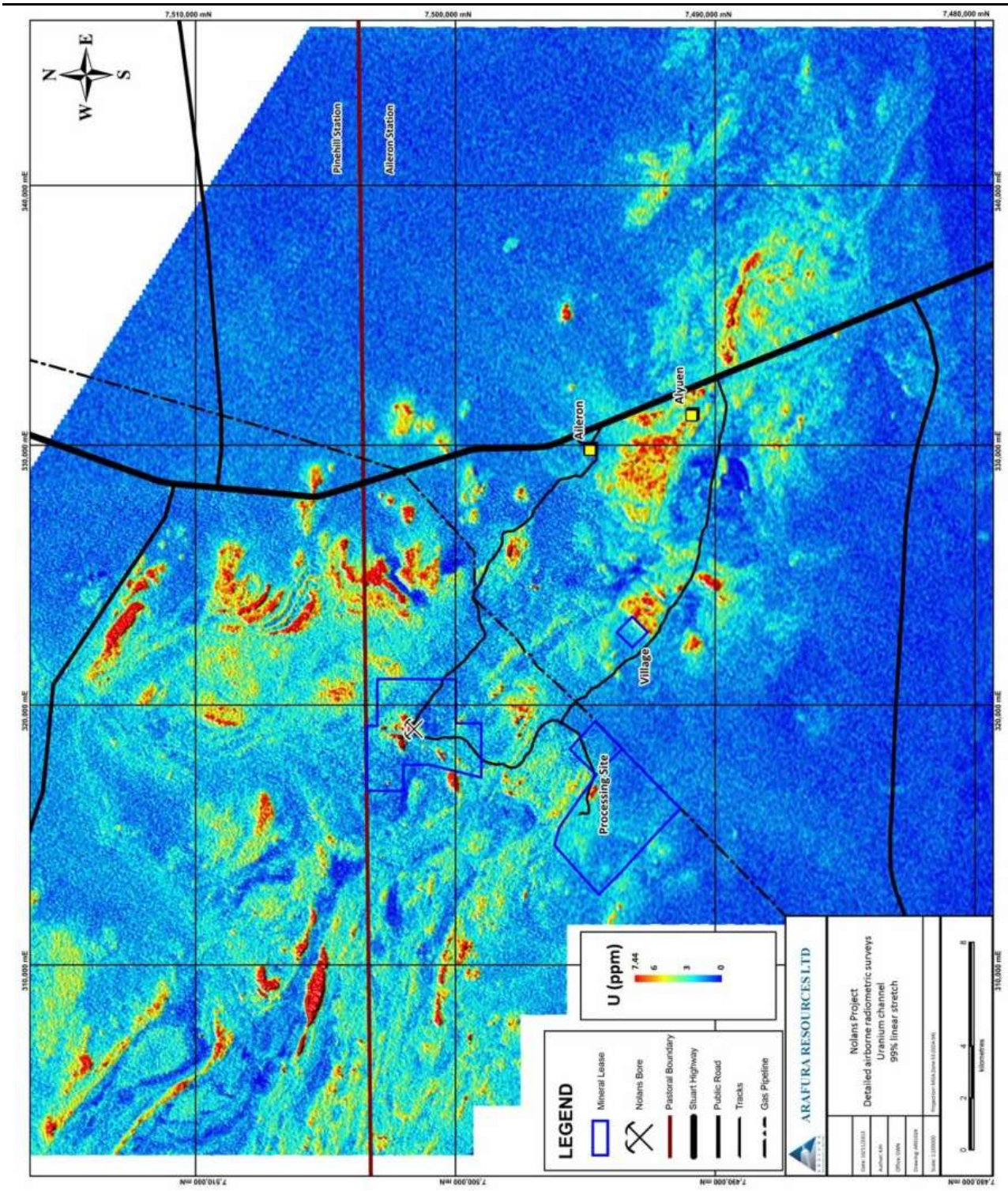

Figure 20. Average uranium content at the surface for the Nolans project area based on Arafura's detailed low-level radiometric surveys. The average UCC is estimated with a two-sigma error at 2.7 ± 1.2 ppm U (Rudnick and Gao 2004). Clearly there are numerous areas with above average U and most of them are related to outcropping granite and metamorphic rock units. Same area as Figure 19.

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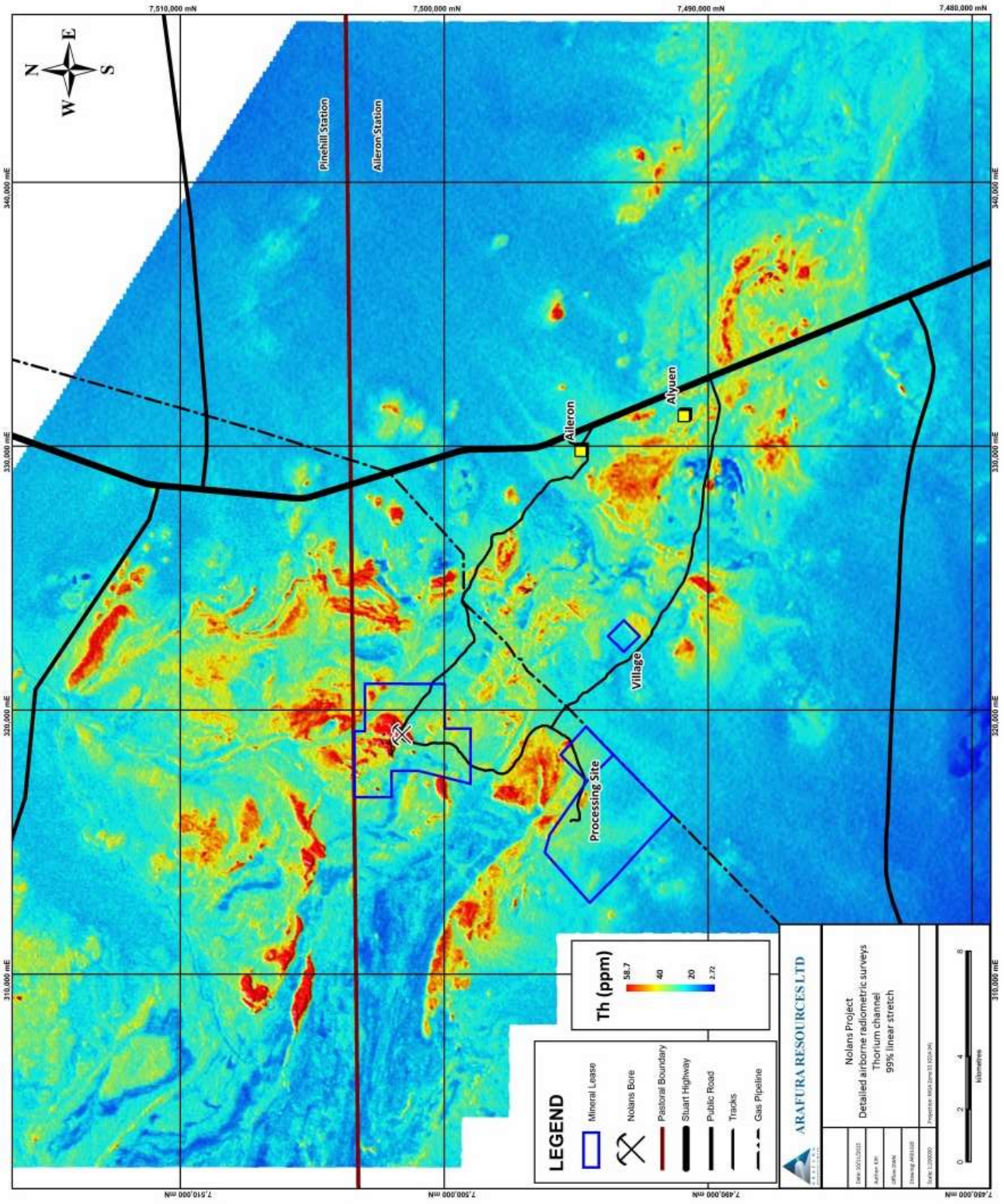

Figure 21. Average thorium content at the surface for the Nolans project area based on Arafura's detailed low-level radiometric surveys. The average UCC is estimated with a two-sigma error at 10.5 ± 2.0 ppm Th (Rudnick and Gao 2004). Clearly there are numerous areas with above average Th and most of them are related to outcropping granite and metamorphic rock units. Same area as Figure 19.

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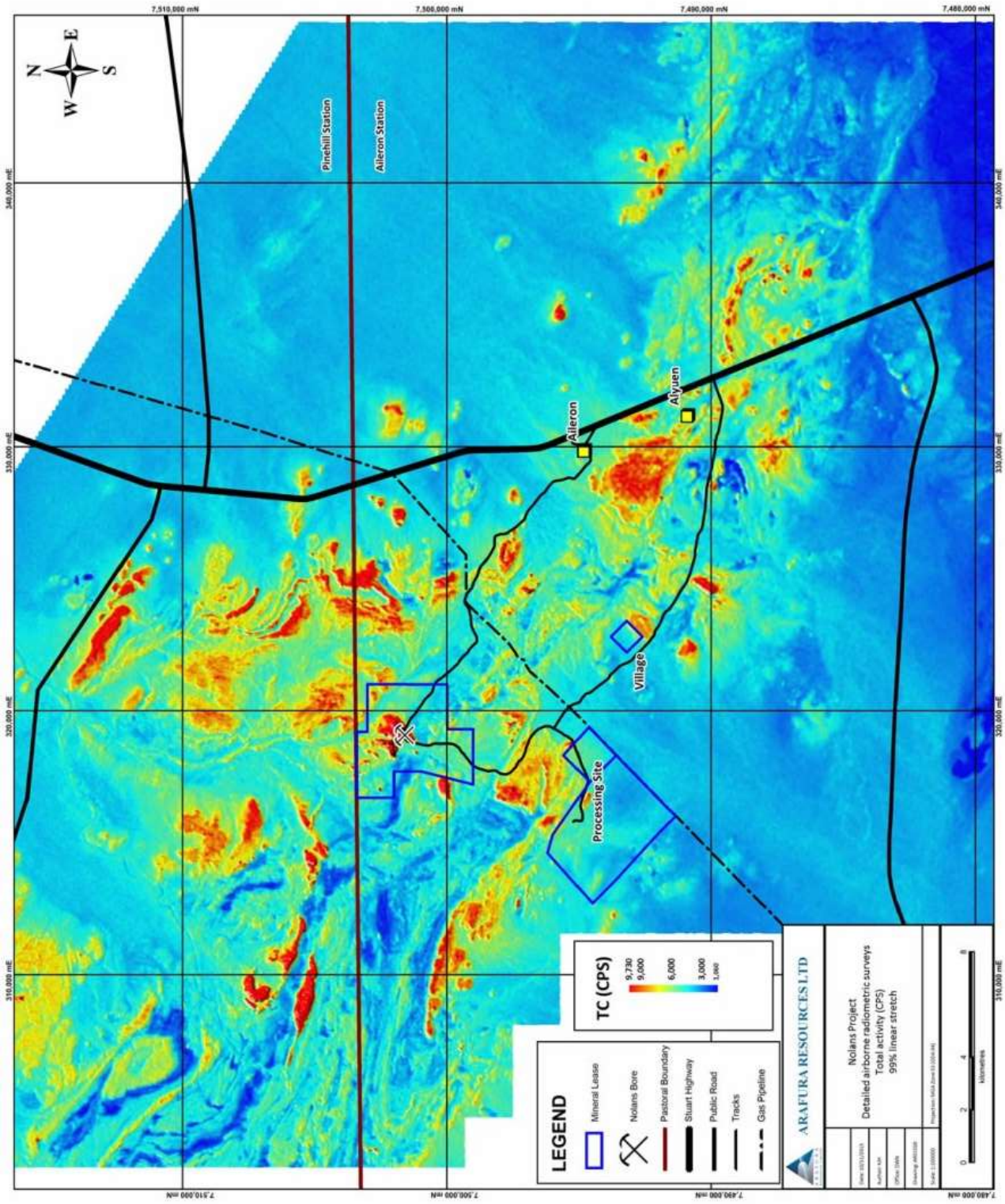

Figure 22: Total activity at the surface for the Nolans project area based on Arafura's detailed low-level radiometric surveys. Same area as Figure 19.

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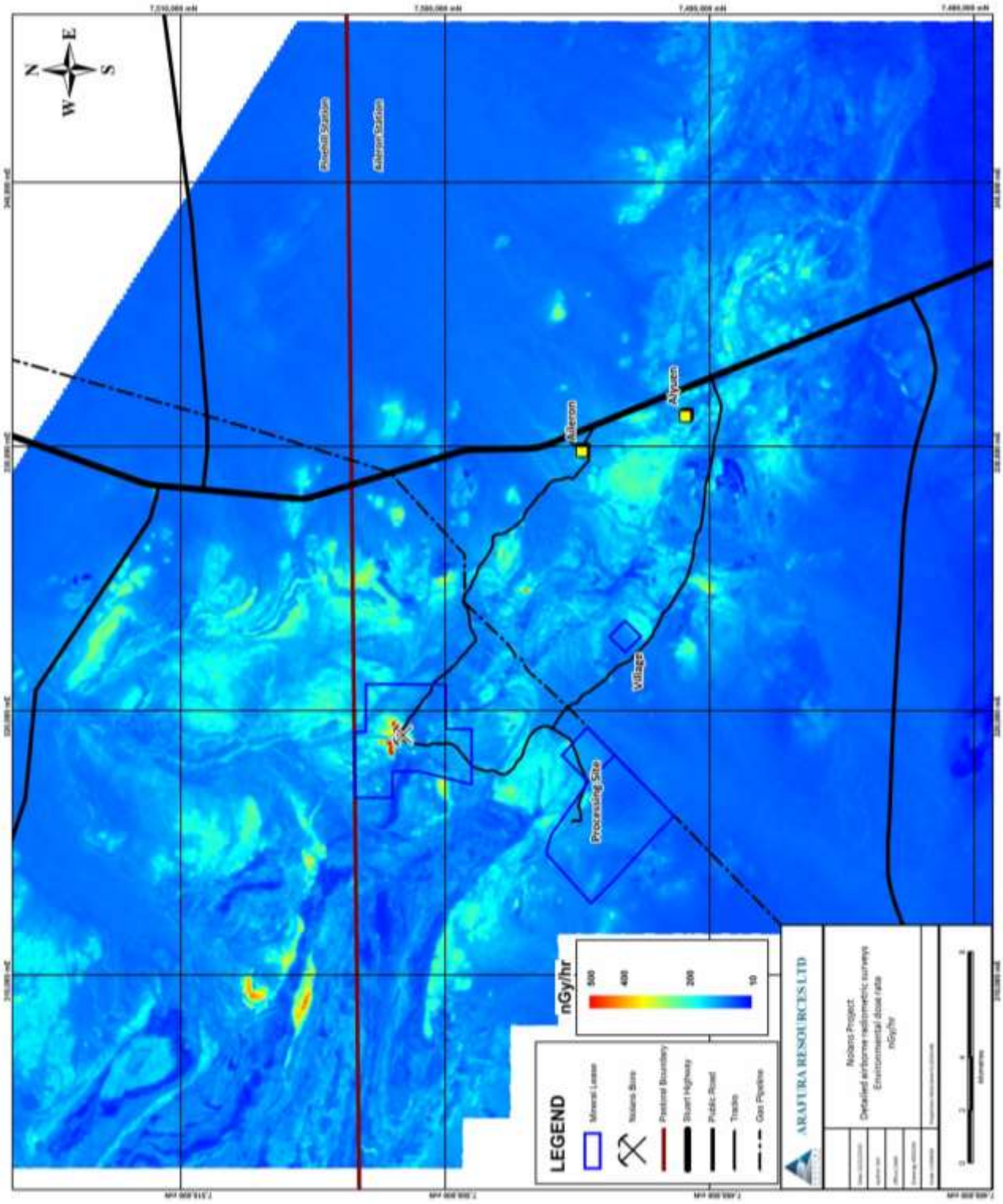

Figure 23: Average dose rate at the surface for the Nolans project area based on Arafura's detailed low-level radiometric surveys. Same area as Figure 19.

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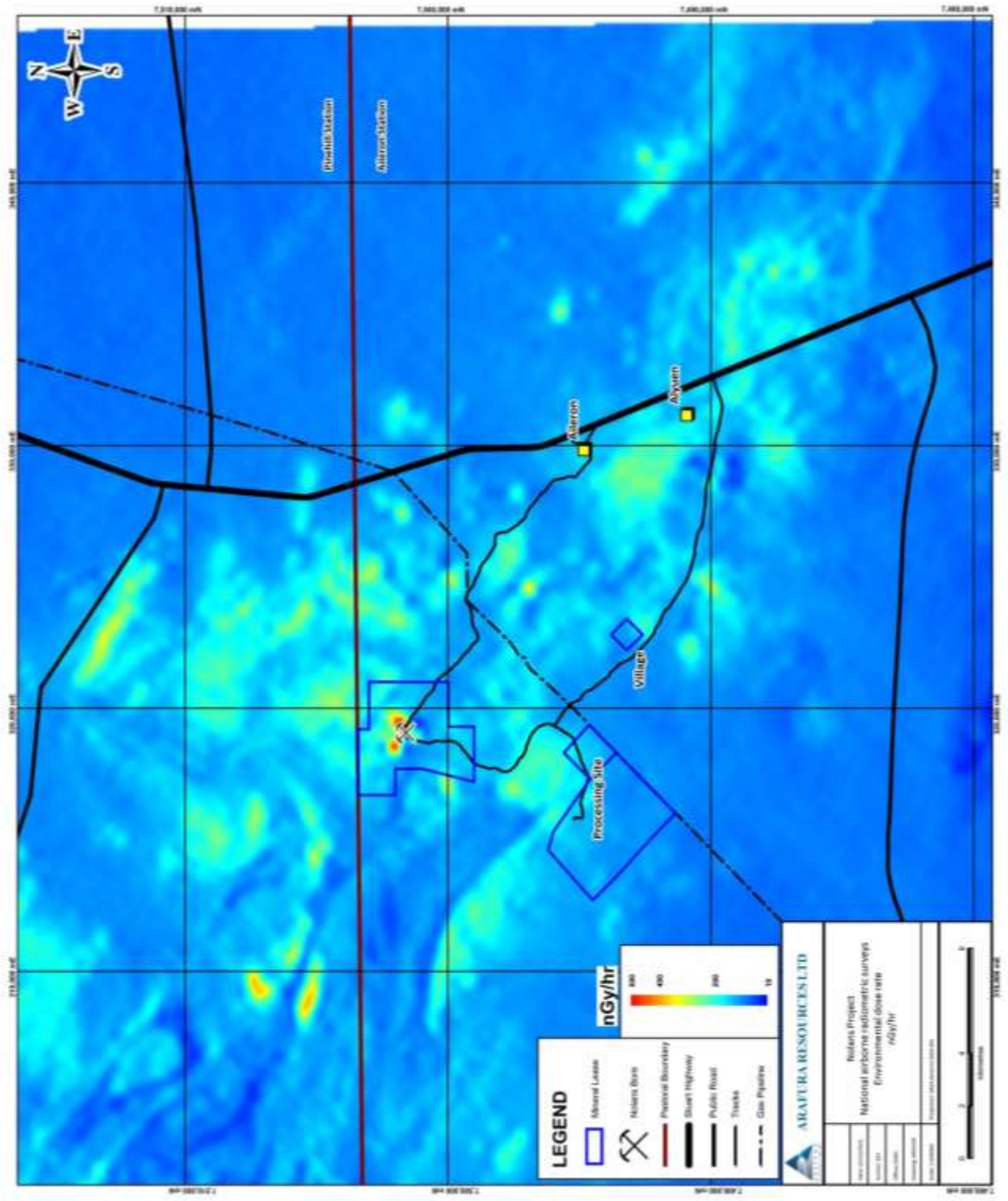

Figure 24: Average dose rate at the surface for the Nolans project area based on data used for Radiometric map of Australia. Compare with Arafura"s more detailed radiometric data shown above in Figure 23. Note the range and colours used in Figure 23 and Figure 24 are identical. Same area as Figure 19.

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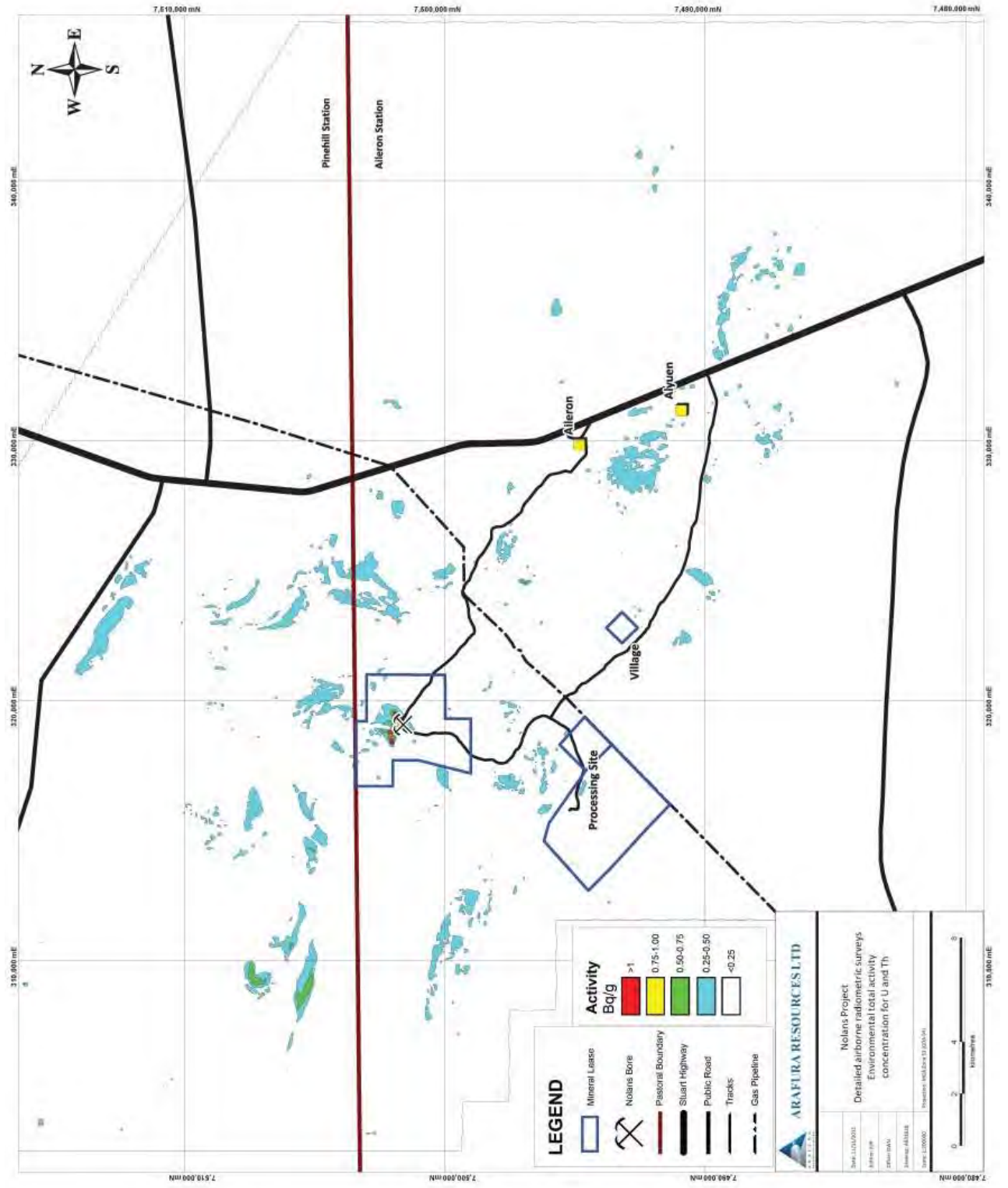

Figure 25: Thematic map showing the calculated combined U and Th activity concentration at the surface for each 100m x100m pixel in the Nolans project area based on Arafura"s detailed airborne survey data. Despite widespread variability and localised highs this image shows that Nolans Bore has the highest average activity concentration in the region. Same area as Figure 19. This image is clealry scale dependant as there are a small geological units in this area that are up to 5Bq/g but these are averaged with there adjacent surrounds and plot in areas classified as less than 1Bq/g.

