Radiological doses to mammals in the Montebello Islands, Western Australia: results from 2019 field work

ANSTO- C1886

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12/20/2023

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Project planning, sample design and sample collection were performed in collaboration with Colleen Sims and Tim Hunt, Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) with additional support from Sean Garretson and Mark Blythman as well as Andy Edwards and the crew of the Keshi Mer II. The study would not have been possible without funding for sample analysis and assistance with sample collection provided by the DBCA (Colleen Sims, Tim Hunt).

Contents

SUMMARY

During the 1950s, three nuclear tests (Hurricane, Mosaic G1, Mosaic G2) deposited radioactive fallout onto the local islands of the Montebello Archipelago along with some deposition onto mainland Western Australia. While many of the short-lived radionuclides that initially had high radioactivity concentrations have now decayed to low levels, there remain today elevated levels of other radionuclides with medium to long-lived half-lives in some areas of islands. These include the gamma-emitting radionuclides of ^{137}Cs, ^{152}Eu and others, the beta-emitting ^{90}Sr, as well as alpha-emitting radionuclides, especially the plutonium isotopes of ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu and ^{241}Am.

The activity concentrations of these radionuclides are variable across the islands, with persistent and elevated levels in some areas including a few locations with relatively high levels (Johansen et al., 2019). The highest levels of plutonium (Pu) in soils exceed 20,000 Bq/kg, well above those found at other sites in Australia that have radioactive wastes (e.g. Maralinga, mining waste sites) (Child and Hotchkis, 2013; Johansen et al., 2019; Johansen et al., 2014). These levels surpass reference criteria for release of materials (e.g., 100 Bq/kg for unconditional release of material, IAEA 2004b) as well as reference levels established for clean-up at international sites (e.g., 1000-3000 Bq/kg at US sites). While the persistence of these radionuclides in specific areas does not necessarily indicate clean-up or similar actions are required for the conditions/exposures at the Montebellos, they do indicate the need for further evaluation, including assessment of potential impacts on wildlife.

In the 1990s an eradication program was carried out to remove feral cats and introduced rodents from the Montebello Islands. By 1998, some of the islands within the Montebello group began to be used as sites to translocate a number of threatened mammal species as part of conservation and reintroduction programs (Dunlop et al., 2021; Morris et al., 2000). These species currently include: *Bettongia lesueur* subsp. (Barrow and Boodie Islands) (burrowing bettong, boodie); *Isoodon auratus barrowensis* (Barrow Island golden bandicoot); *Lagorchestes conspicillatus* (spectacled hare-wallaby); *Lagorchestes hirsutus* (*NTM U2340 unnamed central Australian subspecies*) (mainland rufus hare-wallaby; mala); and *Pseudomys gouldii* (Shark Bay mouse, djoongari).

Upon arrival on the islands, these mammals would have been exposed to the soil contamination from the nuclear tests and begun absorbing radionuclides into their bodies via ingestion and inhalation pathways. The general knowledge on uptake of radionuclides by mammals is well established (Whicker, 1982) and uptake rate estimates have been measured in world studies for a range of mammal species and radionuclides (Beresford, 2010; Howard et al., 2012; IAEA, 2013; Johansen et al., 2013, 2020). Such uptake is also well documented in Australia, including at other nuclear sites (Hirth et al., 2017; Johansen et al., 2016; Johansen and Twining, 2010).

As part of the mammal translocation programs, the Western Australian Department of Biodiversity, Conservation and Attractions (DBCA) conducts monitoring programs at mammal research sites. Prior to this study, no radionuclide measurements had been made at designated mammal research areas on the islands. Knowing the levels of radionuclides at these sites is important for understanding the potential impacts to island flora and fauna, including the mammals that have been placed on the islands as part of threatened species conservation and island ecological restoration programs.

In the initial stages of the mammal translocation programs, an assessment of potential doses to the translocated mammals was conducted (Langford and Burbidge, 2001). However, the dose estimates in that study were deficient in that they considered only the gamma-emitting radionuclides and omitted alpha and beta-emitting radionuclides (e.g., Pu isotopes and ^{90}Sr,) which are common in the island soils and therefore must be included to understand potential dose impacts. Since 1990, it has been known that the Pu isotopes are the most important radionuclides for human exposures in the Montebello Islands (ARL, 1990), yet no assessment which includes Pu has been made for resident mammals which have similar dose exposure pathways to humans (e.g., lung-inhalation pathway). Therefore, a complete mammal dose assessment that includes Pu and all relevant radionuclides is needed.