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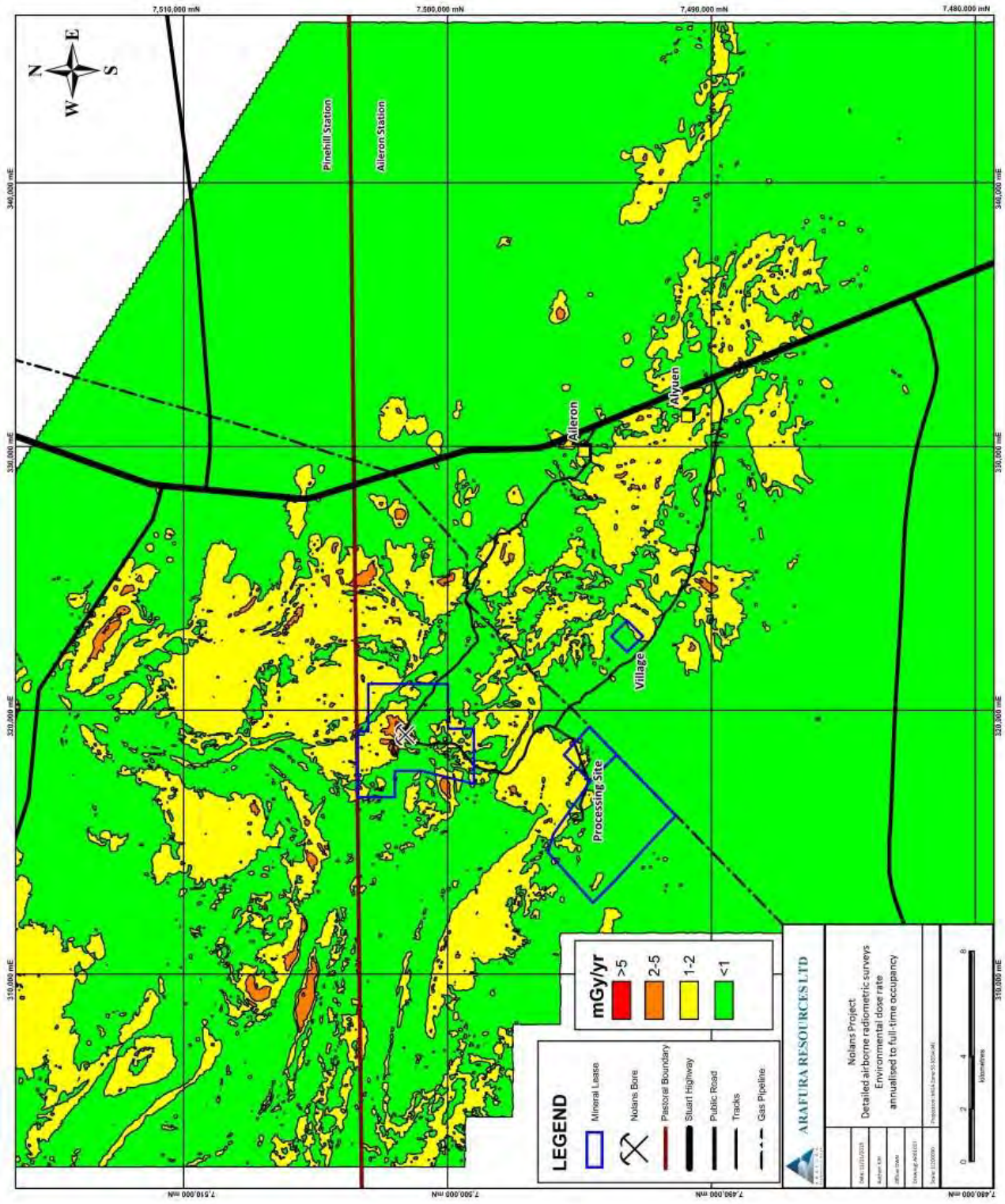

Figure 26: Thematic map showing the average annualised terrestrial dose rate at the surface for full-time occupancy at each 100m x 100m pixel (1 ha) across the Nolans project area based on Arafura"s detailed airborne survey data. This image clearly highlights the inheritant natural variability of the background radiation in the region. As a comparison, the data in the Radiometic map of Australia indicates the Australian average is about 0.37mGy/yr. Same area as Figure 19.

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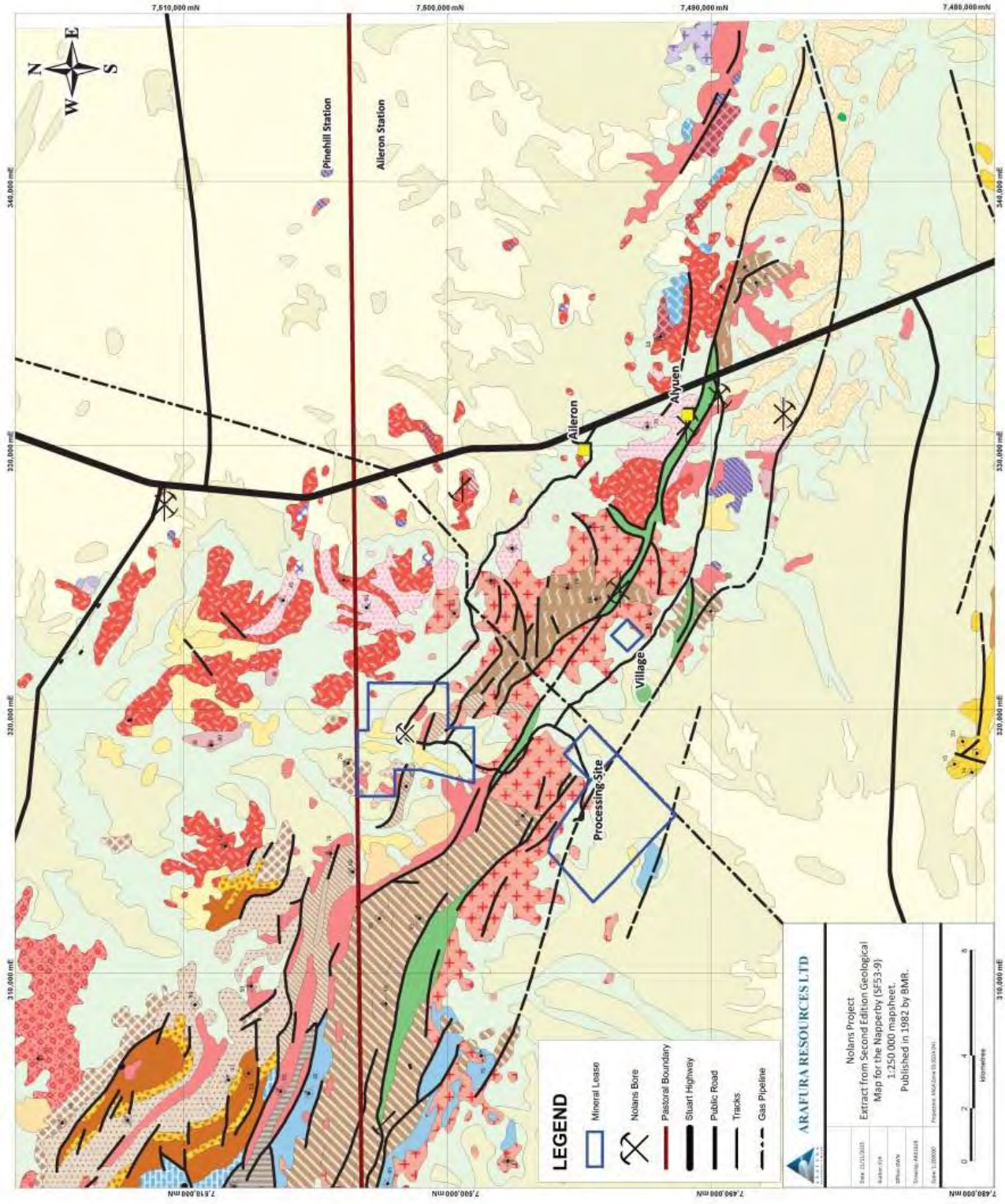

Figure 27: Regional geology of the Nolans project area (digitised version from NTGS, after Stewart and Pillinger 1982). Same area as Figure 19.

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Airborne survey calibrations and robustness of results.

Airborne survey contractors routinely calibrate and check their instruments against benchmarks and areas of known composition (*ie* activity concentration) are repeated as QAQC throughout each survey. As a confirmation, geochemical assays of reconnaissance samples collected in areas of relatively uniform exposures of granitic and metamorphic rocks and soils were used to confirm if the airborne results are robust. The exploration data indicates that the U and Th assays are consistent with the compositions determined from airborne surveys (Figure 28 and Figure 29). The comparative results show a remarkably good relationship given the scale and method differences and the inherent errors and assumptions made in each dataset. Figure 29 indicates the thematic map presented in Figure 25 is robust and representative at a regional scale and that Figure 20 and Figure 21 are also robust and representative at this scale.

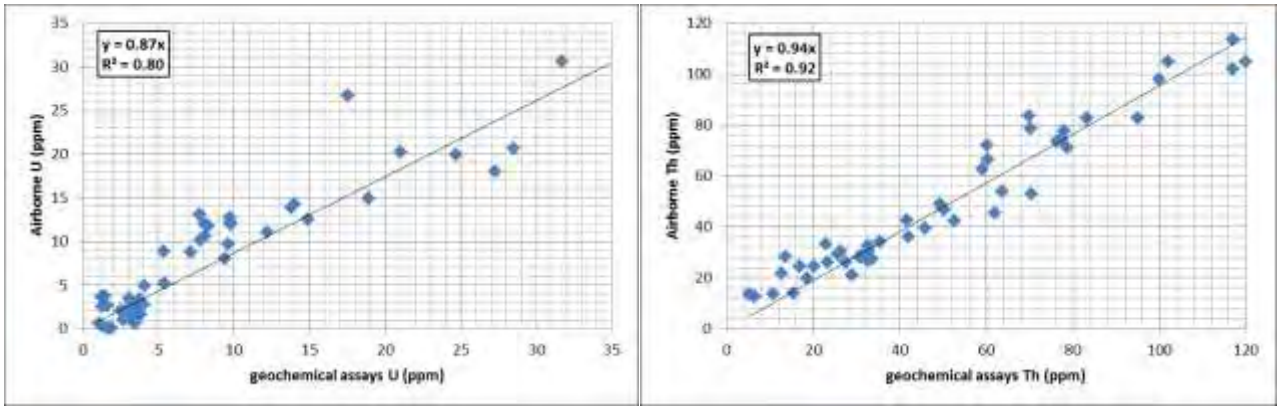

Figure 28: Relationship between the compositions determined by airborne radiometric surveys and reconnaissance exploration geochemistry in areas of relatively uniform geology. Note the exploration geochemistry samples are a combination of soil and whole rock assays. These assay samples were not collected for airborne radiometric calibration purposes and they are not representative of an equivalent area covered by an airborne survey but the samples have been vetted and considered as typical examples which might be close.

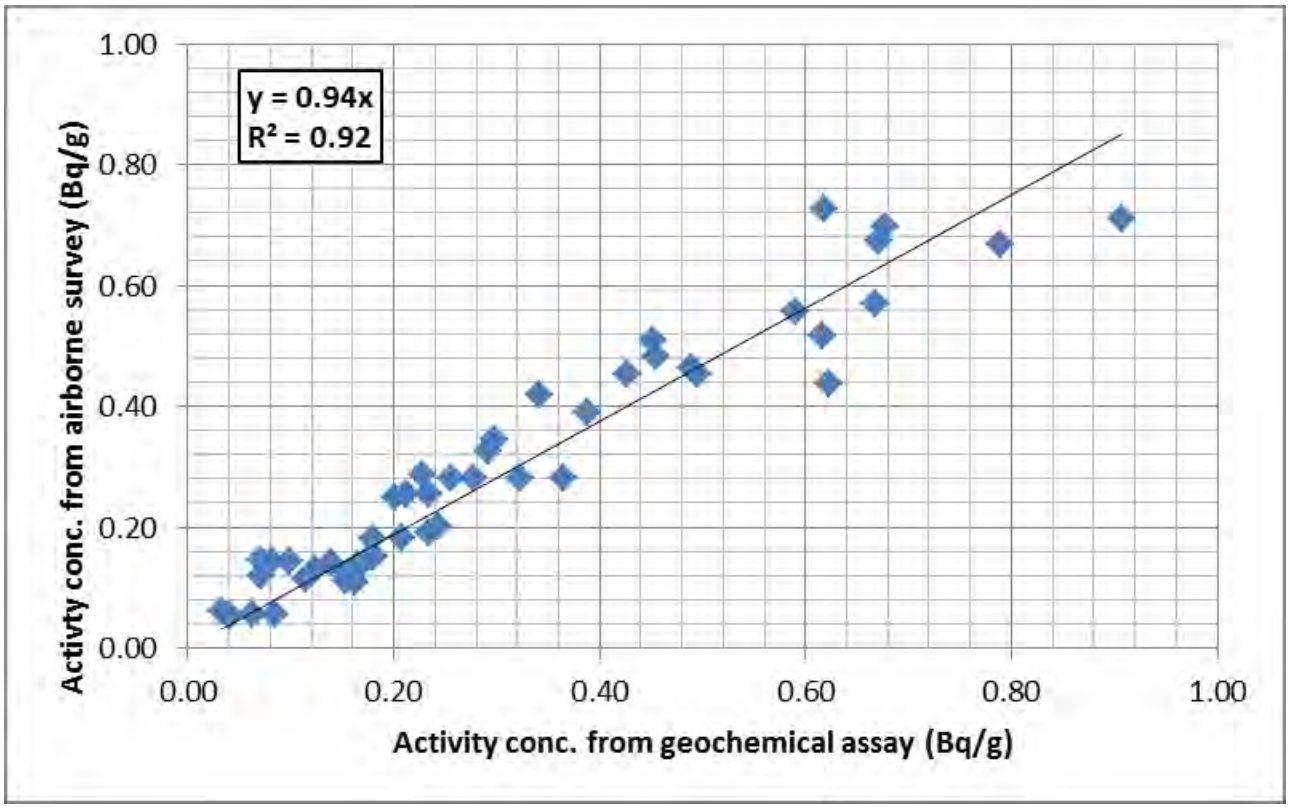

Figure 29: Comparison of the combined U and Th activity concentration determined from Arafura"s detailed airborne radiometric survey and reconnaissance exploration geochemistry in areas of relatively uniform geology. Note the exploration geochemistry samples are a combination of soil and whole rock assays. These assay samples were not collected for airborne radiometric calibration purposes and they are not representative of an equivalent area covered by an airborne survey but the samples have been vetted and considered as typical examples which might be close.

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Figure 23 indicates maximum of about 1200 nGy/h in the project area. This equates to a full time occupancy terrestrial gamma exposure of about 10.5mGy per year which is significantly less than the results of numerous ground based surveys completed at Nolans Bore. The regional airborne data clearly under-estimates the localised higher ground doses measured at Nolans Bore itself however the regional trends and patterns correlate on a broad scale in a regional sense. This scale difference occurs because the airborne survey averages readings over a much larger area and there is considerable localised variability at Nolans Bore.

To investigate the apparent difference in natural background environmental dose rates at Nolans Bore and to confirm that the dose rates reported from the airborne surveys were appropriately calibrated, Arafura used special thermo-luminescent dosemeter (TLD) badges tied to star pickets at 1m above the ground surface and left these in place for an extended period of time. The TLD badges therefore effectively serve as area monitors, recording the background environmental gamma dose in a specific areas and these values can be used to determine if values from the airborne survey are correct.

Two separate environmental TLD area monitor surveys were completed in the Nolans project area. The first was done in 2008 and supervised by Rolf Hallenstein of Arafura Resources using a radial pattern as directed by Mark Sonter. A total of 52 TLD area monitors were set in place for a period of 59 days in September-October 2008. The TLD badge readings were originally reported to Arafura by ANSTO as standard personal user badges rather than as area monitors. This oversight was not realised until the author investigated the dose results for this report. ANSTO has since re-reported the results as area monitors rather than a wearer"s badge (*ie* the background value of the site control badge was not subtracted from the area monitor badges). Further analysis by the author indicates that one result from the 2008 survey TLD area monitors is highly suspect; the reading does match that of the reported GPS locational setting and airborne data, nor does it match the good data correlation seen at all other sites. The suspect dose result is more akin to values recorded at Nolans Bore rather than an area of low background suggesting the monitor was placed at a different spot and incorrectly recorded. Hence this single obviously erroneous value has been discarded from any further analysis. The reported location with a suspect dose reading will be followed up in due course to confirm my suspicions. To complement the 2008 dataset, a second set of 26 TLD badges were also placed at the 2015 environmental monitoring sites as area monitors. These badges were set in place for about three months, however due to animal disturbance one badge was not found at the end of the period. The location of the 76 TLD badges is shown in Figure 30 and a comparison of the actual recorded dose rate at each site with the result derived from the airborne dataset is shown in Figure 31.

Figure 31 shows there is a good linear relationship between the airborne dataset and the TLD area monitors placed at a specific locations. This is an excellent result given the geological complexity and variability observed at some sites, and the inherent errors in measuring and determining the dose rate via different methods. For example, the values reported for TLD badges typically have an associated error of ±25% for dose readings above 400nGy and the relative error is much greater (*ie* ±100nGy) for readings below 400nGy (Gordon Gee ANSTO, *pers comm* 2015). Based on the length of time these badges were set it place, there is a 25% error for dose rates above about 280nGy/h in the 2008 survey and above about 180nGy/h in the 2015 survey, with bigger errors in the dose rates below this. Similar or potentially larger errors might be expected in the airborne dataset.

Figure 31 also clearly shows that the localised environmental background radiation can differ from the airborne dataset which averages dose rates over much larger areas. While most of the TLD area monitors correlate with the airborne dataset and are essentially within error of one another, both low and high deviations are observed. These differences are relatively easy to explain and relate to the natural geological variations and the different rocks and soil present at each specific site compared to the average for the area sampled by the airborne survey at its sensor height which is then calculated as a ground dose and estimated into each pixel.

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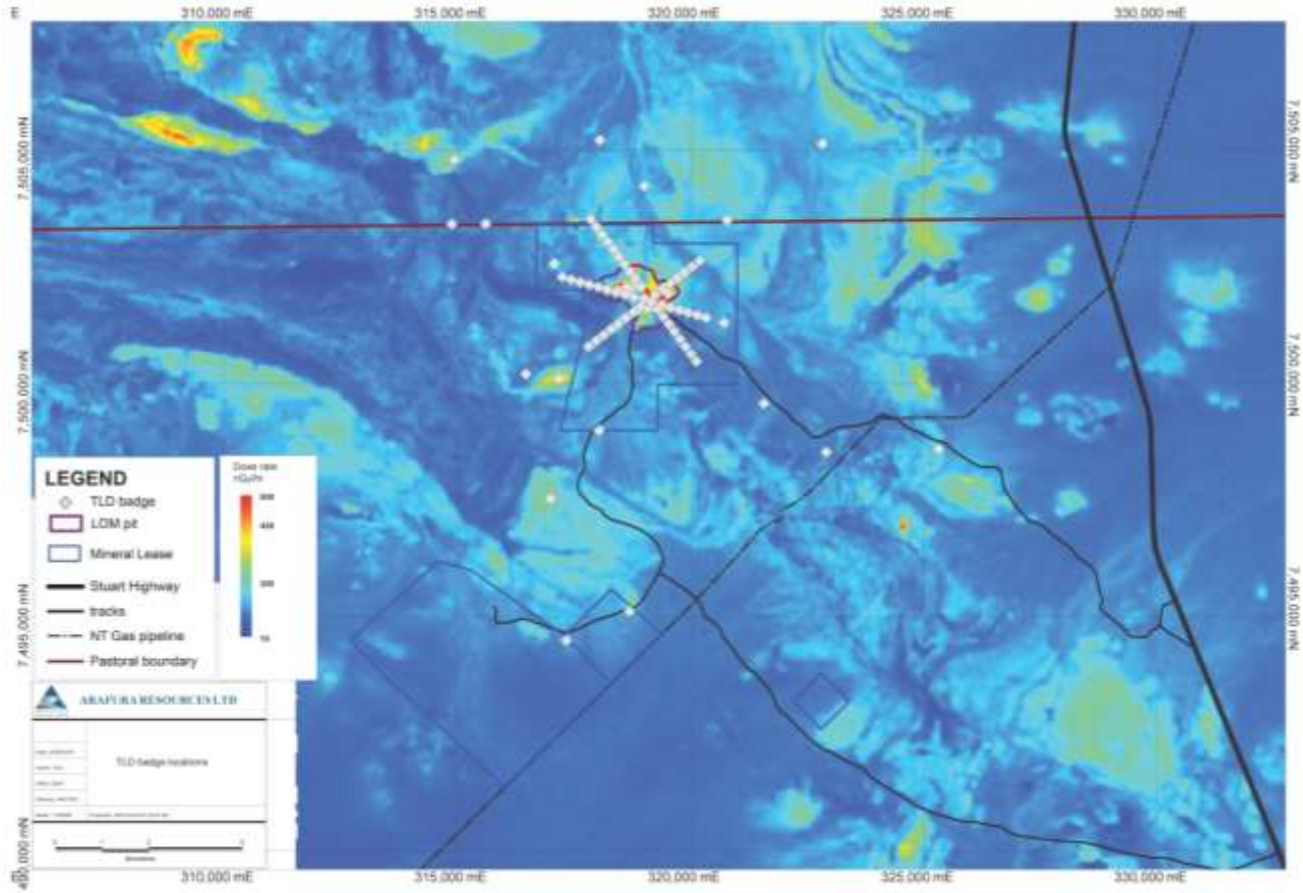

Figure 30: Location of TLD badges used as area monitors to confirm the airborne data set is correctly calibrated.

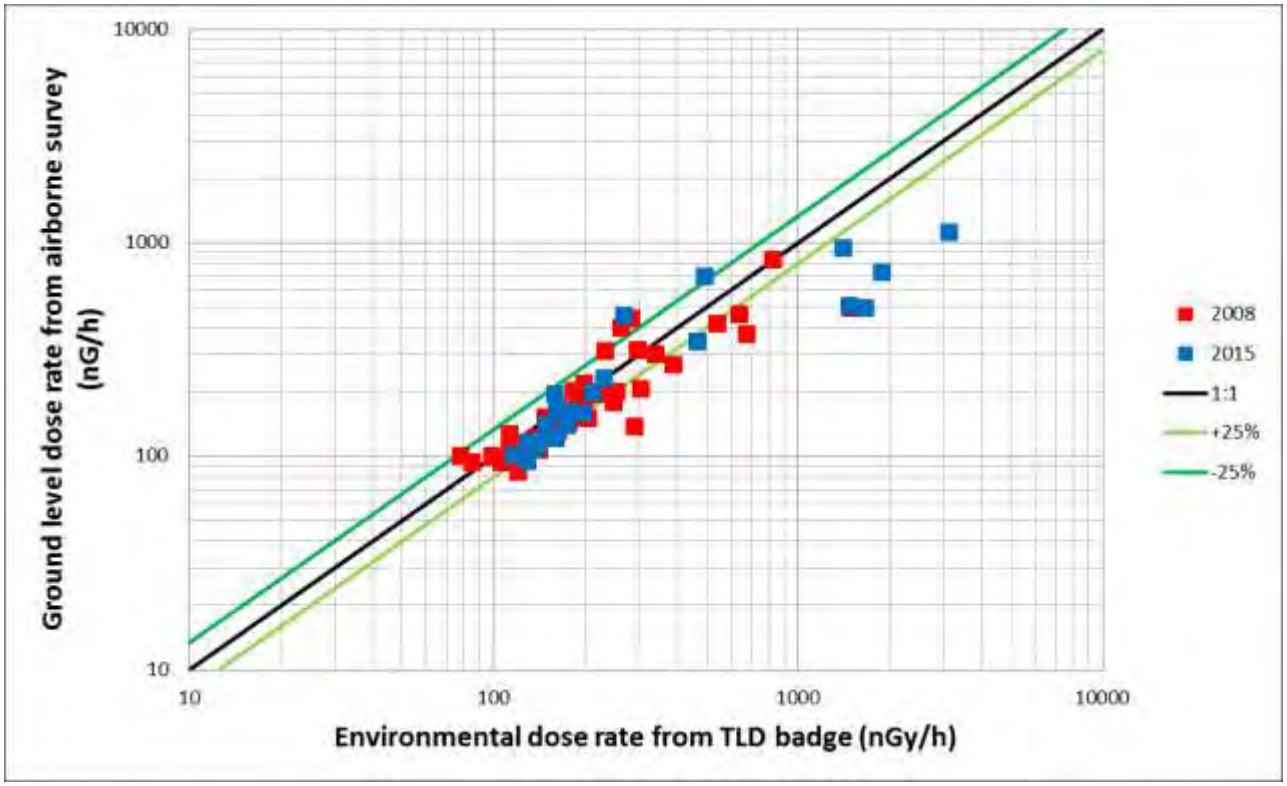

Figure 31: Comparison of dose rates estimated from airborne surveys with that of environmental TLD badges used area monitors and placed at 76 specific locations in the Nolans project area.

Arafura"s exploration protocols mean that count rates or more commonly dose rates are routinely measured. At Nolans Bore this is normally done by placing a hand-held RDX nuclear DX-1 Geiger counter directly on

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the outside surface of all RC drill residues. The recorded dose rates are not precise and are simply the estimated average value based on the movements of the analogue display needle. To keep this instrument dry and free of dust, mud and water during field operations, it is entirely encapsulated in numerous layers of a strong transparent masking tape. The RDX nuclear DX-1 Geiger counter detects both beta and gamma radiation however encapsulating it in a thick layer of tape and measuring on the outside of the bag effectively shields out a proportion of the beta radiation. The results are also likely to be slightly lower in moist or wet samples. This methodology has been used at Nolans Bore since the initial RC drilling program and the measured dose rate is used to assist in assay sample selection. It also means that there is a representative record of the dose rates for mineralisation and country rocks at Nolans Bore. It is recognised that Arafura"s RDX nuclear DX-1 dose rate measurement is not a standard measurement of the environmental dose rate. However the RDX nuclear DX-1 results are consistent for all RC drilling programs and they are likely to be similar to and an indication of the environmental dose rates during mining operations.

Arafura also routinely uses Radiation Alert® Inspector instruments; these have digital readouts and operate in either count rate or dose rate modes averaged over a period of time. The Radiation Alert® Inspector instruments typically record higher dose rates when placed directly on the rock"s surface than the RDX instrument because the Radiation Alert® Inspector also measures alpha radiation as well as beta and gamma. The Radiation Alert® Inspector instrument shown in Figure 32 is typically attached to a belt and is often left on in active audio mode while traversing during reconnaissance exploration in the field. The instrument detector is protected by the leather case and therefore measured dose rate are essentially an environmental gamma dose rate when worn on the hip because the alpha and a proportion of the beta radiation is blocked by the case.

Figure 32: Example of naturally occurring colluvial soils (unconsolidated fine gravels and sands) in a drainage feature with elevated background radioactivity and dose rates about 2.3km NW of Nolans Bore that was discovered in March 2009 by following up radiometric features in the Nolans airborne radiometric survey. The dark minerals are natural accumulations of locally derived heavy minerals (magnetite, monazite and zircon). The 3.3 µSv/h dose rate which is measured on the ground at this site decreases to an environmental dose rates measured at hip height of about 0.5-1.5 µSv/h in this general area.

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As a general guide experience has demonstrated that most Nolans Bore-type mineralisation emits about 3-30µSv/h although the occasional high grade sample may reach a maximum of 50-70µSv/h. This range in dose rates is based on measurements made directly on the surface of all RC drill sample residues (averages about 30-35kg per metre) from the Nolans Bore project area. The highest dose rates recorded at Nolans Bore have been measured by placing the Radiation Alert® Inspector instrument directly on top of rare localised clusters of mm-sized thorite and or thorianite minerals in drill core with highly localised surface dose rates of 100-275 µSv/h however one-metre RC samples of this material typically average 20-30 µSv/h. The dose rates on drill core are consistent with those measured on the RC sample residues. The high grade drill core samples are stored in Arafura"s secure storage area with limited access. The dose rate drops off quickly with distance from the drill core or RC samples typically reading background levels within about 1-3m depending on the amount of material and the dose rate. The dose rates from the small assay pulp samples stored in Arafura"s shed are typically indistinguishable from background at 20-50cm.

A number of other prominent airborne radiometric features also have elevated U and Th in the project area. Most of the areas with elevated U and Th coincide with areas of outcropping granite or metamorphic rocks although the highest values are often associated with localised pods or lenses within these units, with maximum assays of up to about 500-1000ppm of Th or U depending on the rock type, and in most cases Th > U. There are also some localised and anomalously high U and Th airborne radiometric features with natural background environmental dose rates similar to that at Nolans Bore. For example surface dose rates of 5-13µSv/h have been measured Radiation Alert® Inspector instrument on outcropping melanocratic monazite-apatite-biotite gneiss. This anomalous units forms an elongate body up to about 5m wide and 100m long about 4.6 km SSW of Nolans Bore near environmental site ARA6460. A localised reading of 25µSv/h was also recorded from a small coarse-grained monazite-biotite pod in a pegmatite body about 6km NW of Nolans Bore. At Nolans Bore similar rocks in drill core have only yielded up to 9 µSv/h. These localised radioactive units are not obvious in Figure 25 and Figure 26 because they are small units and hence they have been averaged together with their surrounds.

A number of distinct radiometric anomalies have elevated U and essentially no Th or K. Exploration and mapping has shown that these locations are related to outcropping calcretes. Arafura has assayed calcretes samples with up to about 125ppm U in the general project area however other exploration companies have found samples approaching 1000 ppm U west of the Nolans project area.

There are also numerous examples of monazite-rich sediments and soils derived from monazite-bearing metamorphic rocks in the area (*eg* Figure 32). In fact the soils in the general project area typically exceed crustal averages and a large percentage of soils and drainage features near outcrops in the ranges have elevated Th and U (Figure 20 and Figure 21).

The highest K values generally coincide with areas of outcropping granites although some metamorphic rocks also show elevated K. This is consistent with the mapped geology and corresponds to areas dominated by K-rich minerals (*ie*. K-feldspar and biotite). The K-poor parts of the area correspond to outcrops that lack significant amounts of K-rich minerals (*ie.* quartzite, quartz-rich metasedimentary rocks and carbonates). There is also considerable variation in the amount of K in areas of no outcrop. This variation is due to weathering, erosion, dispersion and deposition of K-rich minerals including K-clays.

The intricate airborne radiometric patterns that occur away from outcrops are largely controlled by the geological setting with factors such as topography, drainage and provenance determining the source and composition of the soil. A substantial amount of externally derived aeolian material can effectively mask or blend with and dilute dispersive run-off signatures. An aeolian component is significant in the north east of Figure 19, Figure 20 and Figure 21 and to the south and southwest of these image areas where the superficial material is dominated by quartz-rich aeolian sources (*ie.* poor in K, Th and U and a low total activity, see Radiometric Map of Australia, not shown).

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Ground-based radiation surveys.

The first ground-based radiometric survey of the Nolans Bore area was done in 1995 by PNC. This was used to aid in the development of the first detailed geological map of Nolans Bore and to locate areas of mineralisation (Thevissen 1995). This detailed reconnaissance ground-based survey was part of PNC"s systematic exploration program to locate and explain the sources of 180 radiometric targets identified in the region by their 1994 airborne survey of their Napperby project area. PNC found that 88 of these anomalous radiometric targets in the Aileron-Reynolds Region were felsic intrusives (granite) with 22 of these containing visible secondary uranium minerals. Radiometric soils, gravel in minor drainages, calcrete, and metamorphic rocks make up the remainder of their targets. A small number of the lower-priority airborne targets were not located in 1995 and the presence of an anomaly was unable to be explained by the surface geology and ground based surveys. Arafura has also conducted a number of similar ground-based exploration radiation surveys to locate anomalous radiometric features in the greater Nolans project area. A number of these were new features not previously identified by PNC or NTGS airborne surveys.

PNC"s airborne radiometric target MB02 (Nolans Bore) had a very strong U+Th spectral signature with the highest Th response and consequently the biggest statistical Z score (*ie.* 11.08) in their airborne survey (Thevissen 1995). PNC"s follow up ground-based radiometric surveys and mapping at Nolans Bore lead to the discovery of outcropping veins of apatite mineralisation (Figure 33). PNC"s detailed geological mapping located most of the major outcropping apatite occurrences in the Nolans Bore area however Arafura"s mapping shows that some bodies were clearly missed and PNC surveys did not extend out far enough. Arafura"s more recent airborne and ground-based radiometric surveys are consistent with the original PNC radiometric survey.

PNC acquired systematic radiation survey measurements using their EDA spectrometer to obtain TC-U-Th radiometric data. Unfortunately only contoured radiometric maps were provided in their report to NT DME as shown in Figure 33 below. The contours on Figure 33 closely match the total counts in Arafura"s detailed airborne dataset and subsequent ground based dose rate surveys also yield similar patterns.

Figure 33: The image shows a scan of PNC"s original ground-based total count radiometric survey over the Nolans Bore area. Contours are at intervals of 25 cps. The high areas in this survey closely match the highs measured in Arafura"s ground based surveys and also coincide with the highs in Arafura"s detailed airborne survey. Note this survey area covers a smaller area than Arafura"s surveys and it did not capture all of the outcropping mineralisation or radioactive highs.

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Arafura has completed a number of detailed ground-based gamma dose rate surveys over the Nolans Bore deposit and surrounds. Radiation by its nature is inherently random but the dose rates fluctuate around an average value. Hence readings are typically based on longer period instrument averages and are only recorded once the instrument value stabilises about a mean value. In most cases a dose rate measurement takes about 60 seconds although longer times are often required in highly variable areas. Ball park averages collected in this fashion are typically adequate for most spots because individual dose rate measurements can vary by up to about 50% over a small areas (~10-20m^2) and this is equivalent to the positional accuracy of hand-held GPS instruments. Surveys repeated at different times throughout the project history also slightly vary suggesting that instrumentation differences and exact location differences. It is also noted that different amounts of soil cover or outcrop exposure may influence the measurement (*eg* Figure 13).

Dose rates are routinely measured immediately prior to RC drilling to obtain a natural background dose rate at each drill site. These background readings are used as reference value for each RC drill hole to assist in the collection of radiometric data and assay sample selection. Arafura recognises this is important in elevated background areas where measurements of RC drill sample returns must be measured on top of the RC residue bag in an attempt to shield out the high natural background dose rates from the ground surface. Operationally this is especially important where the natural background exceeds about 1-3 µSv/h because this dose rate is equivalent to the low-grade mineralisation cut-off value used to discriminate samples for assay. Experience has shown that Arafura"s method usually works and readings which are lower than the elevated background values can be measured in most instances. Furthermore these initial background readings can be used as a reference point to ensure the area is rehabilitated back to similar levels. The highest background environmental dose rate measured by Arafura was 25 µSv/h SE of the stock bore near NB1009, however this is not a natural background value because mineralisation was disturbed and exposed by earth works at the time. The area has since been returned to more normal values.

Pre-disturbance environment dose rates were first measured by the author soon after joining Arafura in 2006. Values of about 5-14 µSv/h were routinely measured at 1m above the land surface in the North Zone coincident with PNC"s local highs and outcropping mineralisation. The highest values were measured directly above partially outcropping mineralisation. I also demonstrated to myself at the time that dose rate readings significantly dropped off to the north of the exposed mineralisation and natural background was about 0.2-0.5 µSv/h. All measurements were made with the Radiation Alert® Inspector instrument but actual GPS positions were not recorded at that time.

Arafura"s most comprehensive ground-based environmental survey was done as a specific task just prior to the 2007/08 RC drilling program (Figure 34). Dose rate measurements were recorded within 0.5m of previously drill collar locations and within ±4m of planned drill collars (Dixon 2007). Additional readings were also collected on a 25m x 25m grid pattern over areas with elevated natural background gamma dose rates. The 2007 radiometric survey provides a robust assessment of natural background values across the entire project area prior to any substantial disturbance by Arafura. The 2007 radiometric survey was completed 17-26 September 2007 and used a Ludlum Measurements Inc Model 2241-3 survey meter last calibrated 22 March 2007. The survey utilised the gamma probe attachment with the beta window closed and readings taken over a period of 1-5 minutes averaged in slow mode. The dose rate value was recorded once the digital readout stabilised. Most sites were surveyed prior to the commencement of RC drilling on 22 September 2007. All readings measured after drilling commenced were distal to drilling operations and recorded while the rig was not in operation and approximately 500m away. Arafura had planned additional infill surveying of the elevated background area in the SE but this did not eventuate because drilling operations ramped up. Environmental dose rates were systematically measured at 749 sites in 2007 and a statistical analysis of this data is shown in Table 9 below.

Dixon (2007) concluded that environmental dose rates above 0.8µSv/h are anomalous at Nolans Bore. Arafura"s measurements have since shown background readings outside of the deposit area are typically about 0.1-0.4µSv/h although natural background dose rates can exceed 0.5µSv/h at some locations in the region. Given there is some error in this measurement Arafura has adopted a value of 0.7µSv/h as being anomalous in the deposit region. Dixon"s survey clearly demonstrates that the dose rate across large parts of the Nolans Bore deposit as it stands today naturally exceeds 0.57µSv/h (equivalent to 5mSv per year full time occupancy). The 2007 survey outlined several natural highs with the largest area of elevated radioactivity occurring near the stock bore and cattle yards. Arafura has since measured a number of localised spots at Nolans Bore where the dose rates exceed Dixon"s 11µSv/h maximum (almost 100mSv/y). While dose rates above 10µSv/h are atypical at present, dose rates of these levels and more are anticipated in mining when the massive mineralisation is exposed.

The environmental gamma dose rates were re-surveyed by Arafura in 2015 using a Radiation Alert® Inspector instrument as a follow up ground disturbance during the 2011 drilling program and the subsequent

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rehabilitation of the disturbed areas. The results of the 2015 surveys are shown graphically in Figure 35 below and use the same colour scheme as for the 2007 survey (Figure 34). Arafura"s rehabilitation has covered some of the outcropping mineralisation in the NW part of the deposit and substantially reduced the environmental dose rate (Figure 34).

Table 9: Natural environmental dose rates measured 1m above the surface at Nolans Bore in September 2007 (from Dixon 2007).

	Dose rate (µSv/h)
mean	0.80
SD	1.05
minimum value	0.16
5%ile	0.26
25%ile	0.37
50%ile (median)	0.50
75%ile	0.79
95%ile	2.43
99%ile	5.86
maximum value	11

Robust environmental gamma dose rate surveys were also completed in 2005 and 2006 by Sonter (2005) and Collier *et al* (2007), respectively. Sonter"s 2005 survey was limited to 41 sites at Nolans Bore with two repeats and a few additional measurements to determine background (Figure 36). Sonter estimated a natural background gamma dose rate of 0.2 µSv/h and a global average of 1.3 µSv/h at Nolans Bore. The GPS position of Sonter"s highest reading was not recorded however the location of this surveyed location has been estimated to within about 10-20m based on his description. Sonter"s highest value is not unrealistic as similar or higher values have been recorded by Arafura in the same area. Sonter"s measurements were collected in the earlier part of the project and are clearly biased towards the mineralised areas that were being drill tested at that time. Consequently the global average reported in Sonter (2005) does not provide to fair representation of the average natural background gamma dose rates across the entire Nolans Bore area as it is known today.

ANSTO completed a systematic widespread survey over the Nolans Bore deposit in 2006 (Collier *et al* 2007) subdividing the Nolans Bore area up into twelve major grid sectors with 4 measurements obtained 200m apart in each sector (Figure 37). This early grid-based survey approach covered most of the project area and was considered representative of the area at that time. Collier *et al* (2007) also measured background gamma dose rates at the Aileron Roadhouse and near the creek to the north and south of the Nolans Bore deposit for comparison, with background gamma dose rates of 0.15-0.18µSv/h. ANSTO"s average environmental gamma dose rate for Nolans Bore area is 0.26µSv/h. This average is much lower than all other surveys however the differences are easily explained. The ANSTO survey measured widely spaced data points and the more localised areas of elevated background at Nolans Bore measured by Sonter (2005) and Dixon (2007) were not systematically measured in the ANSTO survey. In addition 26 of ANSTO"s measurements were made in areas dominated by soils and country rocks outside of the LOM pit. ANSTO"s highest dose rate in their gridded survey (site C2-2) is about 9m from a location measured by Dixon and the two values are within 10% of each other. The survey results from Sonter (2005), Collier *et al* (2007) and Dixon (2007) are comparable and appear to be within an acceptable experimental error. Furthermore Dixon"s more detailed site survey clearly demonstrates highly localised variability with differences of 50% or more over distances of 25m or less.

Collier *et al* (2007) reported a high background reading of 5 µSv/h in the cattle yards and also noted that reading was 20 µSv/h at the contact with the ground. Similar observations have been systematically observed by Dixon (2007) and Arafura in general as part of routine exploration activities in this area.

All residual drilling material brought to the surface during RC drilling programs has been buried in accordance with Arafura"s approved MMP and the land surface at each drill hole was returned to its natural shape. In addition the environmental dose rates measured at each site and the burial area are consistent with pre-disturbance values. Finally it should also be pointed out that the earth dam was constructed by Aileron Station after Dixon"s 2007 survey and the NE part of this dam is dug into an area of naturally elevated radioactivity. The location of the earth dam is clearly evident in the image behind the survey data with elevated values evident on the NE margin prior to construction (Figure 34).

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Figure 34: Annualised environmental dose rate measured in September 2007. Background satellite image was captured in 2012 after the 2011 drilling program and shows additional cleared lines where infill definition drilling has occurred since this survey.

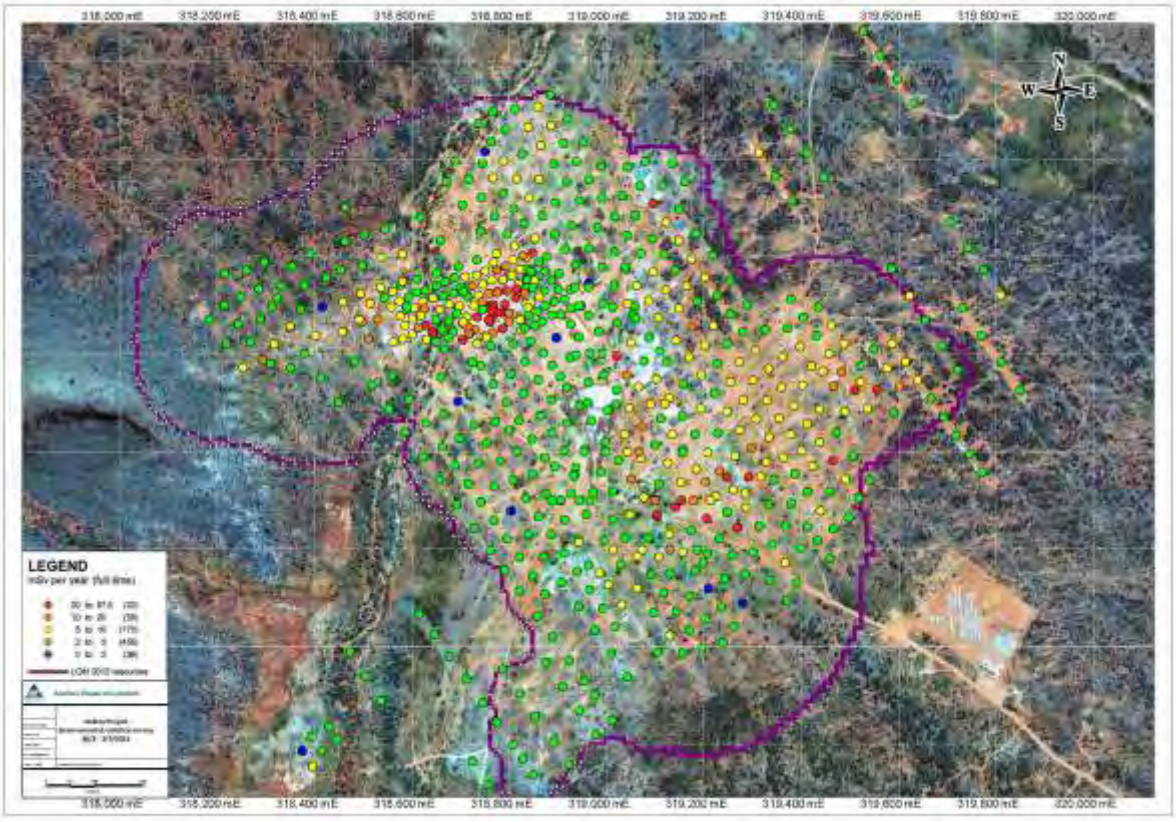

Figure 35: Annualised environmental dose rates measured at each rehabilitated drill collar in 2015. The colour-coded theme is identical to Figure 34 above.

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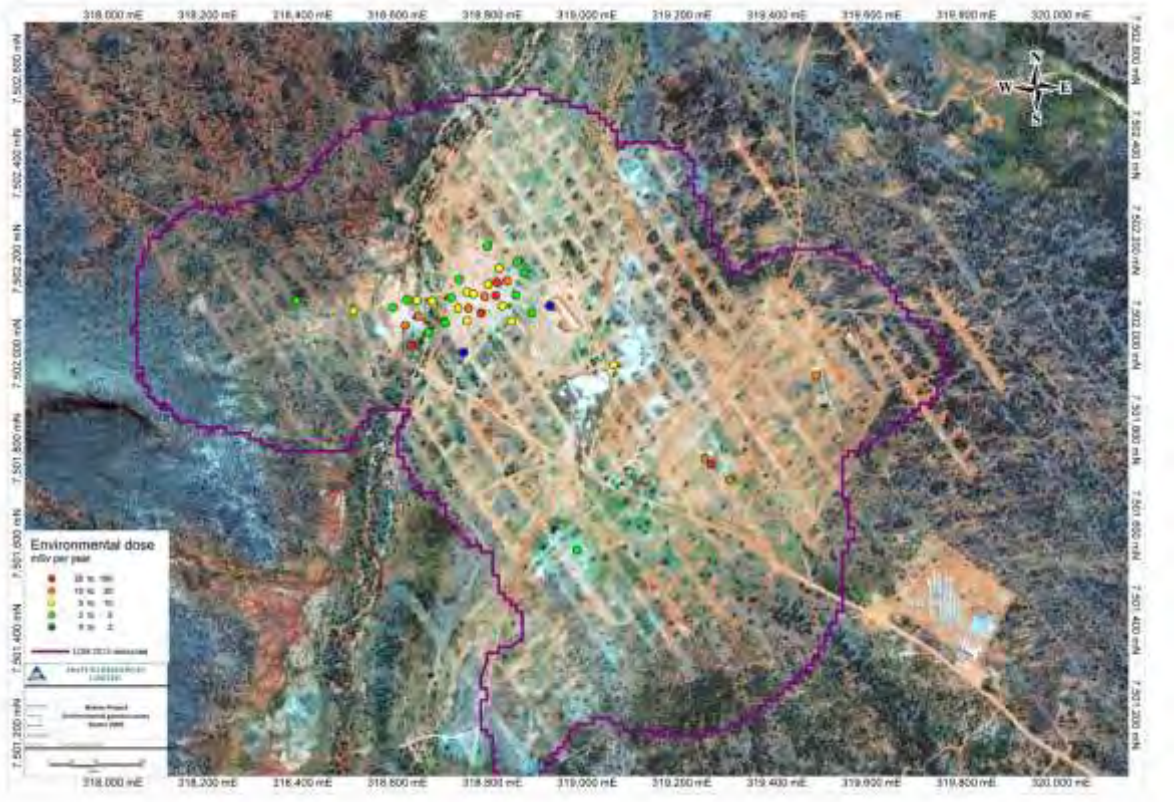

Figure 36: Image showing the results of the environmental gamma dose survey by Sonter (2005). Same area and colour codes as in Figure 34 above.