The key aims of this project are to:

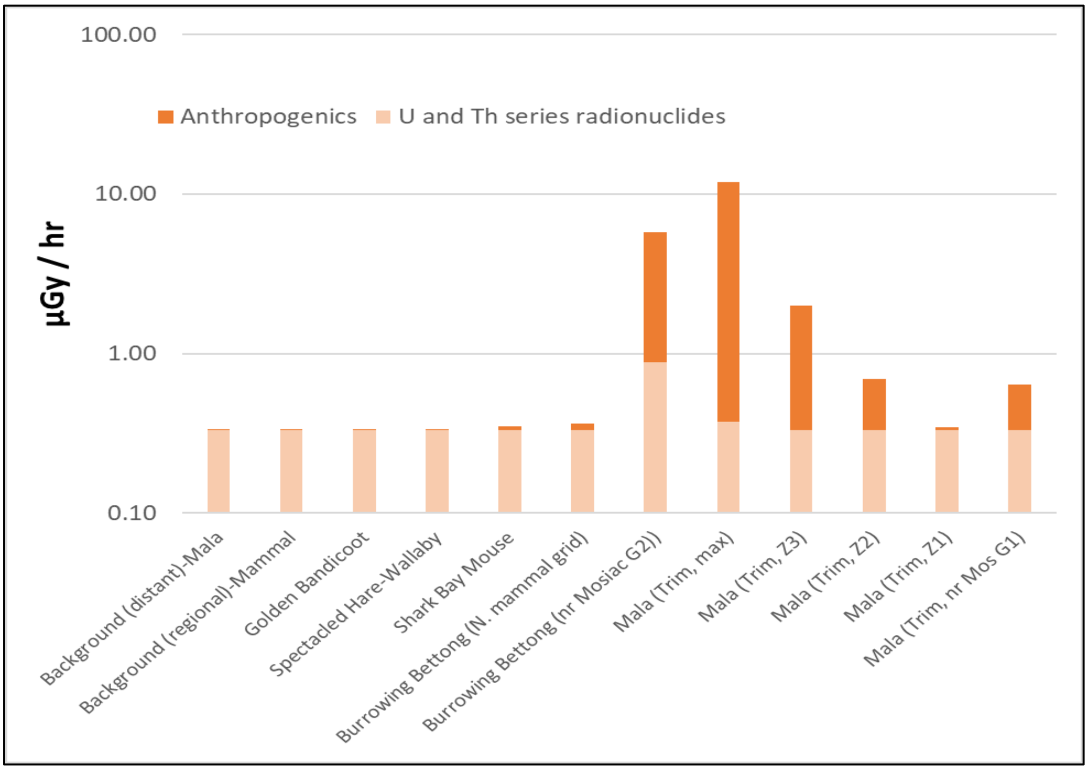
- provide measurements of radionuclides in soils at Montebello Islands mammal research sites with emphasis on Pu, as well as ^{90}Sr, ^{137}Cs, ^{152}Eu, ^{154}Eu, ^{241}Am, as well as U and Th series radionuclides (see Appendix E for description of radionuclides),
- provide measurements of radionuclides in mammal tissues that have been retrieved from the islands, and
- evaluate dose rates for island mammals, especially on Alpha, North West and Trimouille Islands and compare these with international benchmarks for potential harmful effects.

This report specifically addresses the exposures and resulting dose rates of the five mammal species that have been translocated to the islands. A separate analysis is needed for the other representative animals and plants. Radionuclide levels relative to human exposures (e.g., visitor camp sites, researcher activities) are not evaluated here and have been addressed in a separate report (ANSTO C-1715).

The main findings of this work are:

- At most mammal research areas tested, the calculated dose rates are elevated above background levels, but are below reference benchmark levels for harmful effects (e.g., Hermite, North West, and the western portions of Alpha Island; see Summary Figure).

- Dose rates exceed benchmark levels for potential harmful effects in two areas. The first area being on Trimouille Island, the highest dose rates are on the western margin in the area known for its elevated fallout from the Hurricane test (Figure 1). At this location, the activity concentrations of the Pu isotopes exceed 20,000 Bq/kg and other radionuclides are also elevated (ranking highest to lowest: ^{239}Pu > ^{137}Cs > ^{90}Sr > ^{240}Pu > ^{238}Pu > ^{241}Am > ^{235}U > ^{152}Eu). The resulting dose rates to the mala living in this area (up to 12 µGy hr^{-1}) are sufficient to cause harmful effects according to standard international references (i.e., are within the 4-40 µGy hr^{-1} International Commission on Radiological Protection (ICRP) derived consideration reference level (DCRL) band for mammals in which harmful effects may begin to occur).
- The second area with high radionuclide levels is near the Mosaic G2 site on the eastern end of Alpha Island (Figure 1). The resulting dose rates to burrowing bettongs that live in this area (~6 µGy hr^{-1}) are sufficient to cause harmful effects according to standard international references (i.e., are within the 4-40 µGy hr^{-1} ICRP DCRL band for mammals).