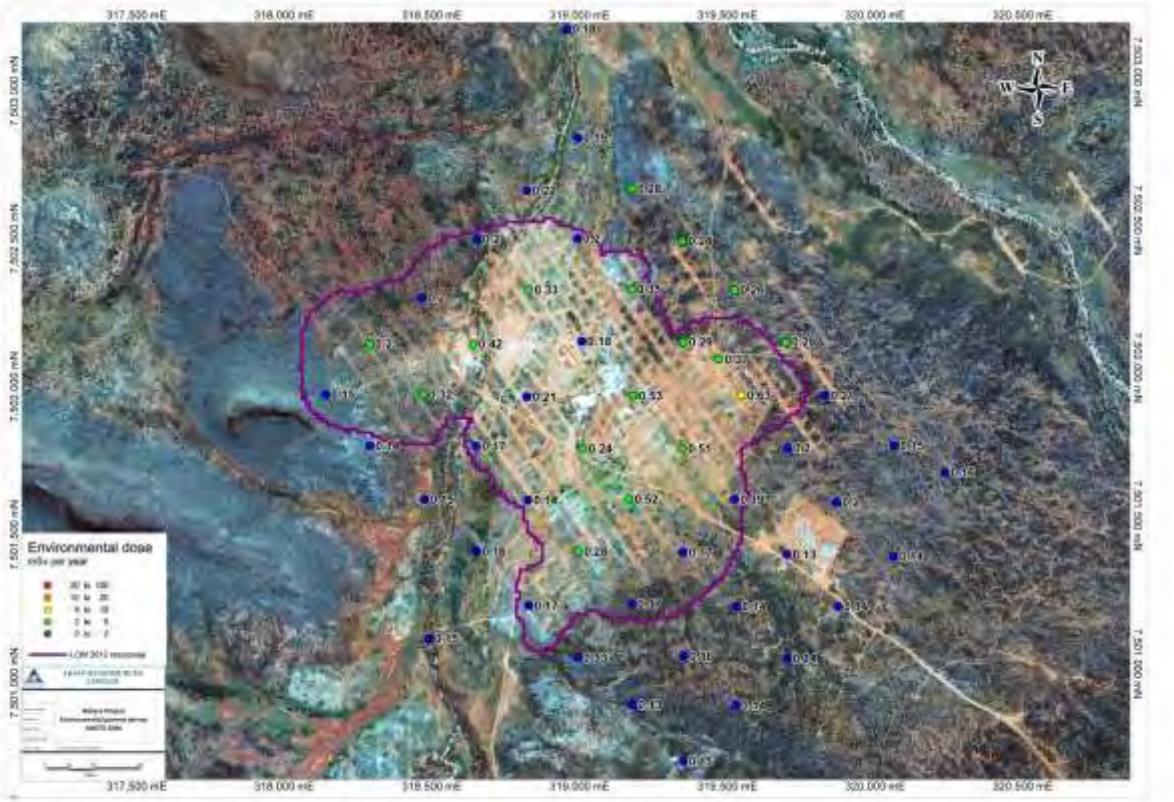

Figure 37: Image showing the results of the environmental gamma dose survey by ANSTO in 2006 (Collier *et al* 2007). Note this is a slightly larger area but same colour codes apply as in Figure 34 above. Measured dose rates in µSv/h are shown for each site.

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Stream sediments

A comprehensive set of representative stream sediment samples were collected from drainage features in the project area in November 2009 for detailed low-level assays of numerous metals by ICPMS. These samples were collected for two purposes. Firstly to determine if the Nolans Bore deposit could be detected by its stream sediment geochemical signature, and secondly to establish base line compositions prior to substantial mining related disturbance.

In summary, detailed analysis indicates it is possible to detect the unique Nolans Bore geochemical signature in stream sediments however this signature is only clearly evident in four proximal samples with a number of other proximal samples also showing positive anomalous responses in some key geochemical indicators. This supports the original stream sediment study in the Nolans project area by Burlinson (2004).

Representative stream sediment samples were collected at each site by scraping away the topmost organic layer (*ie* leaves and grass) and then by scooping up the sediments with a plastic scoop into a bucket at systematic intervals across the entire drainage feature and then it was sieved. The process was repeated at each site for each sieve size. Depending on the overall size of the drainage feature about 3-7 scoops were collected. Assay sample sizes were about 2-4 kg for the -3.3 mm fraction and about 50-100g for the -80# fraction (-180µm). The finer grained fraction can be directly compared to an earlier baseline geochemical study of the area which also used the same mesh size (Burlinson 2004). The coarser fraction of Burlinson (2004) is -20# and +80# and clearly different to the -3.3mm fraction sampled and assayed in the 2009 survey.

A total of 54 stream sediment pairs (-3.3mm and -80#) were collected from 51 separate sites within about 4km of Nolans Bore in 2009. Duplicates show that the results are repeatable to with an acceptable error. In most cases, U- and Th-bearing minerals often occur as fine grained heavy minerals in stream sediments and these are typically diluted by silicate minerals in the coarser fractions. This is observed in the Nolans project area as higher U and Th concentrations are mostly found in the finer grained fraction (Figure 38). A single stream sediment sample (site 24) had more U and Th in the coarser grained fraction and repeats the findings of Burlinson (2004) from a similar location in the same drainage feature. This implies that it is a likely to be a natural feature associated with proximity of outcropping Nolans Bore-type mineralisation although it may be related to localised disturbances (see below).

The stream sediment geochemistry shows that the detritus is derived from sources with variable Th/U ratios (Figure 39) and detailed analysis indicates that U and Th alone are not good discriminators of Nolans Bore-type mineralisation. Despite this, U and Th are useful at aiding in the detection of Nolans Bore type signatures especially when other diagnostic geochemical parameters such as the REE, Sr and P are also considered (Figure 39). The U (Figure 40 and Figure 41) and Th (Figure 42 and Figure 43) concentrations at each site are shown as a thematic coloured map for each size fraction. The coarser grained fractions highlight some localised U and Th anomalism in the stream sediments around Nolans Bore but there are exceptions and some sites do not highlight Nolans Bore. Clearly U and Th assays of the fine grained fraction do not always differentiate Nolans Bore from its surrounds. Figure 43 shows that the stream sediments in the entire region is relatively enriched in Th with most fine grained samples exceeding 5 times the average UCC.

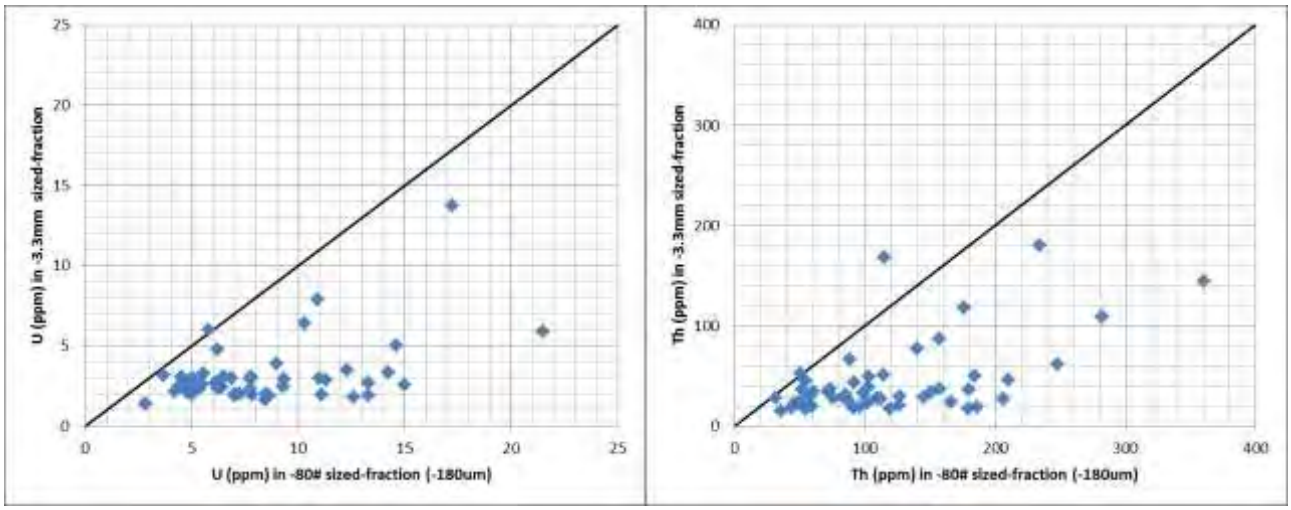

Figure 38: Composition of U and Th in different sized stream sediment fractions from the Nolans Bore area.

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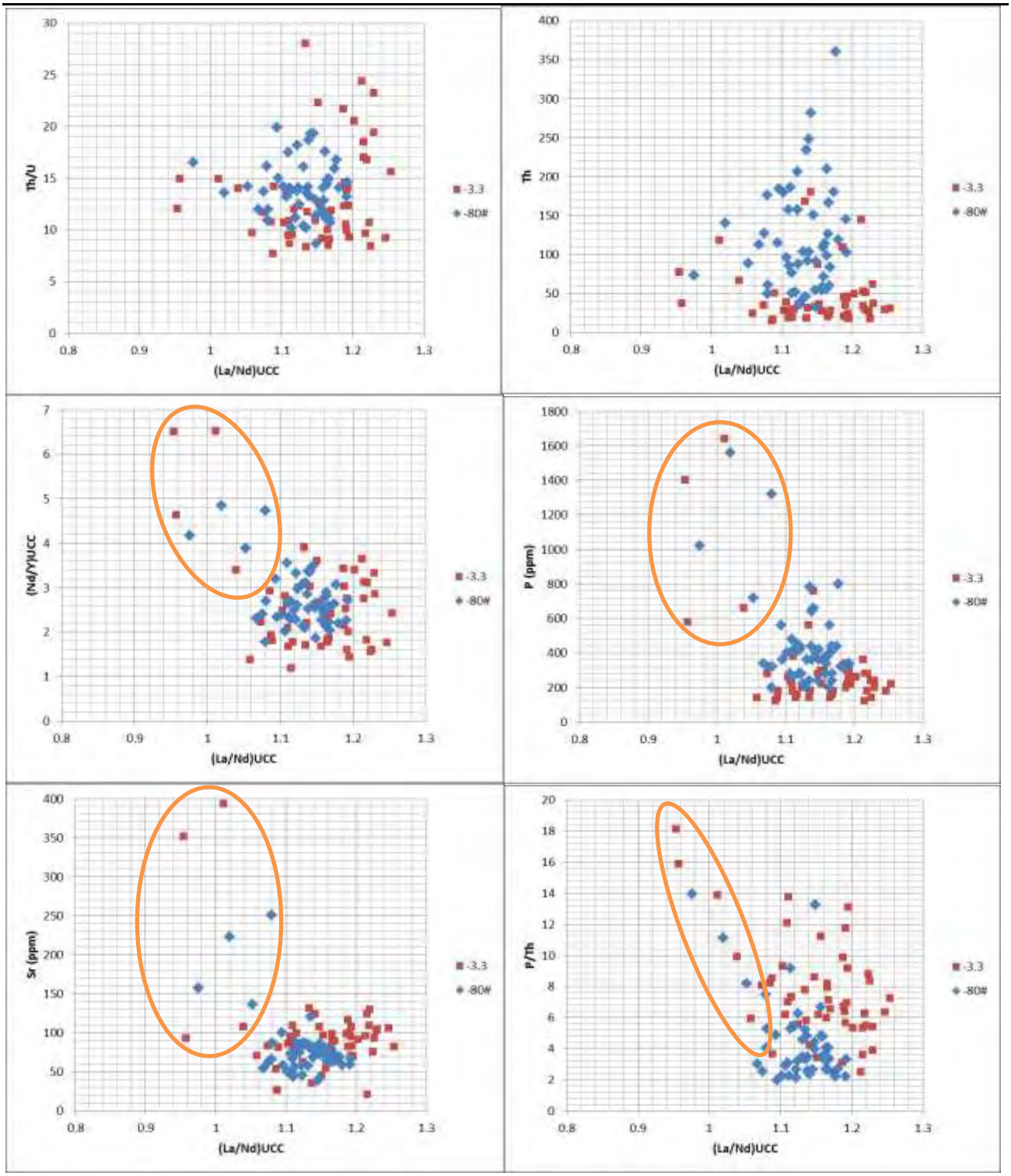

Figure 39: Various plots showing the chemical compositions of stream sediment pairs in the Nolans project area. These plots clearly show that four samples pairs consistently standout from the rest. These four samples (outlined in orange) highlight an obvious Nolans Bore-type signature while the remainder of the possible samples are less clear and cluster near samples with more regional signatures.

The plots shown in Figure 39 use the fact that the geochemistry of Nolans Bore-type mineralisation (*ie* its REE fractionation pattern and other associated elements such as P, Sr, Th and U) is distinct and very different compared to the average continental crust (*eg* Figure 16). Figure 16 clearly shows that $(La/Nd)_{UCC}$ is less than one for Nolans Bore-type mineralisation and this strongly contrasts with the vast major of the surrounding rocks in the project area, almost all of which tend to be slightly more LREE fractionated than the average crust [*ie* $(La/Nd)_{UCC}$ values greater than one]. Hence plots utilising a selection of elements or pertinent ratios specific to Nolans Bore mineralisation can readily differentiate samples with a clear Nolans Bore-type geochemical signature from samples derived from other sources.

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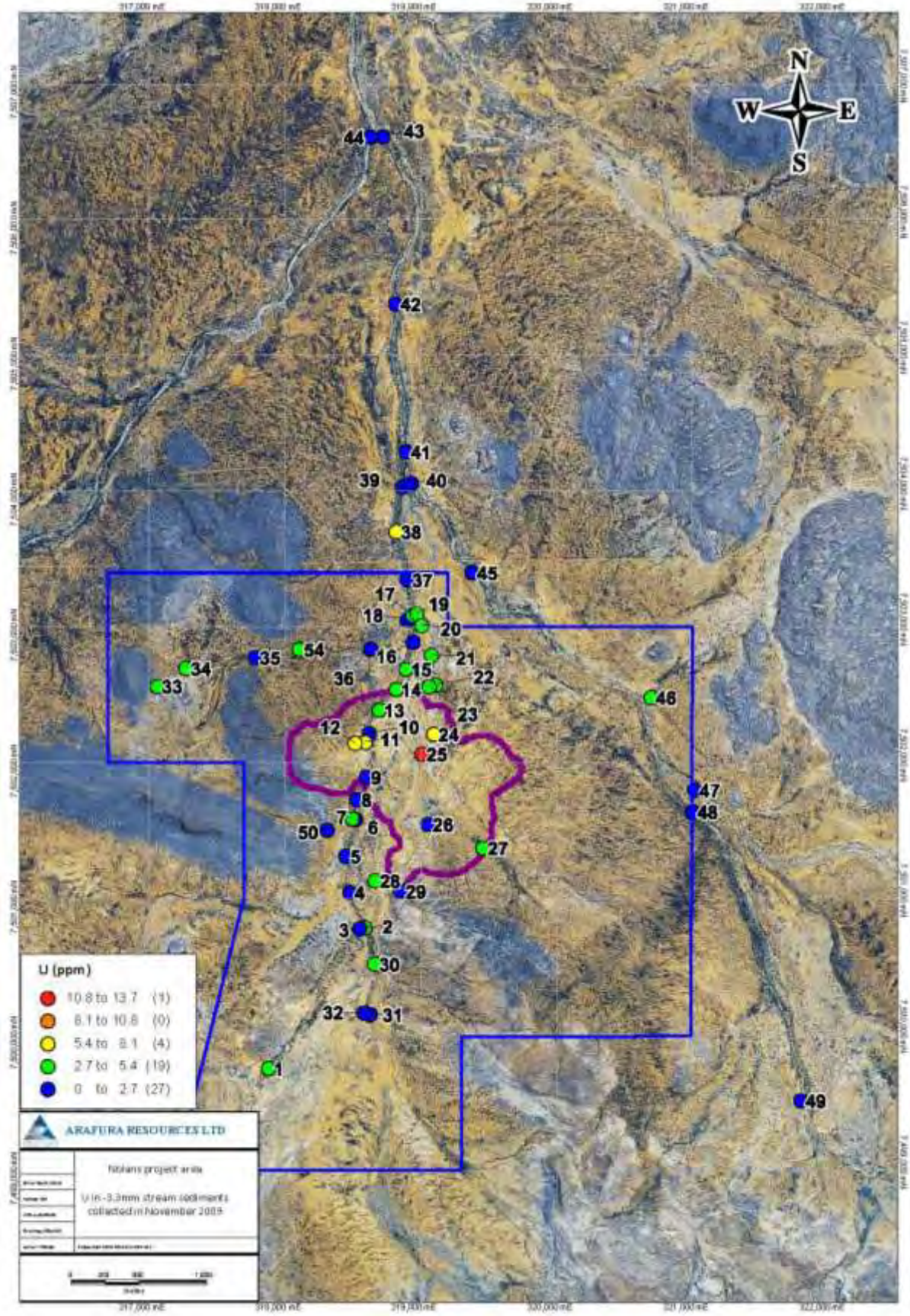

Figure 40: Thematic map showing the U composition of the -3.3mm fraction of stream sediment material at each sample site (numbered). Most sites generally have less than 5-10% coarser material. Values are coded relative to the average UCC (2.7 ppm) and displayed as follows; blue less than UCC, green 1-2 x UCC, yellow 2-3 x UCC, orange 3-4 x UCC and red more than 4 x UCC.

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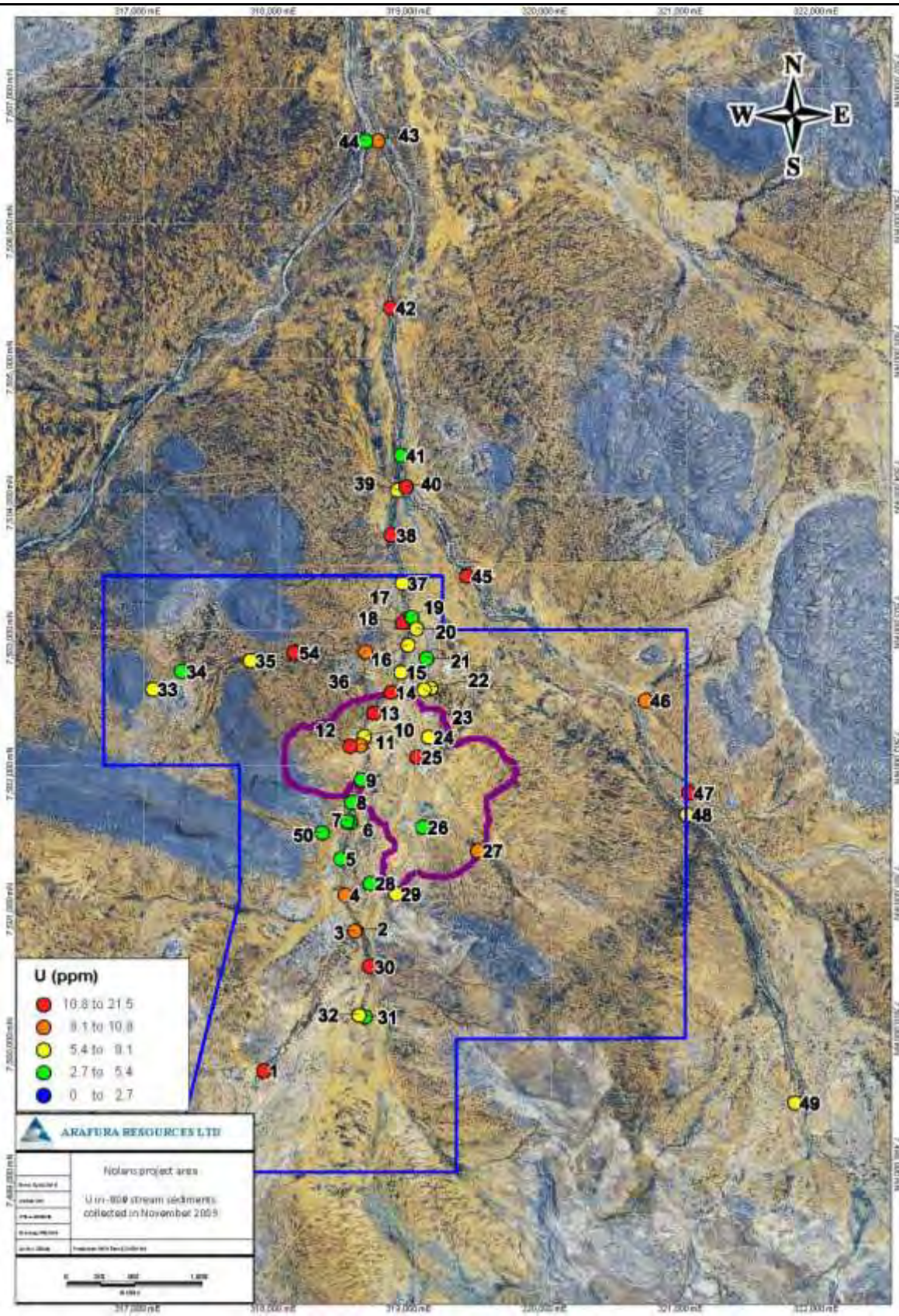

Figure 41: Thematic map showing the U composition of the -80# fraction of stream sediment material at each sample site (numbered). Values are coded relative to the average UCC (2.7 ppm) and displayed as follows; blue less than UCC, green 1-2 x UCC, yellow 2-3 x UCC, orange 3-4 x UCC and red more than 4 x UCC. Compare with coarser sized fraction in Figure 40.

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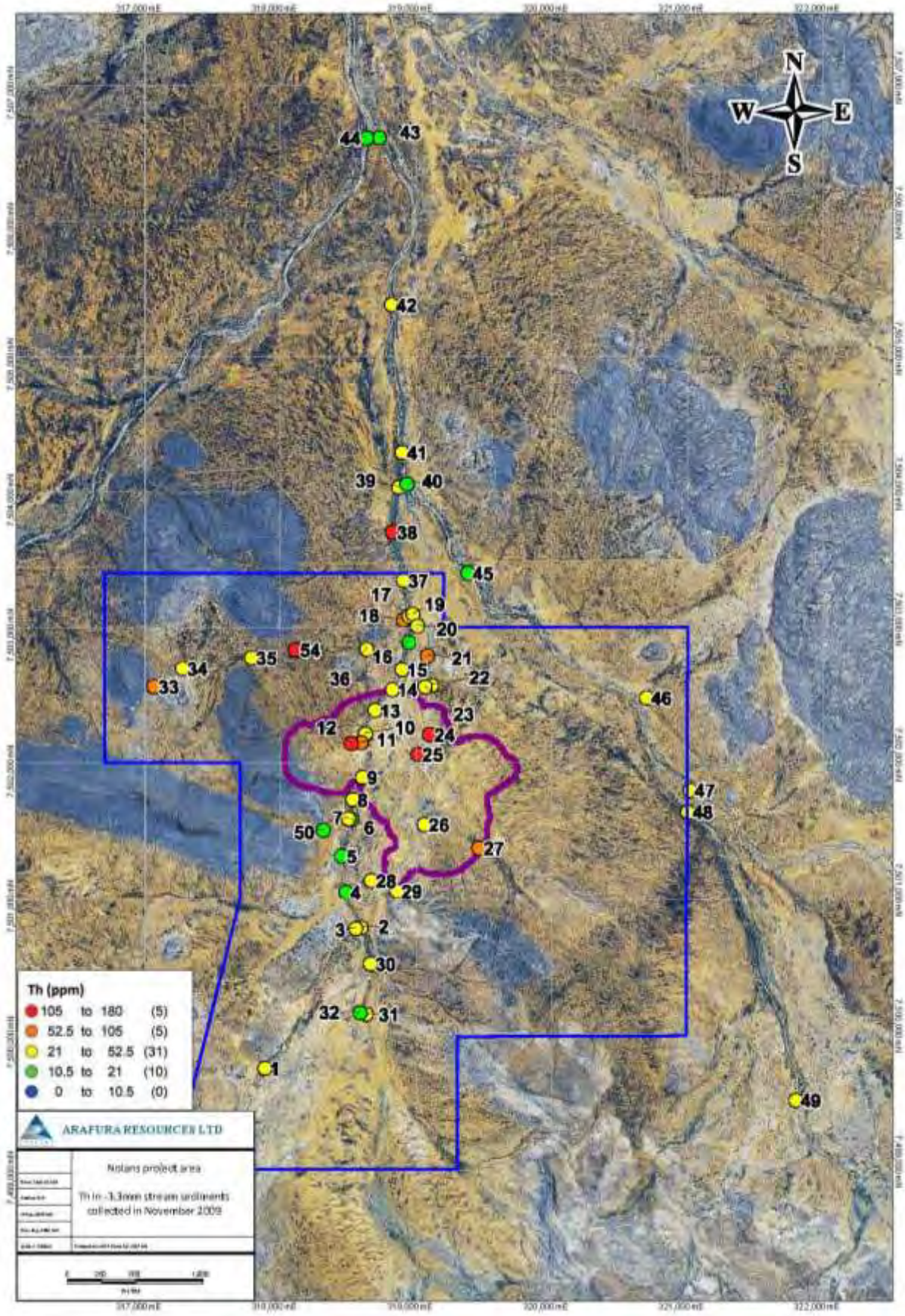

Figure 42: Thematic map showing the Th composition of the -3.3mm fraction of stream sediment material at each sample site (numbered). Most sites generally have less than 5-10% coarse material. Th values are coded relative to the average UCC (10.5 ppm) and displayed as follows; blue less than UCC, green 1-2 x UCC, yellow 2-5 x UCC, orange 5-10 x UCC and red more than 10x UCC.

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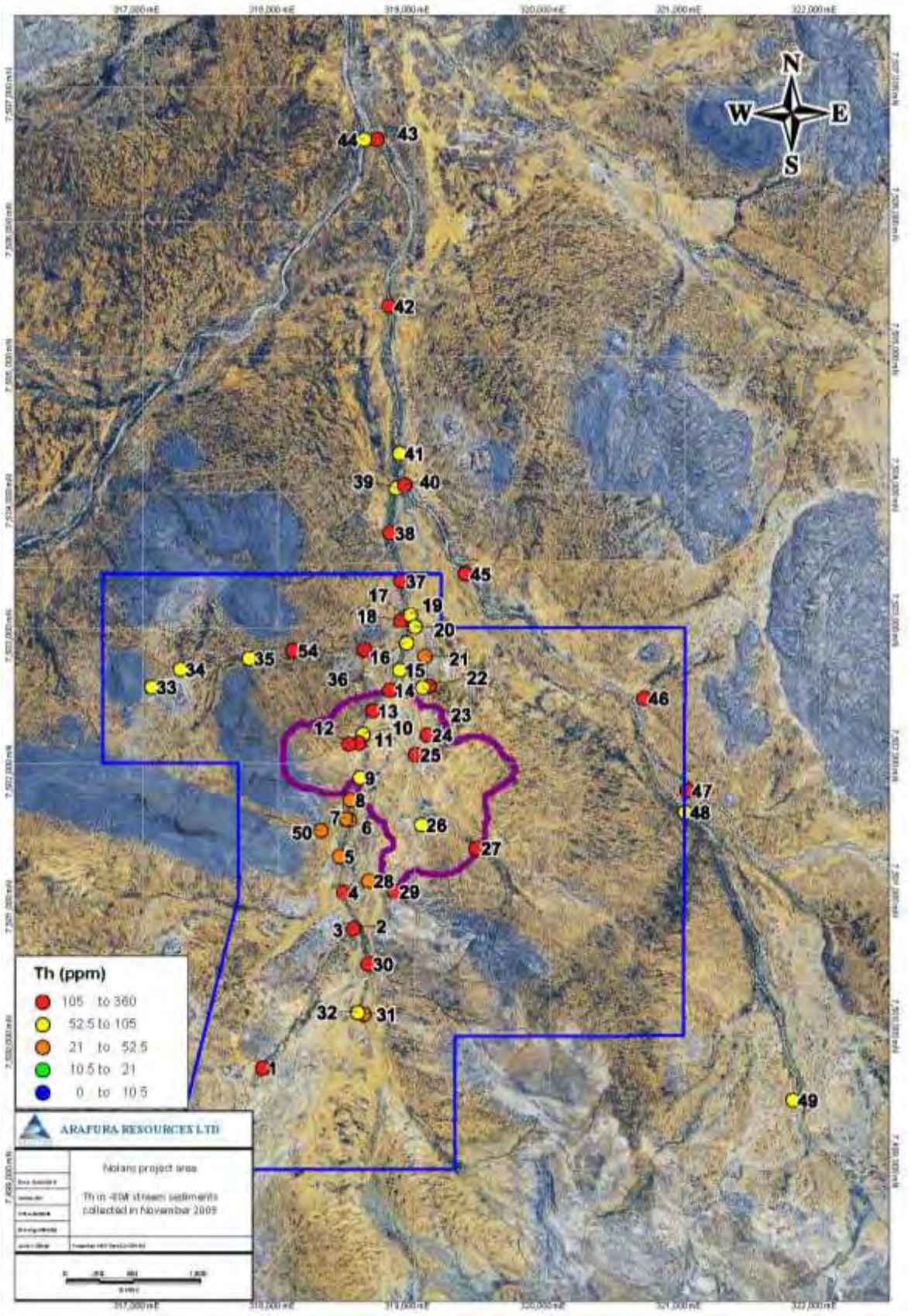

Figure 43: Thematic map showing the Th composition of the -80# fraction of stream sediment material at each sample site (numbered). Th values are coded relative to the average UCC (10.5 ppm) and displayed as follows; blue less than UCC, green 1-2 x UCC, yellow 2-5 x UCC, orange 5-10 x UCC and red more than 10x UCC. Compare with coarser sized fraction in Figure 42.

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Sites 11, 12, 26 and 33 have stream sediment REE characteristics that are clearly indicative of Nolans Bore-type mineralisation in both the coarse and fine fractions and their geochemical signatures have been highlighted in Figure 39. Sites 13, 18, 19, 21, 22, 24, 25, 27, 34, 35, 38 and 54 also show one or more anomalous chemical signatures indicative of Nolans Bore type mineralisation. Apart from site 13 which is downstream of outcropping Nolans Bore mineralisation, all of the geochemically anomalous stream sediment sites occur in minor drainage features. This is typically seen where there is limited outcrop or the contributing sources are rapidly degraded or readily swamped by the regional detritus. In particular sites in the most significant drainage feature that passes through Nolans Bore (*ie* sites 9 and 10) show no anomalous results.

There are other elements and ratios that could also be used in addition to those shown in Figure 39. For example, fluorine is much more abundant in Nolans Bore-type mineralisation than in the other rock types in the region, but F is not routinely assayed because it is costly compared to a routine ICPMS element suite.

Furthermore, Nolans Bore-type mineralisation has a very distinct and relatively low $^{87}Sr/^{86}Sr$ ratio of about 0.705-0.708 with very little Rb (Huston *et al* in press). Despite a wealth of background whole rock $^{87}Sr/^{86}Sr$ data in this area, the low Sr isotope signature of Nolans Bore type mineralisation is almost certainly unique in the area, especially considering the felsic igneous and sedimentary rock units that dominate the catchment areas around Nolans Bore (*cf* Sr isotope data reported from the greater Aileron-Reynolds region by Black *et al* 1983; Collins *et al* 1995; Cartwright *et al* 1999). There are some outcrops of mafic granulite and amphibolite in this area and it is possible that these units may have similarly low $^{87}Sr/^{86}Sr$ ratios. However mafic igneous rock types are rare in this region and their compositions are likely to be more evolved than the Nolan Bore signature (*ie* higher ratios). Hence an elevated Sr content and the low $^{87}Sr/^{86}Sr$ ratio are likely to be very distinct and indicative of Nolans Bore-type mineralisation, especially when the diagnostic REE signature is also considered.

Arafura plans to complete a baseline Sr isotope study on the country rocks in the Nolans Bore area because the Sr isotope signature and the REE fractionation pattern both standout as distinctive geochemical features which strongly contrast with the surrounds. Hence it is postulated that Sr isotopes and REE patterns can be used to accurately fingerprint and model material derived from Nolans Bore-type mineralisation. Likewise these distinct geochemical and isotopic signatures should be utilised as part of ongoing environmental monitoring studies in the future to track and monitor downstream contamination from the Nolans Bore mineralisation.

Given U and Th in the stream sediment samples are not diagnostic pointers to Nolans Bore mineralisation, it is therefore not critical to obtain U and Th decay chain radionuclides in stream sediment samples as these will not be diagnostic at fingerprinting Nolans Bore type mineralisation. The same will apply to waste rock and residue storage areas where the secular equilibrium of the decay chain has not been affected. However decay chain analyses may be useful were Nolans Bore type mineralisation has been chemically processed.

Finally it should be noted that the coarser grained stream sediment assay samples discussed above will be close to, but not identical to, the natural composition of the stream sediments at each site. This occurs because the creeks are generally dominated by sand- and silt-sized detritus. However the actual U and Th composition at each site are likely to be slightly different.as most locations also have a small amount of oversized gravel that exceeds 3.3mm.

Considerations re geochemical interpretations of stream sediment data.

The area around Nolans Bore has been disturbed and it is clearly not pristine, so all of Arafura‟s stream sediment assay results are potentially biased by additional contributions from localised disturbance associated with pastoral and or exploration activities.

The drainage catchments for all stream sediment samples collected in this study have been subjected to minor earthworks associated with development of station tracks, yards, fence lines and the construction of earth dams. The impacts of these activities are essentially insignificant although newly constructed roads and earth dams can have a minor impact if they are not consolidated and stabilized. This is not normally regarded as a major geochemical issue especially when compared to the impacts of intense grazing or exploration activity which can provide additional sediment that is geographically biased.

The higher U and Th concentration observed in the coarser size fraction at site 24 suggests a proximal source and basically repeats the findings of Burlinson (2004). Irrespective of whether this is a disturbance related influence or not, colluvial sheet flow sediments are deposited across the area. These sheet flow processes are capable of transporting both the coarse and fine grained fractions and they contribute to the alluvial sediments deposited in the drainage features in the area.

Arafura‟s ongoing rehabilitation returns all areas disturbed by exploration activities back to their original

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landform as soon as possible. Arafura uses blade up clearing, does not scarify the cleared drill lines and limits its traffic to specific access tracks which means that cleared lines are allowed to revegetate. This minimises erosion and means that freshly exposed soils and subsurface rocks are only briefly exposed as additional sources. Furthermore the main disturbance is localised to a small area at each drill hole, costean or pit. This means the erosional potential impact is likely to be minimal provided the composition of the soil at the surface does change and the proportion of the disturbed area is small compared to the drainage catchment being tested. Arafura"s rehabilitation protocols also ensure that the radioactivity at each site is consistent with pre-disturbance levels which means that the potential for new sources brought to the surface by exploration activities is very low.

The result from site 24 may be natural given Burlinson"s stream sediment survey. However there are also impacts from the activities of Aileron Station to be considered. Aileron constructed an earth dam about 200m north of Nolans Bore in 2008 (Figure 44) and hence the repeat result may be a fluke as this earth dam is directly on top of the Central Zone and up stream of this site. It is therefore highly likely that this earth works disturbed mineralisation; it definitely uncovered weakly radioactive pegmatite, calcrete and carbonate-cemented hard-pan soil. A major rain event occurred in November 2008 filling the dam with a layer of fines and resulted in significant turbid drainage and sheet flows across the area as it followed a dry period and intense grazing at Nolans Bore. The grass in the area was eaten out and hence the surface water run off would have transported disturbed soils. Situations such as this may have contributed to the geochemical signature at site 24 and at Burlinson"s site.

The soils in area around Nolans Bore are often effectively tilled by a large number of cattle using the bore and yard. This intense grazing and the sheet flow run-off and soil erosion means an additional supply of sediment derived from the area around Nolans Bore itself has contributed to the colluvial and alluvial sediments since about 1978. Despite this Nolans Bore is currently difficult to detect in stream sediments collected in distal downstream locations; it is only evident in proximal locations.

Figure 44: Earth dam constructed by Aileron Station on top of Central Zone in 2008. Image taken November 2008 looking to north.

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Other stream sediment studies.

Because the stream sediments in the area are dominated by quartz and other silicates, Arafura has also collected bulk stream sediment samples (~25kg of the -3.3mm sized-fraction in round one and ~50kg of the -3.3mm sized-fraction in round two) from numerous sites throughout the greater Aileron Reynolds project area. Samples sites were selected to obtain a broad understanding of the rock types and key heavy minerals present in regional drainage catchments across the general area. Samples were collected from targeted heavy mineral trap sites (trees and rock bars) and panned to further concentrate the heavy minerals prior to assays and detailed petrology. As expected all of these heavy mineral samples contained elevated U and Th. However as with the stream sediment data above, it is difficult to detect distal Nolans Bore signatures using the heavy minerals.

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Analysis of the environmental monitoring sites.

A total of 26 environmental monitoring sites were established for the Nolans Project in 2015. The results and studies completed at these sites are documented in Dean and Grose (2015) and the locations are shown in Figure 45 below. A total of nine environmental monitoring sites are located inside the life-of-mine (LOM) pit which is outlined in black in Figure 45. These sites will be lost when mining occurs but are considered important because they are representative of the current setting associated with typical Nolans Bore-type REE mineralisation. Sixteen environmental monitoring sites were selected because they are distal to Nolans Bore-type REE mineralisation. Importantly these sites are also distal to ground disturbance by Arafura.

One environmental monitoring site (ARA8001) is located outside of the main mineralised area but is about 60m northeast of outcropping mineralisation at the Steinerts prospect. This monitoring site is on a sheet flow fan deposit that sheds off mineralisation and other rock types in the area. Site ARA8001 is about 40m away from two historic widely-spaced inclined exploration drill holes, one of which intersected mineralisation at depth. The actual environmental monitoring site was not disturbed during exploration RC drilling activities in 2005 although blade up clearing to remove grass and shrubs occurred immediately north of this site. The area around ARA8001 has since completely revegetated.

Some of the monitoring sites have been subjected to long-term and periodically intense grazing. Introduced grass such as *Chenchrus ciliaris* (buffel grass) is widespread and observed at most sites. Hence the environmental monitoring sites are not pristine but they are representative of the area.

A few additional sites are planned as follow up work to this study. In particular the current sites do not document and test the localised carbonate-rich areas where slightly more alkaline conditions are anticipated. These proposed sites will target carbonate-rich soils and substrates south of ARA8014 and northwest of ARA8019. At least two more sites will also be documented and tested inside the LOM pit over strongly calcareous soil north of ARA8008, and an additional site at Goanna northeast of ARA8011 is also planned. Furthermore a detailed analysis documenting additional plant species at some sites and determining the composition of the underlying bedrock and the variability of the soil profiles is also planned.

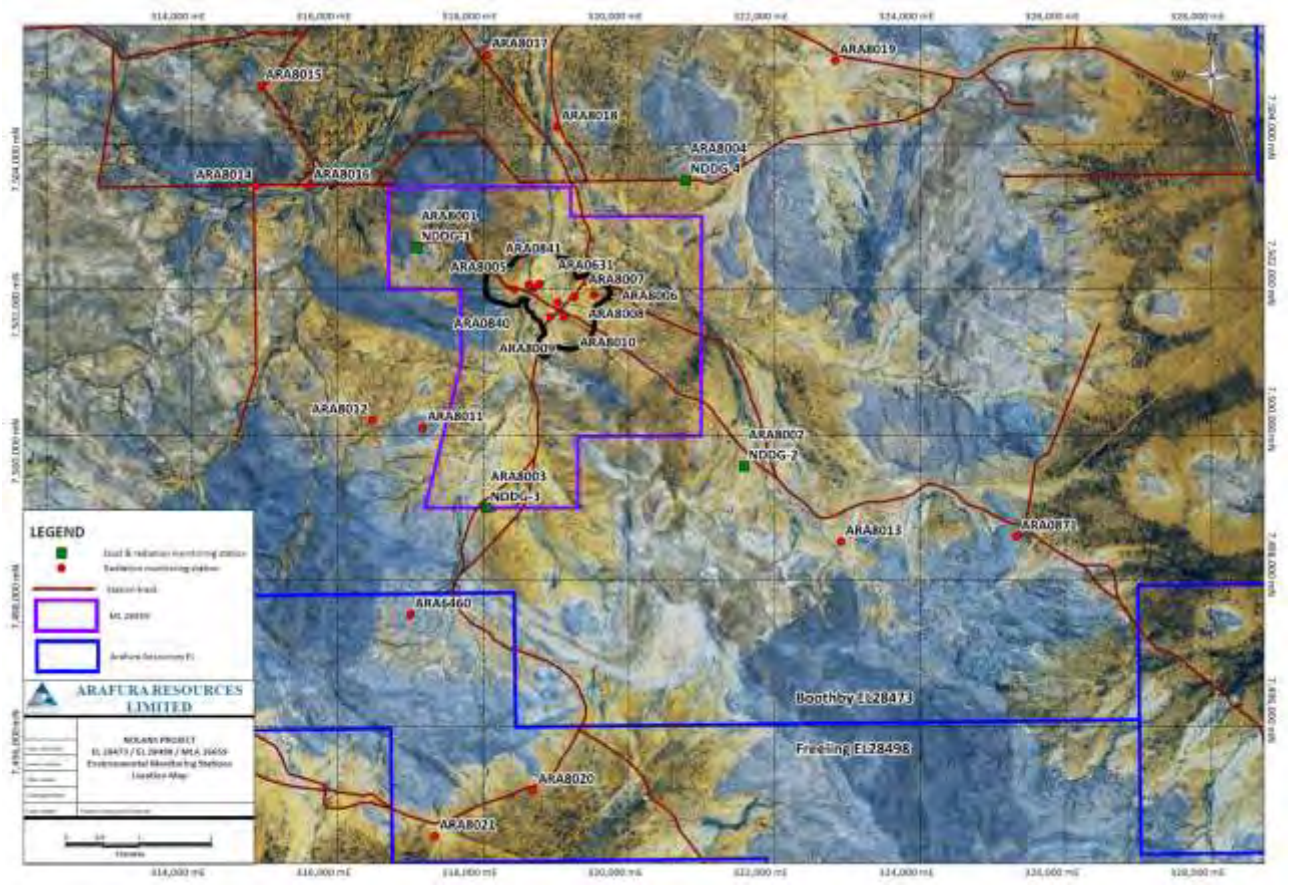

Figure 45: Location of environmental monitoring sites with long term dust deposition monitoring sites shown in green and all other sites shown in red. The LOM pit is outlined in black.

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Introductory background and site selection

Arafura"s environmental monitoring sites were established on Aileron and Pinehill pastoral properties to document the baseline conditions prior to substantial mining related disturbance activities. The overall aim of these sites was to document and determine the compositions of various environmental samples, and determine the natural radiological variability and uptake of uranium and thorium by various plants at these locations. Some of these sites will also be used for detailed analyses of U and Th radionuclide decay chain when enough material is available. Most environmental monitoring sites are close to existing tracks for ease of access. Sixteen environmental monitoring sites are located outside of Arafura"s planned disturbance and hence these have the potential to serve as long term monitoring sites during mining operations.

Since 2012 it is likely that the people from cattle station have driven pass some of these sites more frequently than Arafura. This is because Arafura has done limited work in this area since 2011. Arafura periodically visits all four of its dust monitoring stations at intervals of about 1-3 months to collect natural dust deposition samples (NDDG1-4 inclusive at sites ARA8001-8004, respectively). Arafura also visits biogeochemical reference sites, some of which are environmental monitoring sites, at least once each during biogeochemical sampling program. Arafura is unlikely to visit the environmental monitoring sites outside of the pit area during routine regional exploration activities.

An area northwest of Nolans Bore near the boundary of Pinehill and Aileron Stations was burnt by a lightning-induced fire associated with a major storm and rain event in early January 2007. This fire was not an intense destructive burn. Although the fire impacted area has largely recovered environmental monitoring sites were placed outside of the fire-affected region. Hence as far as the author knows all environmental monitoring sites have been free from bushfires since well before 1995 when the author first visited the area.

Three of the distal environmental monitoring sites are adjacent to cleared fence lines (ARA8004, ARA8014 and ARA8016). These sites have been disturbed by pastoral activities clearing fire breaks that are up to 10m-wide either side of the boundary fence between Pinehill and Aileron Stations. The last extensive clearing of all trees and vegetation occurred in late-2009 with some minor follow up track development and assess clearing in 2014.

The locations of the environmental monitoring sites were largely chosen based on the predominant wind direction being from the E and SE. This is based on a set of long-term observations between 27 May 1987-30 September 2010 (5482 at 9am and 5455 at 3pm) at the Territory Grape Farm, Bureau of Meteorology Site no. 015643, about 43 km NE of Nolans Bore. These results are consistent with Arafura"s own weather stations records which have been recorded at Nolans Bore since September 2008. Locations were also specifically targeted after considering the local geological setting and radiometric variations.

These monitoring sites can also be used to determine and model the impact of mining and wind-blown dust deposition. Hence it was important to place sites down-wind, up-wind and orthogonal to the predominant wind direction. A ring of four sites was established about 2-3 kilometres from the pit and close to the mineral lease boundary. These sites also coincide with long term dust monitoring stations established in 2010. Four additional sites were also added at a similar distance to ensure a ring of sites about 1 km from the lease boundary. There is also an outer ring of sites about 5km from Nolans Bore, or about 2-3 km from the Nolans Mineral Lease boundary. Two additional monitoring sites were placed inside the mineral leases for the processing plant.

Summary of environmental monitoring

Dean and Grose (2015) report the following analyses at each site environmental monitoring site:

- comprehensive low-detection limit, multi-element analysis of soil, grass and leaves of tree or shrub.
- environmental gamma dose was measured using TLD badges located one-metre above the ground and secured in place for 3 months.
- environmental thoron and radon was measured using RADUET badges, in place for 3 months.

Some of this data has been assessed in this report and a brief summary and analysis of the data is presented in the following sections below.

Each site was chosen by the author to test the results for a range of different geological and regolith settings in the Nolans project area. The sites were also selected using the airborne radiometric survey data to cover a range of radioactivity and environmental gamma doses. Most of the monitoring sites were located in open woodland, grassland or shrubland developed on gently sloping, transported (colluvial or alluvial) red sandy soil plains between hilly outcrops. This setting is broadly similar and consistent with that found around Nolans Bore itself. Fine- to coarse-grained lithic- and quartz-rich gravel lags, and clay are present at most

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sites, but sand- and silt-sized fractions are typically the dominant component. Site ARA8008 is in an area dominated by gravel lags. Isolated low-lying outcrops of fresh to moderately weathered rocks sometimes slightly protrude above the red sandy soil plains across region.

The main differences between these environmental monitoring sites is the depth to bedrock (ie. 0-5m) and the composition of the regolith and underlying bedrock. Where the underlying bedrock composition is not known, the UCC can be used a reasonable approximation. A couple of monitoring sites were placed in hilly areas for comparison.

Chenchrus ciliaris (buffel grass) and *Acacia anuera* (mulga) were sampled wherever possible because they are widespread and common species across this area. Both are also grazed by stock, although mulga is typically only grazed after grass supplies have been denuded. Furthermore and in addition this this environmental dataset, Arafura has an extensive biogeochemical database on mulga and other native trees and shrubs from this general area.

Environmental gamma doses.

The environmental gamma, radon and thoron measurements and methodologies are documented in Dean and Grose (2015). Radon and thoron are not discussed here. The natural background environmental gamma doses are measured one metre above the ground surface and relate to the local geology at each site. In most cases the environmental gamma dose strongly correlates to the U and Th composition of the soil at each site (Figure 46) and the TLD badges have been used to confirm the airborne radiometric datasets are robust (Figure 31).

As discussed above, the dose rates from TLD badges yield results that are similar to the dose rates derived from airborne surveys, especially in areas where the geology of the site is uniform and representative of a much larger area. However as expected, significant differences are evident where the local surface geology is not uniform. This scale dependence of surface geology, geochemistry and gamma is commonly seen radiometric surveys and is further highlighted by the mis-matches shown in Figure 46.

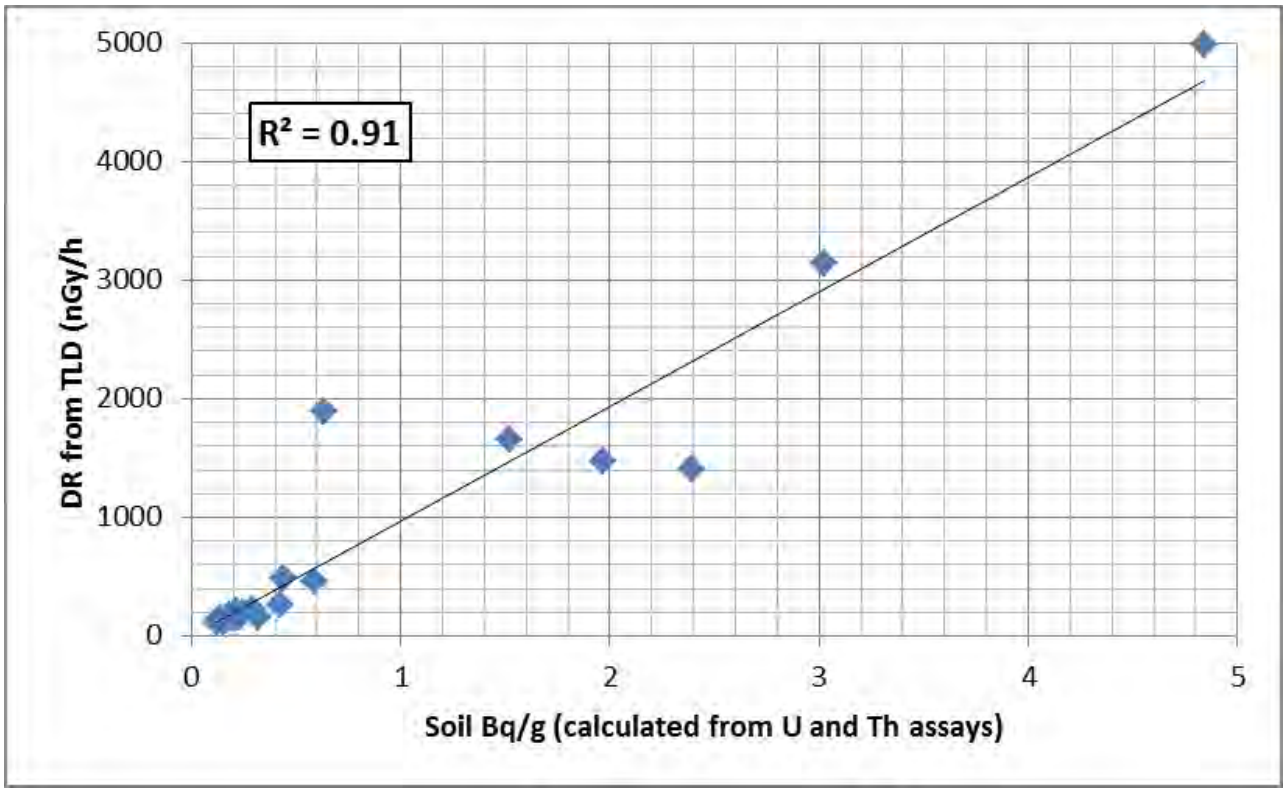

Figure 46: Environmental dose rate as measured by TLD badges in 2015 compared to the activity concentration of U and Th in the underlying soil.

A summary of the assay results collected at each environmental site and relevant to this report are provided in Table 10 and Table 11 below. Apart from U and Th, Table 10 also summarises Pb and Bi elemental data as isotopes of these elements are formed during the decay of both U and Th. The Group II elements (Ca, Sr and Ba) and La are shown in Table 11 as these elements can used as geochemical proxies

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for other radioelements in the U and Th decay chains. Ca, Sr and Ba are chemically similar to Ra and even though the uptake of other Group II elements doesn"t prove it, they can be used as chemical proxies to assess the uptake of Ra (*eg* Medley and Bollhöfer 2016). In addition to these, La can be used as La and Ac have very similar chemical properties and they typically occur together in nature. Additional relevant exploration data is also provided in Table 10 and Table 11.

Table 10: Elemental concentrations for some key radionuclides in U and Th decay chains for the Nolans project area.

		U (ppm)				Th (ppm)				Bi (ppm)				Pb (ppm)			
	number	average	median	min	max	average	median	min	max	average	median	min	max	average	median	min	max
Average UCC		**2.7**				**10.5**				**0.16**				**17**			
***stream sediments -3.3mm	51	3.16	2.64	1.36	13.7	44.5	31	14.6	180	0.2	0.2	0.04	0.44	14.5	13.2	5.4	32.8
***stream sediments -80#	51	8.21	7.04	2.81	21.5	119	103	31.7	360	0.23	0.2	0.08	0.52	20.4	19.2	11.2	35.2
* soil (on deposit)	9	22.0	10.2	3.28	83.3	328	168	44.1	950	0.83	0.46	0.26	2.36	33.0	29.6	15.2	57.8
* soil (off deposit)	17	5.51	3.46	2.47	24.3	63.2	33.6	23.2	416	0.32	0.30	0.1	0.76	18.3	17.2	11	39.6
**first drill metre (on deposit)	142	55.6	7.1	1.4	655	791	114	10.4	8730	na	na	na	na	na	na	na	na
**first metre (off deposit)	18	5.85	4.05	1.6	19	50.5	44	9.55	149	na	na	na	na	na	na	na	na
* grass (on deposit)	9	0.022	0.02	<0.01	0.06	0.22	0.19	0.10	0.39	<0.02	<0.02	<0.02	<0.02	<0.2	<0.2	<0.2	<0.2
* grass (off deposit)	17	0.015	<0.01	<0.01	0.12	0.14	0.04	0.02	1.37	<0.02	<0.02	<0.02	<0.02	<0.2	<0.2	<0.2	<0.2
* tree leaves (on deposit)	10	0.046	0.045	<0.01	0.06	0.15	0.09	0.03	0.59	<0.02	<0.02	<0.02	<0.02	<0.2	<0.2	<0.2	<0.2
* tree leaves (off deposit)	17	0.01	<0.01	<0.01	0.08	0.02	0.02	<0.01	0.04	<0.02	<0.02	<0.02	<0.02	<0.2	<0.2	0.4	<0.2
**all tree 'leaves' (on deposit)	75	0.077	0.05	<0.01	0.48	0.537	0.23	0.01	5.31	na	na	na	na	<0.2	<0.2	<0.02	0.47
**all tree 'leaves' (off deposit)	1127	0.016	<0.01	<0.01	0.71	0.021	0.02	<0.01	0.34	na	na	na	na	<0.2	<0.2	0.02	1.43
**mulga phyllodes (on deposit)	51	0.067	0.04	<0.01	0.45	0.736	0.43	0.01	5.31	na	na	na	na	<0.2	<0.2	<0.02	0.47
**mulga phyllodes (off deposit)	867	0.006	<0.01	<0.01	0.08	0.024	0.02	<0.01	0.34	na	na	na	na	<0.2	<0.2	0.02	1.00
**Groundwater (in deposit)	5	0.354				<0.0001				<0.0001				0.00014			
**Groundwater (off deposit)	9	0.361				<0.00005				<0.0002				0.0001			

*environmental samples; **exploration samples; ***combined exploration samples

Table 11: Elemental concentrations for some chemical proxies of key radionuclides in the U and Th decay chain for the Nolans project area. Ca, Sr and Ba are proxies for Ra and La is a proxy for Ac.

		Ca (ppm)				Sr (ppm)				Ba (ppm)				La (ppm)			
	number	average	median	min	max	average	median	min	max	average	median	min	max	average	median	min	max
Average UCC		**35900**				**320**				**628**				**31**			
***stream sediments -3.3mm	51	2885	2980	570	6300	98.1	92.8	20.7	393	444	406	179	1580	69.6	49.2	19.2	324
***stream sediments -80#	51	3318	3200	1390	7360	80.0	70.0	38.1	251	394	366	286	929	178	143	66.2	523
* soil (on deposit)	9	12200	7100	2500	38200	282	177	112	777	599	544	372	1330	1835	2256.4	2677.4	3098.3
* soil (off deposit)	17	2400	1900	1100	4900	64.6	50.6	31.9	151	347	317	215	657	440	552	663	774
**first drill metre (on deposit)	142	74457	43600	900	295000	657	245	24.4	5914	508	320	40	3280	1499	218	23.3	12800
**first metre (off deposit)	18	31283	2400	700	180000	114	41.1	18.8	543	421	240	40	1820	109	81.9	27.1	439
* grass (on deposit)	9	2487	2310	1430	4350	25.8	19.4	7.7	49.9	48.4	42.4	11.1	86.5	1.26	1.48	1.70	1.92
* grass (off deposit)	17	1984	2060	410	4250	24.6	18.9	3.05	83.3	27.7	19.7	2.4	72.1	1.79	2.27	2.76	3.24
* tree leaves (on deposit)	10	9158	6535	3740	23100	74.9	56.8	20.9	150	54.9	46	14.1	135	1.21	1.48	1.74	2.01
* tree leaves (off deposit)	17	11092	11400	2600	18200	107	87.3	28.2	326	21.1	17	2.9	71	1.40	1.75	2.11	2.46
**all tree 'leaves' (on deposit)	75	15333	15100	3740	34500	124	125	9	295	47.1	37.3	2.1	169	1.08	0.66	0.02	7.20
**all tree 'leaves' (off deposit)	1127	12028	11400	1490	37000	87.3	80	3.3	397	28.9	16.1	0.7	278	0.36	0.28	0.04	3.71
**mulga phyllodes (on deposit)	51	18092	16900	10200	34500	148	137	9	295	40.0	32.4	9.7	169	1.45	0.93	0.02	7.20
**mulga phyllodes (off deposit)	867	11762	11400	5010	34500	87.8	81.8	23.7	347	25.0	17.3	1.45	204	0.34	0.30	0.05	1.66
**Groundwater (in deposit)	5	150.3				3.99				0.03				<0.0001			
**Groundwater (off deposit)	9	65.9				1.09				0.074				<0.0002			

*environmental samples; **exploration samples; ***combined exploration samples

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Dust

Aeolian components (mostly silt- and clay-sized particles) are ubiquitous in this environment but they are not preserved as a significant component in the regolith (Hill 2009). Hill (2009) indicates the area is an erosional setting rather than depositional setting and hence most of the natural aeolian material that is deposited in the Nolans Bore area is removed by erosional processes. Dust however is an omnipresent nuisance in trace element biogeochemistry and the impact of dust must be considered, see below.

Natural dust deposition data has been continuously collected from four monitoring sites in the Nolans project area since 2010 and is reported in Dean and Grose (2015). These sites are approximately equal distance from Nolans Bore; being sited upwind, downwind and orthogonal to the principal wind direction. Unfortunately not all of the natural dust deposition data can be used in its entirety due to a lack of critical metadata for some sampling periods.

An analysis of the natural dust deposition data indicates an average natural dust deposition rate of about 14g/m^2/year in the project area. In addition, the composition of the observed dust has a REE fractionation pattern that closely approximates the pattern of the average UCC and differs from most rocks and soils in the project area. This observation indicates a very large regional, or perhaps a global, influence on the composition of the natural dust deposited in the Nolans project area. The monitoring period has corresponded to about average rainfalls and the variability of rainfall throughout this period is typical of the region. There have been extended periods of drought during this time however the amount rainfall in 2010 was well above average. It should be noted that the dry spells recorded in this monitoring period are not as significant as other events witnessed by the author (eg mid-1990s) where higher natural dust deposition rates would most likely have occurred.

The dust data was chemically assessed by normalising the concentration of Th, U and REE to average UCC. These elements were chosen because they are diagnostic and typically present in measureable quantities in dust samples.

A single unusually high uranium value was reported in a dust sample collected from NDDG-2 between 1st December 2013 and 26th February 2014. The compositions of the other three dust deposition samples collected at the same time are very different to the NDDG-2 sample, but similar to each other. The unusual U result is considered to be geochemically unrealistic based on naturally associated elements. It is therefore sensible to discard this as an erroneous laboratory result. It should be noted that Arafura was not drilling in the area at that time of the problematic result although minor earthworks associated with the rehabilitation of the Mulga prospect drill sites occurred about 4km north of NDDG-2 until 2 December 2013. When the spurious U result is removed, all dust assay samples are geochemically similar (Figure 47).

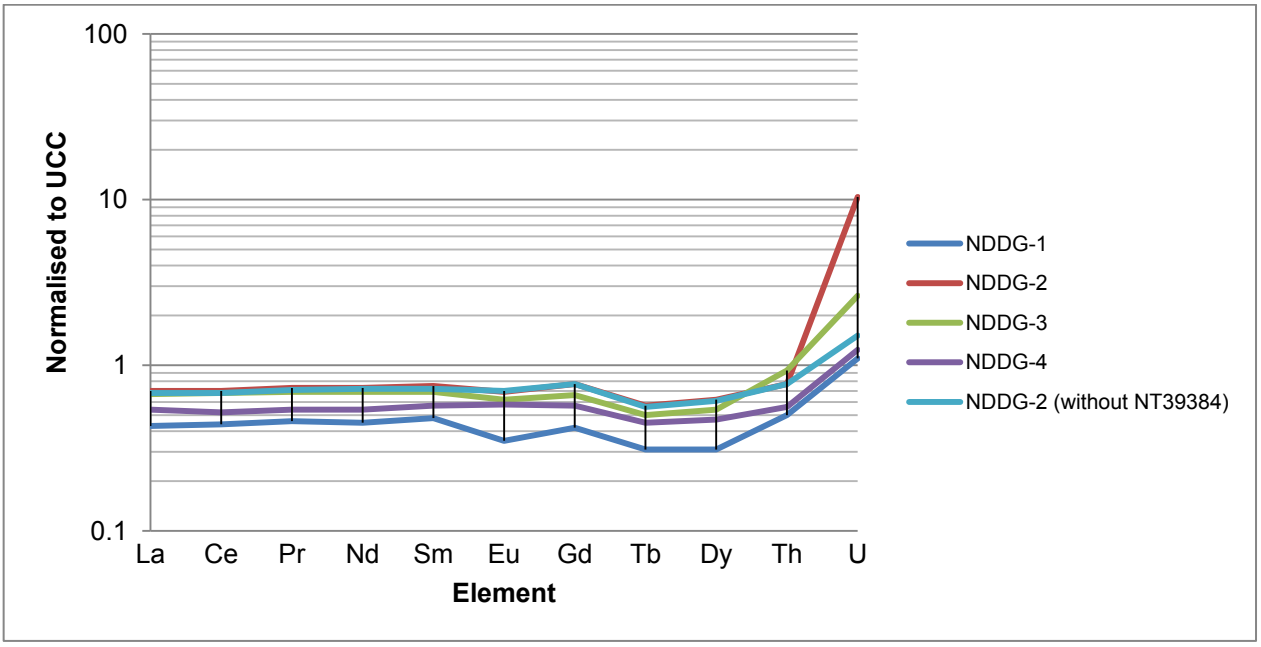

Figure 47: Average composition of the natural dust deposited in the Nolans project area (after Dean and Grose 2015).

Figure 47 shows that the natural dust compositions from four sites in the Nolans project area are essentially uniform and their UCC normalised patterns essentially parallel each other. The patterns differ in their actual normalised amounts but this is due to the variability of other components such as quartz (SiO_2) in the dust.

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The uniform Th, U and REE compositions clearly indicates no major compositional bias towards any site. NDDG-1 is downwind of Nolans bore and has the highest dust deposition rate but it has lowest REE, U and Th composition. This contrast with NDDG-2 which is upwind of Nolans Bore and has the highest REE, U and Th and lowest dust deposition rate. The data indicates the impacts from Arafura‟s exploration activities at Nolans Bore are not evident in the natural dust dataset. The element ratios and patterns are basically identical irrespective of the direction from Nolans Bore. In contrast if Arafura‟s operational dust impacts were present, NDDG-1 should show a different pattern because NDDG-1 is directly downwind of the principal wind direction and source compositions at Nolans Bore are distinct.

The UCC normalised plot in Figure 48 below demonstrates that the average composition of the natural dust in the Nolans project region is slightly enriched in U compared to Th and REE, which closely mirror the UCC composition. The source of this slight U enrichment is unknown, but it may be related to U mobility and leaching in oxidised environments or mechanical differences in the mineralogy and composition of dust in different source regions. The UCC normalised Th, U and REE pattern of the natural dust deposited across the region is also clearly geochemically distinct and different to local sources (Figure 48). This indicates that there can only be a small contribution from the local environment. Clearly there must be at least some contribution from local sources as the author has observed „willy-willies‟ stirring up regional and resource area soils on numerous occasions. It is also important to realise that the U composition of natural dust must be slightly higher if a component of local dust source is invoked.

Modelling indicates that a very small proportion of dust derived from mineralisation will significantly affect the composition of the natural dust (Figure 49 and Figure 50). Clearly Th, U and REE, and particularly Th, U and La, will serve as important geochemical indicators to assess dust compositions and model the impact and contributions from various sources. Modelling shows that dust sources with contributions from about 0.05%MIN or 0.5% resource area soil or 2% regional dust are basically identical to natural dust (Figure 49). Modelling also shows that dust sources with contributions from 0.1%MIN or 1% resource soil or 5% regional dust start to be distinct from natural dust (Figure 50). Of course the dust sources from the Nolans project will be a combination of various sources and not be as simplistic as this. Nevertheless apart from dust deposition rates it seems that geochemistry will also be useful to fingerprinting the sources of dust.

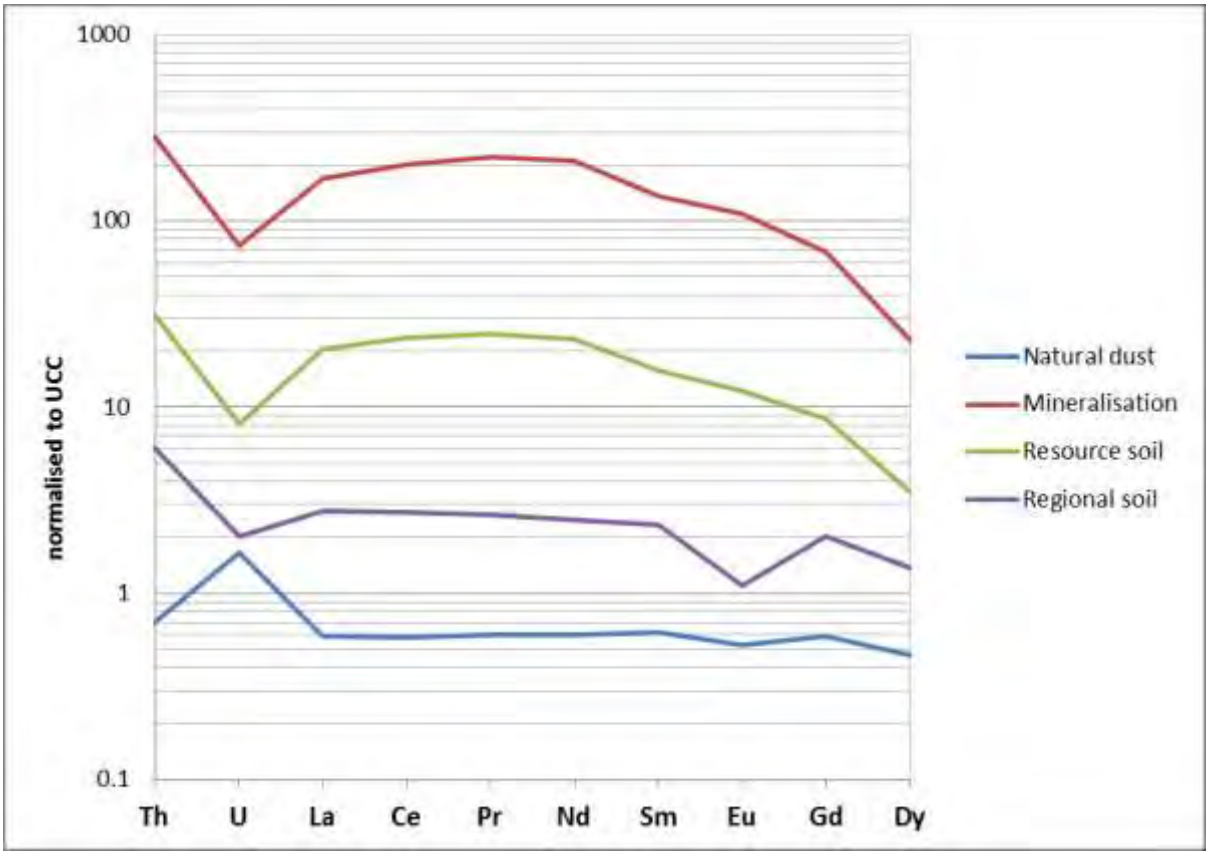

Figure 48: Average composition of the natural dust and other sources in Nolans project area normalised to the average UCC. The flat REE pattern is typical of natural dust and multi-element pattern of the naturally deposited dust clearly differs from the average resource area soils, average regional soils and the average composition of the Nolans Bore-type mineralisation. The average rock in the Aileron-Reynolds Range area probably has a pattern very similar to the regional soil.

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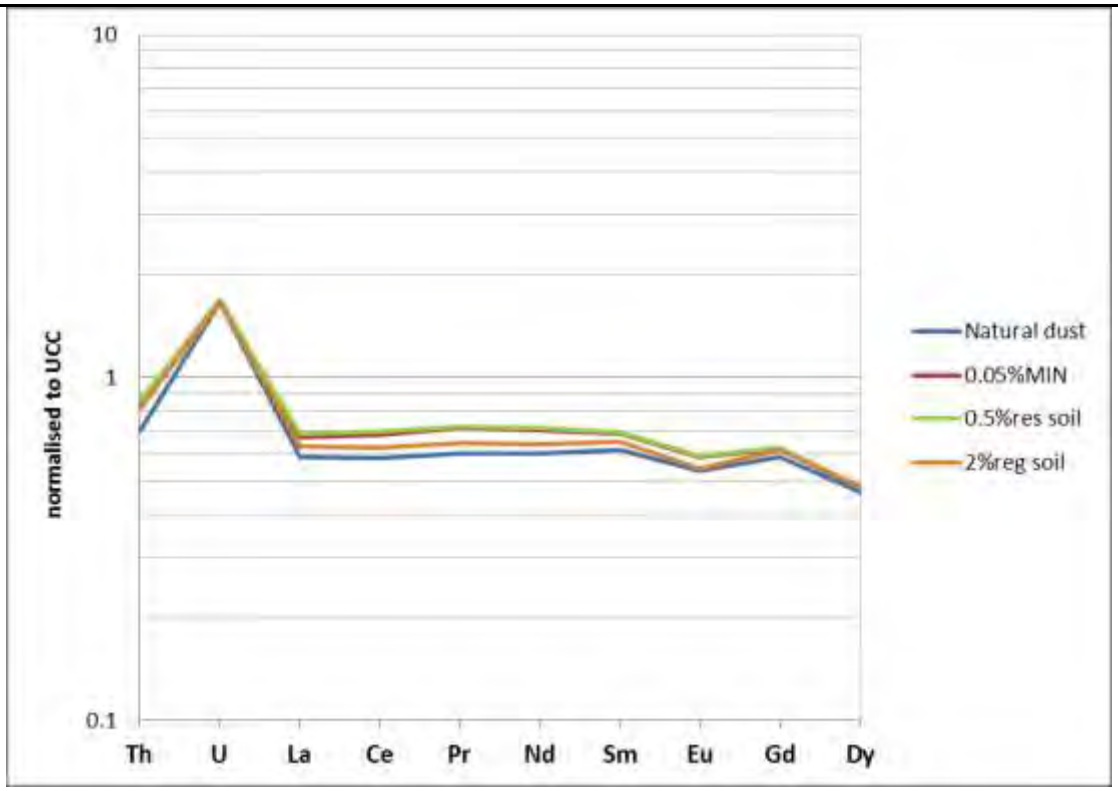

Figure 49: Modelled dust compositions showing potential sources that are basically indistinguishable from natural dust. The modelled compositions plotted here assume an admixture of the indicated component and the remainder is the same a natural background dust. The natural dust is also shown for comparison.

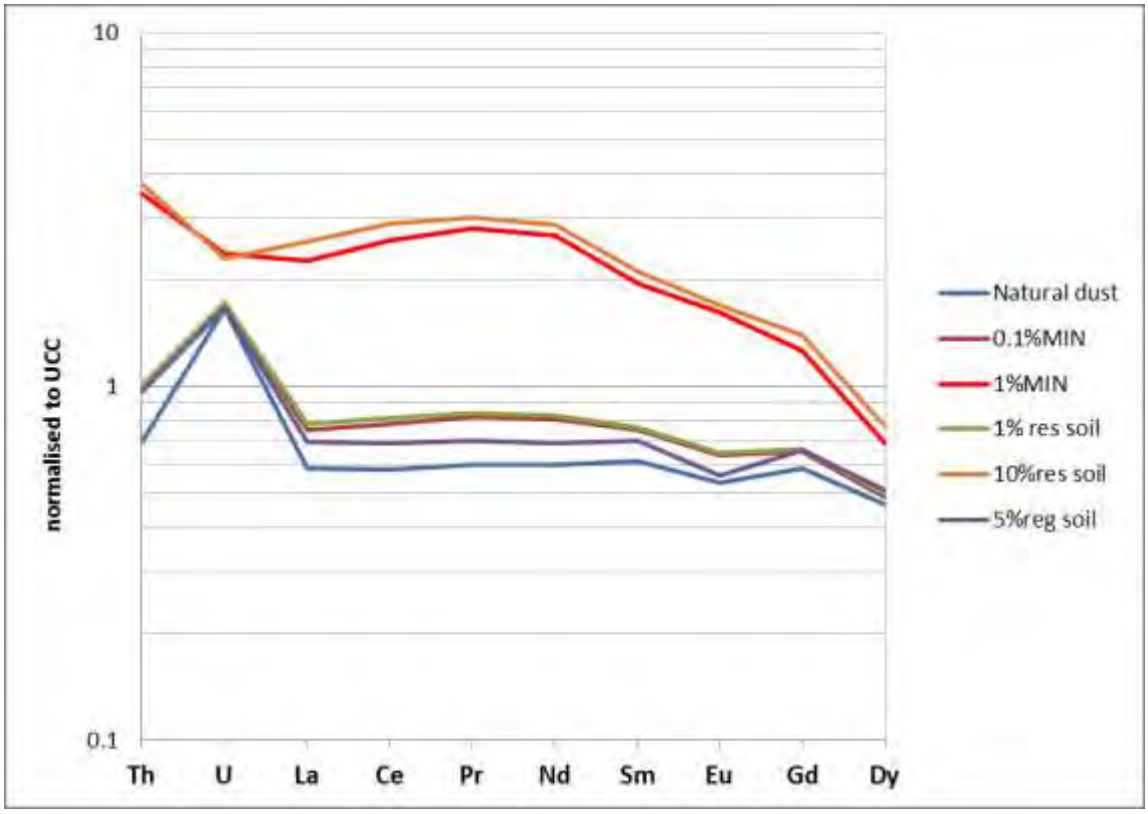

Figure 50: Modelled dust compositions showing potential sources that can be distinguished from natural dust. The modelled compositions plotted here assume an admixture of the indicated component and the remainder is the same a natural background dust. The natural dust is also shown for comparison.

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Soil compositions

Soils were representatively sampled at each environmental monitoring site. The sampling procedure involved scraping away the topmost layer of organic material (grass/leaves) at each site. Four equal-sized samples were collected at each site by digging 20cm deep holes at the corners of a 1m x1m square. The four individual samples were then composited and treated as representative B/C horizon soil sample for that site. The entire assay sample (1-1.5kg) was oven dried and milled to p80-100µm prior to analysis. Soil samples were split in the laboratory. One split was used for pH determinations at NTEL and two splits were prepared for detailed low-level whole rock geochemical analysis; one at NTEL in Darwin for trace elements by four-acid digest and ICPMS/OES and the other at Genalysis in Perth for major and minor elements by XRF. All analytical results are provided in Dean and Grose (2015).

The composition of the soil at each site has been assessed by plotting it against the UCC (Figure 51). The normalised plots highlight deviations from the average composition of upper crustal rocks and demonstrate a wide range of compositional variations across the project area. Furthermore there is considerable overlap between the two different groups shown in Figure 51. The elemental order in Figure 51 follows Hussey (2012) and was principally developed for detailed analysis and assessment in exploration biogeochemistry.

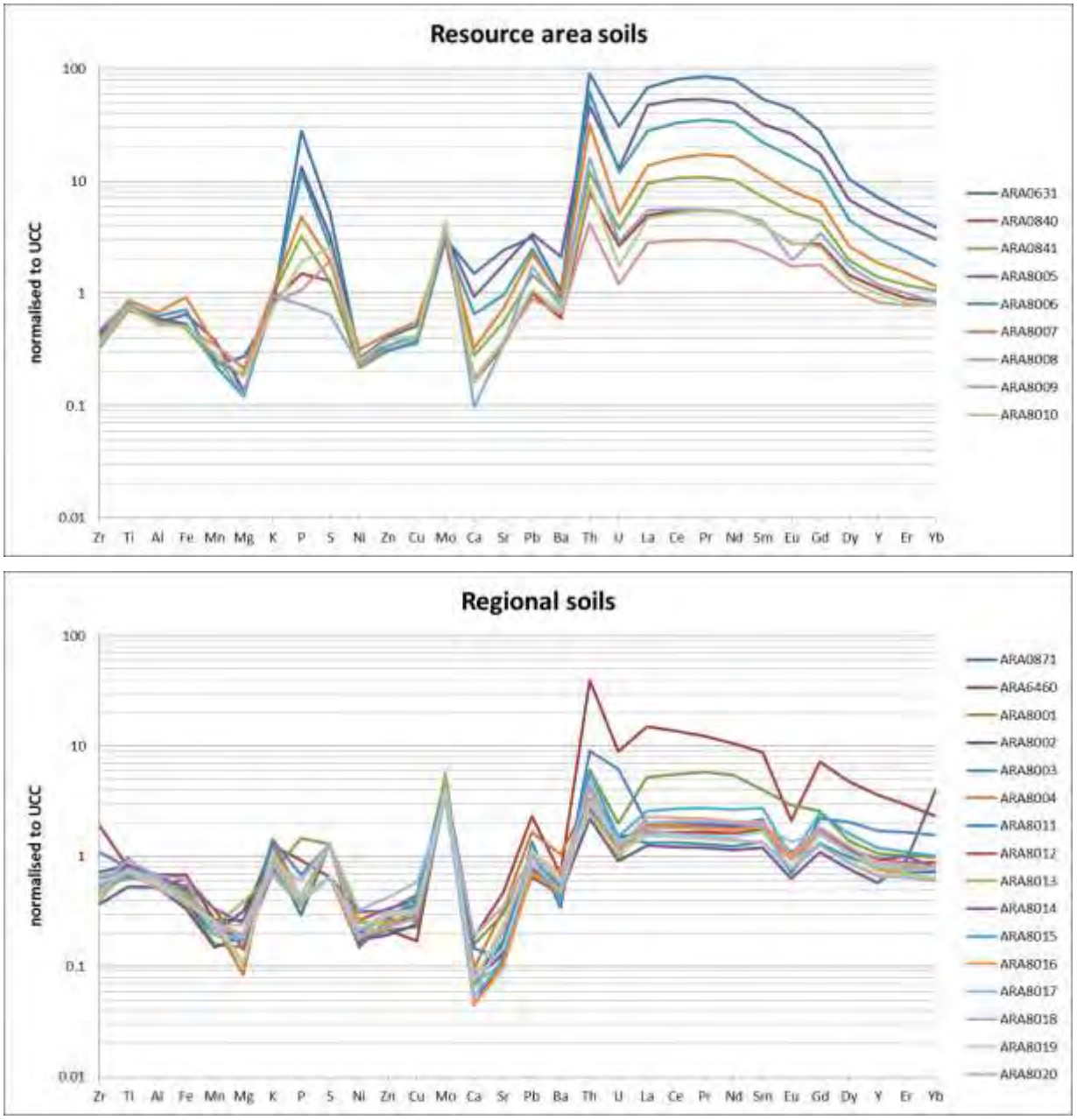

Figure 51: Composition of soil samples in the Nolans area. Additional elements are provided in Dean and Grose (2015).

The geochemical patterns observed in the resource area soils are consistent with anticipated values and

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indicate the soil is derived from an admixture of mineralisation and other country rock material. The negative Eu anomaly observed at site ARA8008 is not typically observed in Nolans Bore-type mineralisation, and together with the shallower REE slopes and generally lower P, Th, U and REE concentrations observed at some sites on top of the deposit, indicates a substantial component of unmineralised material is present. The other material is either (1) derived from proximal country rocks adjacent to the mineralisation, or (2) externally derived transported material, or more likely (3) a combination of one and two. The unconsolidated soils on top of the deposit range from <30cm to about 2-3m in the palaeochannel, with a further 0-2m of consolidated soils in the palaeochannel on top of the Central Zone. Arafura"s regolith assessment of the area (Hill 2009) indicates that these soils are largely transported alluvial and sheet flow sediments and the geochemistry of the soils on top of the deposit are consistent with this. The older underlying carbonate-cemented soils and alluvial material (hard-pan) in the palaoechannel appears to be identical and are also thought to be of a similar composition, albeit more enriched in calcium carbonate.

Despite the variability of the soils shown in Figure 51, Figure 52 shows that there are both similarities and differences in the average composition of the soil across the project area. Clearly all soils in the region are enriched in U and Th compared to the average crust. However Figure 52 also clearly demonstrates that U and Th are typically more enriched in the resource area. The resource area soils are also more enriched in P, S, Ca, Sr, Pb, Ba and REE which is consistent with the elements enriched in the mineralisation at Nolans Bore deposit. The Ca and Sr contents of the resource soil were expected to be slightly higher however as both Ca and Sr are labile, a slightly lower than expected result is not unusual. The slight S enrichment observed in the resource area soils is an interesting result however minor S is present as sulphates in the mineralisation, and hence the result is not unexpected. The slight Pb enrichment observed in Nolans Bore soils is no surprise and most likely related to higher levels of U and Th and radiogenic decay products. The elevated Mo is present in both dataset and clearly is a regional signature not related to the Nolans Bore deposit. The regional soil pattern is consistent with that expected from the average rocks in the area.

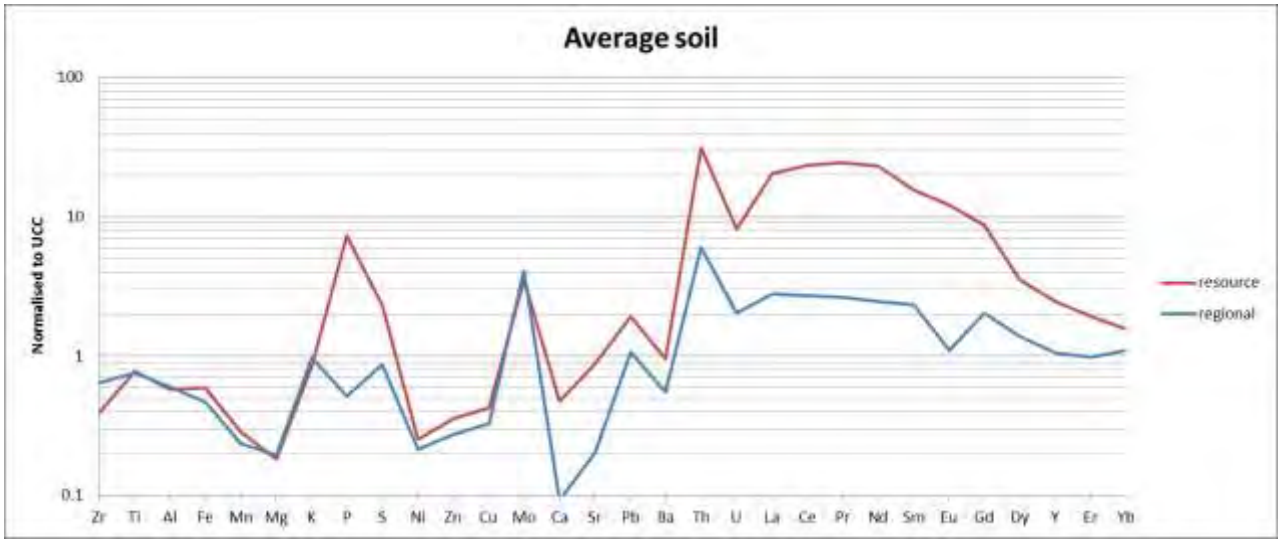

Figure 52: Average soil composition in the Nolans area.

Soil pH was determined at NTEL using the standard 1:5 water dilution method (note the author has confirmed NTEL"s EA method is definitely the water dilution method despite the laboratory"s reporting label of "paste pH"). Soil samples collected from the resource area have a pH range of 6.7-7.7 and an average of 7.1. The pH of the surrounding regional soils average 6.6 with a range from 6.1 to 7.0. While the pH results are generally close to neutral, alkaline samples have only been measured in the resource area itself. This difference would tend to indicate that weak regolith carbonate development may be present in resource area soil samples or it might be related to weathered mineralisation or a combination of both. Regolith carbonates have been observed by the author elsewhere in the region during exploration activities but unfortunately no distal regional soil samples were tested near regolith carbonates. This difference may simply be due to the lack of samples tested in the region and therefore as noted above, a number of additional soil and environmental samples are planned.

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Biogeochemistry and radiological element uptake

The average compositions of soil, grass and tree „leaves" from Arafura's environmental monitoring sites in are shown in Table 10 and Table 11. Table 10 and Table 11 also include exploration data that can be used to provide additional information on the biological uptake of U and Th and other elements of radiological interest. Where drilling data is available, the composition of the surrounding bedrock is also considered in this assessment.

The term „leaves" is used here in a very broad sense and includes phyllodes, and in some cases a small amount of seed pods/fruit/flowers are also been included in the foliage sample. Most of these samples are labelled in Arafura's database as biogeochemical foliage (BGF) samples which is basically „leaves", but also includes some leaf stems and small twigs because it is often difficult to efficiently separate these in the field. Given that Arafura's extensive vegetation dataset has been collected over many years and at various growth stages, the type of foliage available at each site also varies. To account for this Arafura records the maturity and height of the tree and whether the foliage is new or old growth or a combination of both, and differentiates BGG (foliage and seed pods/fruit) and BGL (foliage and flowers) from BGF. While Hussey (2012) noted minor differences, all foliage samples BGF, BGG and BGL are combined for this assessment (Table 10 and Table 11). This assessment also combines the results from several different species and the implications of this are discussed below. Arafura has also collected twigs and bark from various species in the area (eg Hussey 2012) but they are not considered in this assessment. Hussey (2012) reported differences in the trace element concentrations with typically leaves>twigs and bark>seeds and flowers. These relationships are also reported in other studies (eg Dunn 2007). Roots have not been studied in this area as they would be difficult to sample in timely fashion as part of a systematic exploration program. Within the exploration datasets reported in Table 10 and Table 11, the mulga phyllodes are a subset of „tree leaves" and have been specifically differentiated because mulga is also grazed by cattle.

There is only limited Bi data in Table 11. Bismuth was initially assayed in the exploration BGF samples but was eventually removed from the standard biogeochemical assay suite as all samples were consistently below the level of determination (Hussey 2012). Bismuth was included in the recent environmental samples re-confirmed this finding.

Dunn (2007) points out that virtually all elements are taken by plants and a key aspect of this is whether the elements are essential or non-essential to plant growth. Elements essential to plant growth are taken up because the plant requires them whereas, all factors being equal, non-essential elements are accidentally taken up by plants. However this view may be too simplistic, as non-essential elements are probably also taken up because they share chemical similarities to essential elements. Radium for example is not essential for plant growth but it can be taken up is significant amounts and there appears to be no barrier to its uptake (Kovalevsky in Dunn 2007). Radium is key element of radiological interest associated with the U and Th decay chains but it has not been routinely assayed hence the use of chemical proxies. Radium analyses and data on the up take in vegetation from Nolans Bore is reported in Collier *et al* (2007).

Non-essential elements are generally taken up in amounts proportional to their environment, although one must also consider chemical associations as noted above. Research has shown that certain species can also selectively take up certain elements compared to other species. Environmental conditions and periods of plant growth are also important to consider, and in the northern hemisphere it is also critical to compare samples with the same number of growing seasons as accumulated metals can differ with the number of growing seasons (Dunn 2007). Dunn also advised that it would be important to consider drought vs wet conditions in the desert environment (*pers comm* 2007) however the data in Hussey (2012) shows that similar variability is observed on samples from the same tree.

Published research and Arafura's exploration biogeochemistry in the Nolan project area has shown that non-essential elements accumulate in the plants with concentrations varying by several orders of magnitude, and in many instances there is no obvious or reported biological impact on plant growth. Elements such as U and Th are regarded as non-essential elements (Dunn 2007). There is also a substantial variations are observed in the concentrations of U and Th in plants around the world (eg Dunn et al 1985; Dunn 2007) and the values from the Nolans project area in consistent with this (see Table 10 and Table 11). In many cases the amount of U and Th in plants from the project area is consistently close to or below the level of determination (LOD) although examples can exceed the LOD by about 2 orders of magnitude or more. Dunn (2007) notes that the average U content in vegetation is about 10 ppb, which is equal to the limit of determination in biogeochemical samples reported from NTEL. Other laboratories report a 1ppb LOD for U however NTEL strongly dispute the robustness of this data and also question the use of larger digest quantities (John Willis *pers comm*). To overcome LOD issues, low-temperature ashing is widely used by some as it effectively means a 10-20 times increase in the LOD when back-calculated to dry weight prior to ashing (eg. Dunn 2007; Hodkinson *et al* 2015). However a comparative study of vegetation collected from the

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Nolan Bore deposit and elsewhere in the region by the author (*unpublished Arafura data*) clearly indicates that numerous elements are fractionated during the ashing process. For example, some elements are lost (*eg* Th>La>Pb and U) while other elements basically remain the same (*eg* Ca, K) or significantly increase (*eg* Sr, Ba) in the ashed product. This implies that some elements are lost in the organic component which is driven off during the ashing process but this is not surprising given the findings of Gou *et al* (1996) and Shan et al (2003). Hence despite a 10-20 times increase in determination limits, the ashing process raises other biogeochemical issues for the Nolan project vegetation samples.

It is common practice in biogeochemistry to calculate a Concentration Ratio (CR) for each element to assess the uptake or transfer rate (eg Ehlken and Kirchner 2002). The CR for an element is typically reported as the concentration in vegetation (dry weight) divided by the concentration in soil (dry weight). The above formula is the standard method for calculating the CR however there are variations in the literature. The CR can be calculated using elemental concentrations or activity concentrations and vary from element to element and species to species.

The CR is in theory a clearly defined term, however the calculated CR values should not be regarded exact or accurate and there are a number of important points to be considered. For example, the composition of the soil is often highly variable and the plants root structure is sometimes in contact with soils of different compositions. Hence the question really is; how representative is the soil or substrate assay compared to that in contact with the root mass? To further complicate the picture, if transported, the composition of the soil can have very little in common with the underlying substrate or bedrock. This is the case for the Nolans project area and it is also an important factor to consider when interpreting CRs for deeply rooted species. Furthermore the survival of plants depends on access to groundwater, either within the soil profile or from deeper sources such as the underlying water table. Hence the composition of the groundwater, the type of plant and its root structure and the geology needs to be carefully considered.

Hussey (2012) explored the compositions of numerous plant species at Nolans Bore and surrounds from 2006-2012 and demonstrated significant variability in the amount of each element taken up in each plant. Figure 53 and Figure 54 show there is clearly anomalous U and Th biogeochemistry and up take at Nolans Bore however there is also considerable overlap and it should be noted that there is no clear elemental cut-off value that can be used to distinguish between mineralisation and country rock substrates. In fact Arafura‟s exploration data has shown elevated U in numerous other locations as well. In addition to this the uptake of Sr shows no obvious relationship to Nolans Bore mineralisation (Figure 55). The Sr results may at first seem unusual as the amount of Sr in Nolans Bore significantly exceeds that of the other rocks in the area. However the results make sense when one considers that Sr is also present in the groundwater throughout the area (Table 11) and the fact that Sr should also be taken up as a proxy for Ca which is an essential element. This regional groundwater source argument has important implications for radium up take as well and the data in Collier *et al* (2007) indicate elevated radium distal to Nolans Bore.

Hussey (2012) demonstrated that the REE and other key elemental ratios remain relatively constant with consistent normalised patterns reflecting the composition of the underlying substrate. This was seen as a way to develop a better understanding of the biogeochemical signature of Nolans Bore type mineralisation and analysis and removed the order of magnitude variability reported at the same site over time. The observations reported in Hussey (2012) were eventually applied to new exploration targets around Nolans Bore and ultimately lead to the discovery of concealed Nolans Bore-type mineralisation (Hussey 2013; Hussey and Dean 2014). To the best of the author‟s knowledge this is the first time that anyone has discovered concealed REE mineralisation using biogeochemistry. Clearly the geochemical rationale behind Hussey (2012) demonstrates an understanding of biogeochemical uptake of the deeply rooted plant species tested in the Nolans project area.

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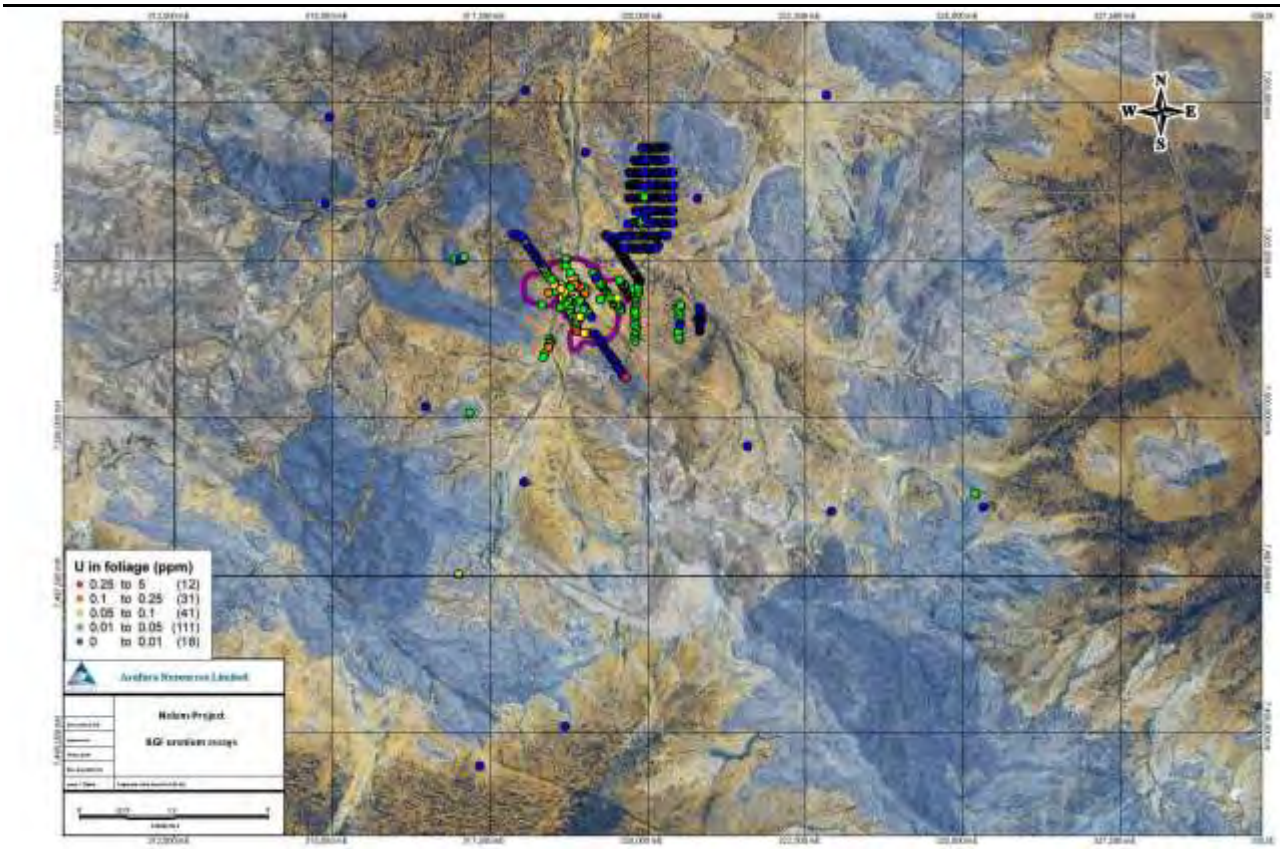

Figure 53: Biogeochemical foliage (BGF) uranium assays of various trees in the Nolans project area.

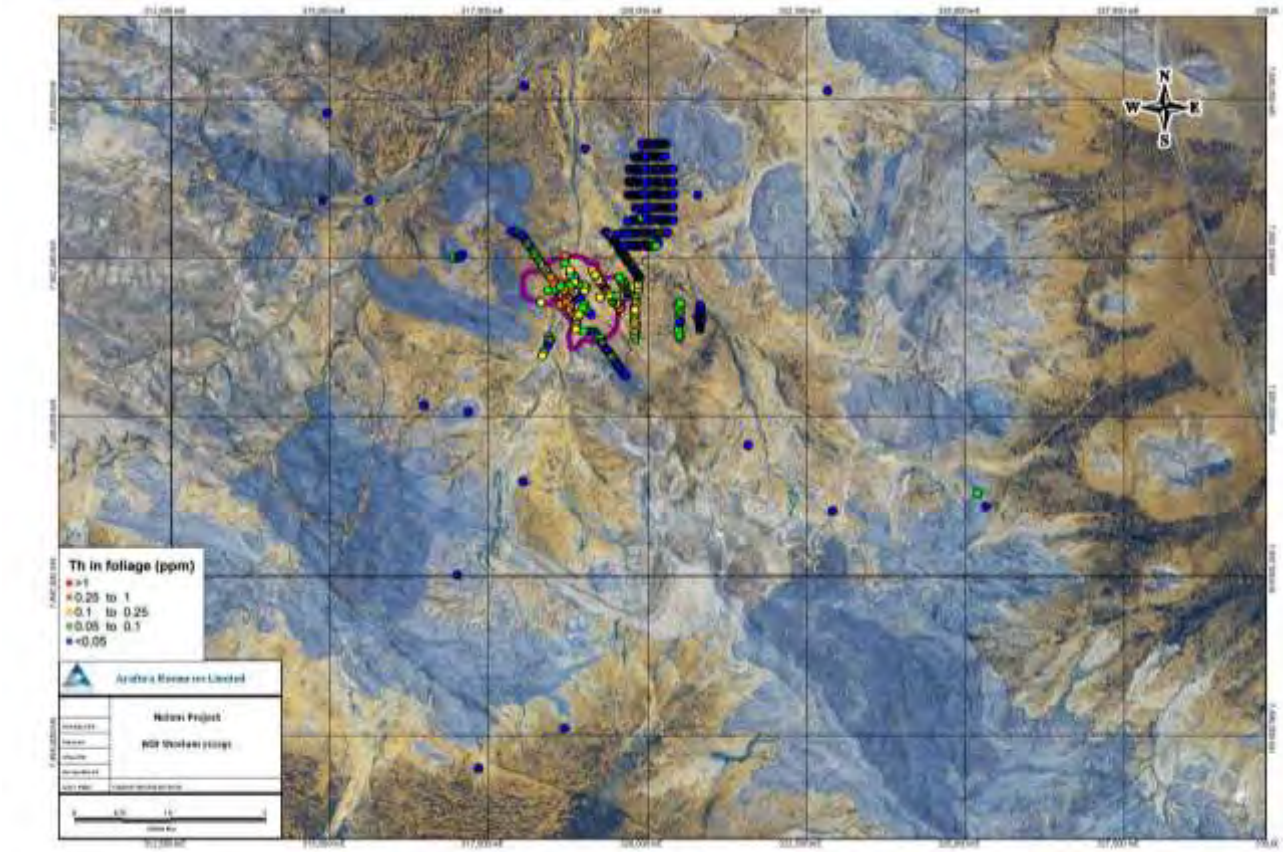

Figure 54: Biogeochemical foliage (BGF) thorium assays of various trees in the Nolans project area.

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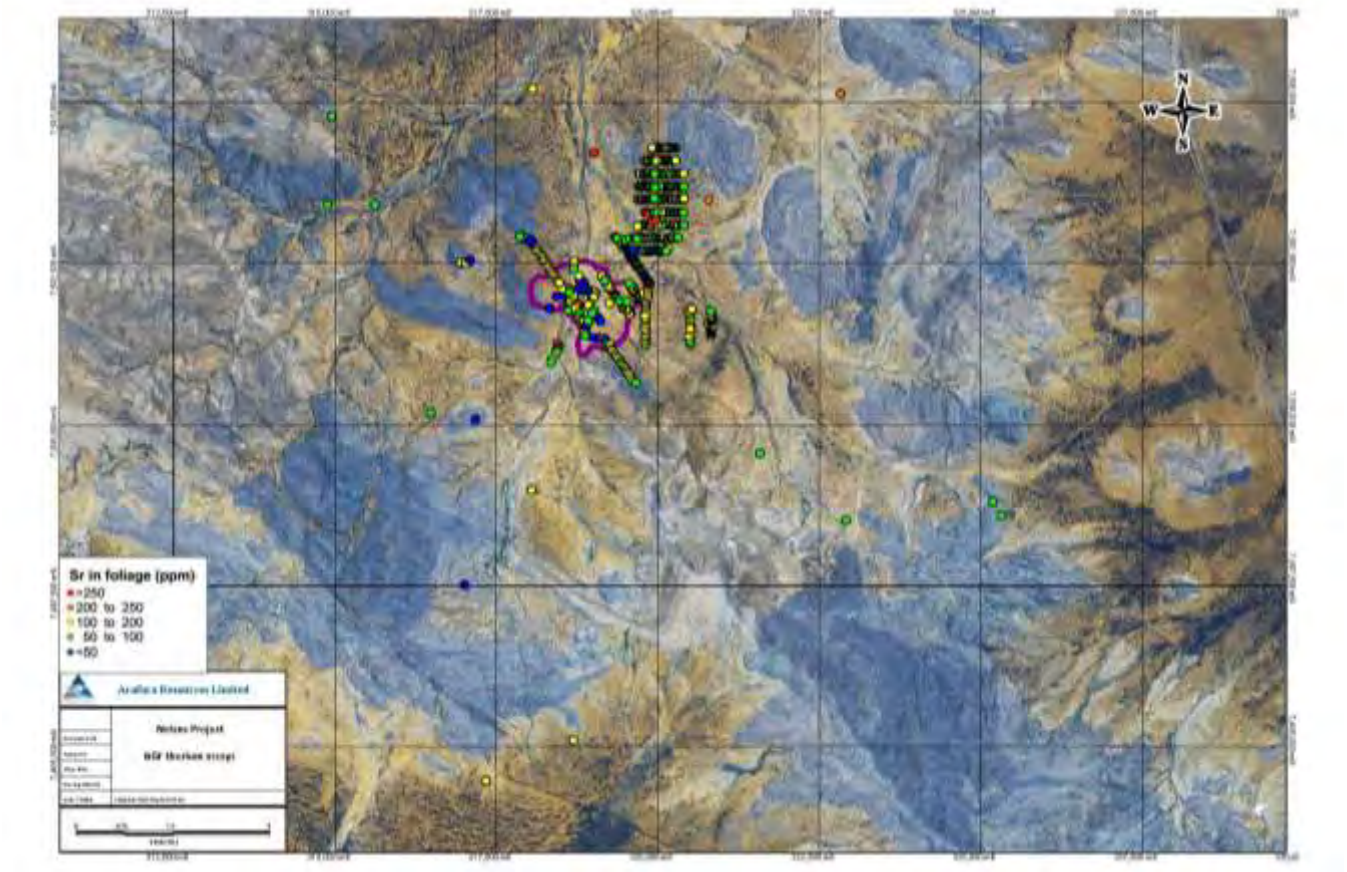

Figure 55: Biogeochemical foliage (BGF) strontium assays of various trees in the Nolans project area.

Figure 56 below shows an example of the vegetation and soil samples assayed at an environmental monitoring site. The species of tree at this location (*Acacia aneura*, more commonly known mulga) is prominent throughout the region and these have been systematically used for exploration biogeochemistry wherever possible. The mulga phyllodes at this site have been routinely sampled for biogeochemistry since 2006 and the concentrations of U and Th in the phyllodes at this site varies by about an order of magnitude. Larger bulk samples were collected from this site and homogenised in an attempt to minimise the "nugget" effect and variability observed at this site. Hussey (2012) points out that assays taken at the same time can vary by up to 50% or more.

Mulga is a deeply rooted drought tolerance species that only shows significant growth spurts after substantial rain events. Observations by the author indicate this species effectively shuts down or completely minimises its growth during drought periods. For example the phyllodes (leaves) typically become very dry and brittle in drought periods, and no new growth has been observed for extended periods at sampling points and only occurs after substantial rain. ARA0840 is located on top of mineralisation however as shown in Figure 56 the composition of the soil at ARA0840 is different to the underlying rocks with the composition indicating a substantial component of transported material (Figure 51). Nevertheless the soil is clearly enriched in U and Th compared to the average UCC and has a similar U and Th pattern to the underlying bedrocks. Most importantly U and Th the composition of the grass and the tree also show similar relationships (ie similar patterns). La also shows a similar geochemical pattern for the four different samples types and hence CR will be similar for U, Th and La. However it should be stated that using the soil to assess uptake in trees means that uptake will be significantly overstated. Furthermore it would seem logical that the grass in mostly growing in the soil while the tree in mostly growing in the average rock composition, or thereabouts, and the calculated CRs for these would therefore be different.

Figure 56 also clearly shows that the CR for the other elements are different to those for U, Th and La. Pb for example, and Bi not shown, is below the level of determination in the vegetation while the compositions in the soil closely matches the UCC and the bedrock is higher. The Group II metals (Ca, Sr and Ba) on the otherhand all show contrasting values and uptake ratios but clearly all indicate a higher uptake ratio. Site ARA0840 shows a different ratio for Ca and Sr between the tree and the rest (grass, bedrock and soil). Figure 56 also shows that the tree takes up more Ca and Sr than is present in the soil but it is less than of the underlying bedrock which is the most likely source.

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Site ARA0631 is another site located on top of strong mineralisation. This site has the highest measured U and Th soil composition and dose rates of the 26 environmental monitoring sites. Higher soil compositions and dose rates have been measured at Nolans Bore. A comparison of Figure 56 and Figure 57 shows that the overall chemical relationships are broadly similar at two strongly mineralised sites however the U relationship is clearly different at site ARA0631 in comparison to site ARA0840. In the published literature elevated U is often attributed to selective uptake (eg Dunn 2007) however caution is warranted here as the biogeochemical processes and sources should always be considered and assessed. The species of tree (Corymbia opaca or more commonly bloodwood) which is present at site ARA0631 is known to grow in areas where its roots seek out groundwater, and unlike the mulga can produced new green growth and flower, albeit less, in drought periods. This observation implies that bloodwoods also continually source at least some of their elements from groundwater. This is further reinforced at site ARA0841 where another member of the same genus also shows a relative enrichment in U over the immediately adjacent mulga (Figure 58). Both of these *Corymbia* species transpire large quantities of water and hence the relative enrichment in U makes geochemical sense given the groundwater composition is enriched in U with essentially no Th (Table 10).

The relative uranium enrichment observed in some vegetation compared to the composition of the underlying substrate is a feature that is not specific to Nolans Bore itself; it has been observed elsewhere in the region (unpublished Arafura data). Hence the data shows there is a need for a careful assessment of each species collected for biogeochemistry and the „suspected" biogeochemical environment or setting utilised by that plant. It also means that the uptake from groundwater needs to be included in any assessment and that a CR based on soil/substrate does not adequately explain the real setting.

Based on the above it seems likely that the bloodwood at site ARA0631 and the ghost gum at site ARA0841 have taken up U from groundwater as well as the bedrock and the soil, although the amount of soil is essentially insignificant at both sites.

Hence it is difficult to determine to accurate CR values for Nolans project area. Despite this Table 12 shows the average CR values that have been calculated from the different sample types collected from the Nolans Bore deposit. These CR values are based on the data show in Figure 59 and are considered a first order approximation although the variability shown in Figure 56, Figure 57 and Figure 58 also needs to be considered. It is also no surprise that the CR values for U in trees varies by about an order of magnitude depending on the species sampled. Figure 59 shows remarkably similar patterns for the various grasses and trees apart from the slight relative U enrichment in the average tree. The data for Pb and Bi are indicative only as these elements were below the LOD in virtually vegetation samples all. Clearly Ca, Sr and Ba areall similar but very different to U, Th and La which themselves have similar CR values. This difference is most likely because Ca is an essential element whereas U, Th and La are non-essential elements. While Sr and Ba may be non-essential elements they are taken up by plants because they are chemical proxies for Ca. One would also therefore argue that Ra should also be enriched and the data in Colllier et al (2007) supports this. However as noted above, the results of the Sr exploration biogeochemistry (Figure 55) favour a groundwater component to the source as well suggesting that Ra enrichment may be a region feature. This would be consistent with the regional groundwater chemistry reported by Hughes and O"Sullivan (1973).

Dust considerations in biogeochemistry.

Given a small amount of aeolian dust is naturally deposited across the entire region, dust must also be considered when evaluating biogeochemical assays. This formed a fundamental part of the initial assessment of Hussey (2012) and is considered extremely important because most metals are present in very low concentrations in plants and the levels are easily masked by natural dust. Hence the question is; what is the biological uptake? Clearly dust is a problem that all biogeochemists must face when sampling and analysing biological material in the natural environment. Other scientists have attempted to get around this issue by thoroughly washing the samples in distilled water and ultrasonic baths. Unfortunately this washing process can damage the plant cells releasing organic liquids due to over handling. Studies have also documented that some metals are leached out during this washing process. As noted above the loss of organics will also fractionate the elemental compositions. The method adopted by Hussey (2012) provides a relatively straight forward method to assess and interpret biogeochemical data for the amount and impact of natural dust deposition on plants as opposed to biological uptake. It also provides a rapid method to visualise the various elemental CRs and most importantly can also be used to infer the composition of the substrate where data is lacking (*ie* generate concealed exploration targets). This method has been adopted here and samples with geochemical dust indicators above acceptable limits have been disregarded.

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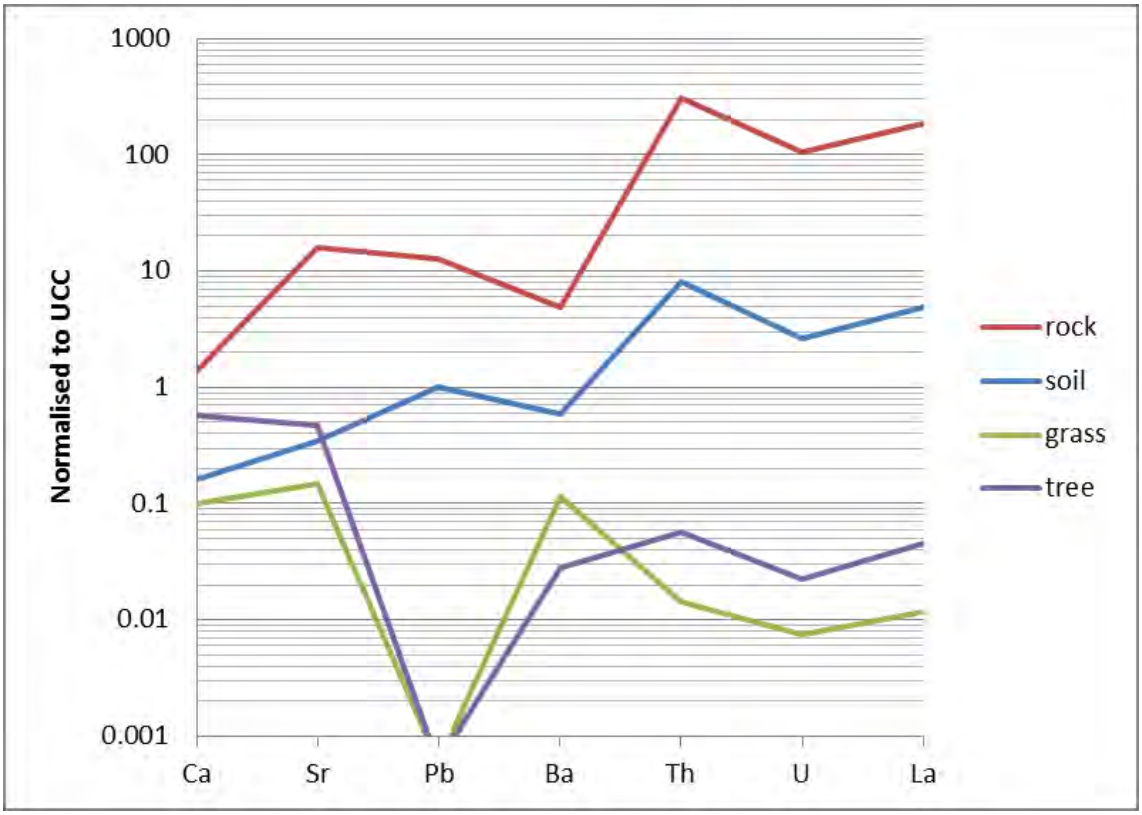

Figure 56: Environmental monitoring site ARA0840 showing the physical location of the samples above with the relevant assay data plotted below. The average rock beneath this site has been calculated using assay data from NBRC184 and NBRC326 within about 20 metres of the stand of small mulga trees (*Acacia aneura*) and grass (*Chenchrus ciliaris*) at this location. Drilling data and the geological model indicate this site is on top of a mineralised zone with a about a metre of soil cover. Plot follows the method of Hussey (2012).

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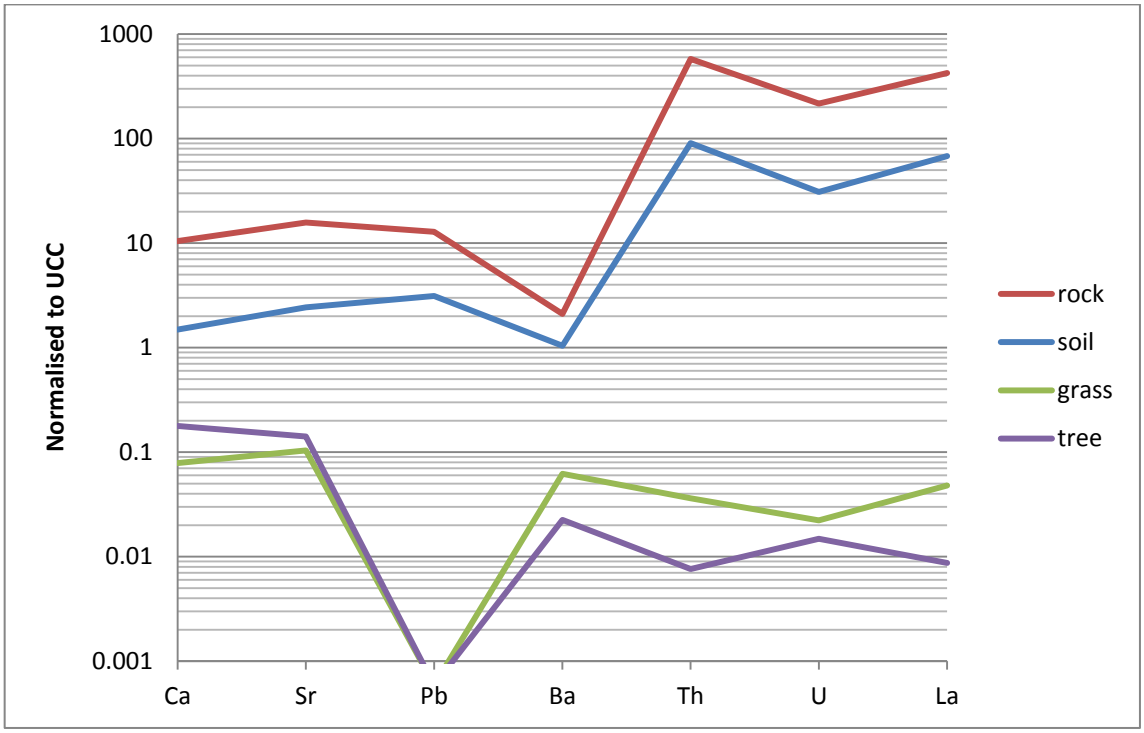

Figure 57: Environmental monitoring site ARA0631 showing the physical location of the samples above with the relevant assay data plotted below. The average rock beneath this site has been calculated using assay data from Costean 4 and NBDH159 both of which are with about 5 metres of the tree (Corymbia opaca) and grass (*Chenchrus ciliaris*) behind the pink post in the foreground. Costean and drilling data indicate this site is on top of a mineralised zone with a very thin soil cover (<30cm).

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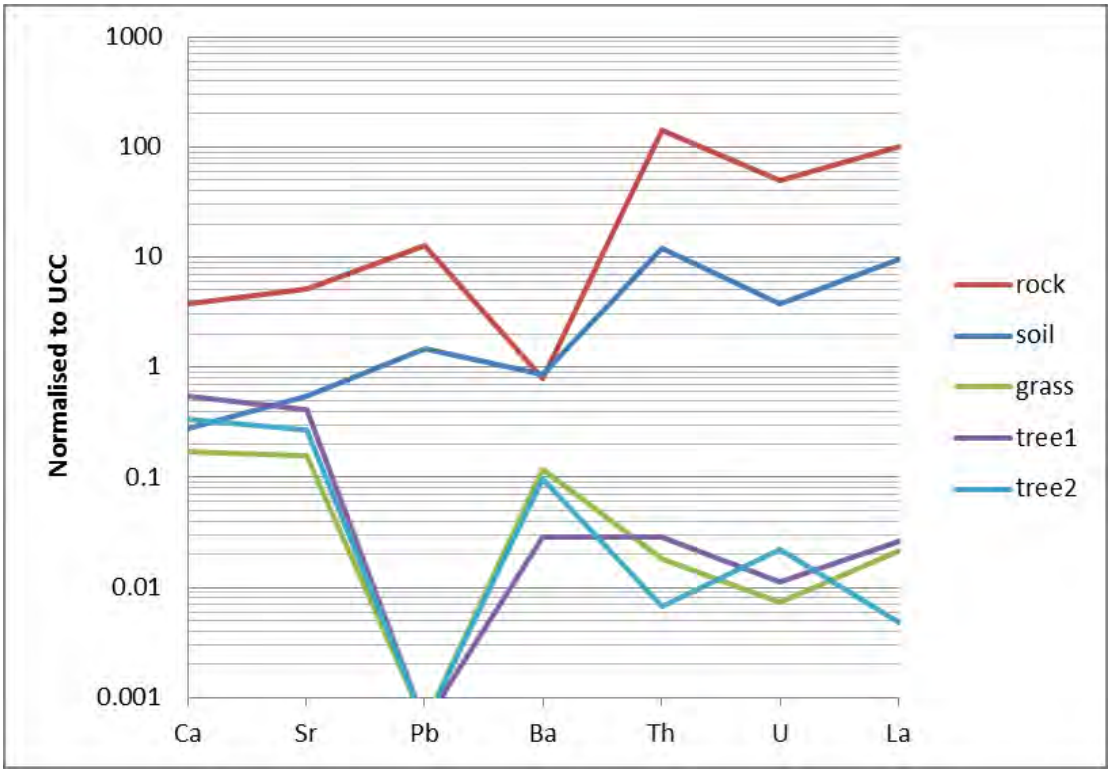

Figure 58: Environmental monitoring site ARA0841 showing the physical location of the samples above with the relevant assay data plotted below. The average rock beneath this site has been calculated using assay data from NBDH168 collared within 10 metres of the trees (tree1- *Acacia aneura* on LHS and tree2 - *Corymbia aparrerinja* on RHS) and grass (*Chenchrus ciliaris*). A sump was dug immediately to the left of the pink post in 2006 and clearly demonstrated that these trees had their roots in mineralisation. Exposures and drilling data indicate this site is on top of a mineralised zone with a very thin soil cover (<30cm).

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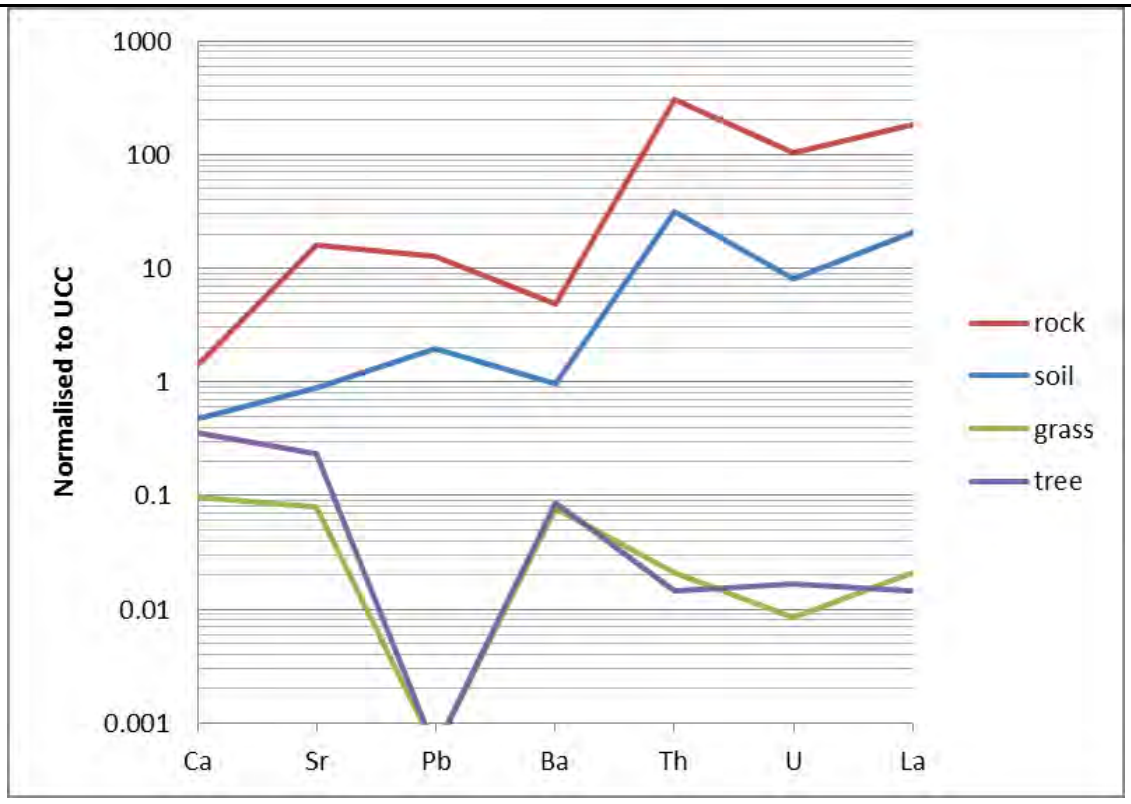

Figure 59: Average compositions of the all samples from the environmental sites within the resource area.

Table 12: Average CR values based on average compositions of the plants and soil at the environmental monitoring sites in the resource area. Note the actual CR values for the trees are likely to be up to an order of magnitude less because the underlying bedrock has a higher concentration.

element	grass	tree 'leaves'
U	0.0010	0.0021
Th	0.0007	0.0005
*Bi	0.012	0.012
*Pb	0.003	0.003
Ca	0.20	0.75
Sr	0.09	0.27
Ba	0.08	0.09
La	0.0007	0.0007

*half LOD used for this element.

The data shown in Table 12 is consistent with other published CR values.

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