Summary Figure. Mammal radiological dose estimates from samples taken 2019 at the Montebello Islands. Anthropogenic radionuclides are ^{241}Am, ^{137}Cs, ^{152}Eu, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{90}Sr, ^{235}U. U and Th series radionuclides are mainly from natural sources. However, some U and Th levels are increased near the test sites. For maps of islands and mammal research areas, see Figure 1 and 2.

- In the above two higher dose areas, the radionuclides are likely to persist for decades. Over such long periods of time many of the resident animals are likely to visit or reside in the higher contamination areas. To compound this, these populations are confined to relatively small islands –they are essentially fenced in along with the areas of elevated contamination. Therefore, a greater proportion of individuals in these island populations are likely to be exposed to the higher doses than in a typical mainland setting where individual and intergenerational movement is not forced to remain near the contamination.

- At locations with higher dose rates, the external dose (gamma radiation from surrounding soils) contributes less to the overall dose as compared with internal dose (mostly alpha and beta radiation from radionuclides accumulated within the animals). This means that measuring alpha/beta emitters and their corresponding internal dose rates is important to understanding the potential radiation effects on island mammals.
- On the western side of Alpha Island, away from the Mosaic G2 site, the mammal research area was not subjected to high levels of fallout despite its relative proximity to the Mosaic G2 test (from which the fallout plume moved more north than west) (Figures 1, 2). At this location, the Pu levels range up to 74 Bq/kg (about x100 higher than typical background levels). The dose rates to burrowing bettongs in the western and southwestern areas of Alpha Island are therefore much lower than those near the Mosaic G2 site and are below the benchmarks for potential effects. Any impacts to burrowing bettongs in these areas would depend on movement patterns over time relative to the contaminated eastern end of the island.
- On North West Island, the higher levels of $^{239,240}Pu$ were recorded at the more western of the two mammal research areas (Figures 1, 2), with this grid returning 170 Bq/kg (for the composite of four grid corners) compared with the eastern grid's 57 Bq/kg composite. This pattern is consistent with the known trajectory of the Hurricane fallout cloud which travelled from the detonation site northward and westward passing between Alpha Island and North West Island (across Kingcup, Gardenia, Bluebell, and other islands) and therefore deposited more Pu at the western areas of North West Island than on the eastern areas. At the western research grid, the estimated dose rates to Shark Bay mouse are noticeably higher than the mammals on Hermite Island and at the western end of Alpha Island, but they are well below the 4-40 μGy hr^{-1} DCRLs.
- The Hermite Island site is located south of the detonation areas ("upwind" at the time of the tests; Figures 1, 2) and the Pu levels range from near background, to slightly higher than (< x10) background levels from global fallout elsewhere in Australia (soil background ranges from 0.01 to ~1.0 Bq/kg) (Child and Hotchkis, 2013; Hancock et al., 2011; Smith et al., 2016). The dose rates to golden bandicoot and spectacled hare-wallaby on Hermite Island are also only incrementally above the natural background level.
- The soil depth profile data indicate the Pu is mostly in the top 10 cm of island soils, but also that a fraction of the Pu has penetrated to beyond 30 cm depth (based on data from Trimouille Island

and Alpha Island, Appendix E). The significance of this is that contamination should not be viewed as a thin layer that could be easily removed and dispersed by wind. Instead, the radionuclides are adsorbed within a 0-30+ cm layer of soil that is relatively persistent and will therefore remain as an ongoing exposure source many decades into the future.

- The uncertainties in this study are substantial and suggest that in the conditions present at the Montebello Islands, the standard approaches used here (e.g., ERICA-tool) would be highly likely to underestimate dose rates, and therefore impacts. The main uncertainties include:
    - The boundaries of the areas of highest contamination are not known.
    - The generic factors used in this study (ERICA-tool defaults, CRs) may underestimate the radionuclide body burdens and dose rates in the Montebello Island mammals. Data from previous studies suggests that the soil-organism uptake amounts are higher in Australia than in temperate environments of the northern hemisphere (Hirth et al., 2017; Johansen and Twining, 2010; Rea et al., 2021).
    - The standard dose calculation and DCRL consideration do not account for radioactive particles ("hot particles" with concentrated radionuclides) which are the prevalent radionuclide form in the Montebello Islands (Johansen et al., 2022; Johansen et al., 2019). The various exposures from these concentrated radioactive particles (hot particles) are not inherently modelled within the ERICA-Tool and therefore the dose rates predicted here may be understated. For example, if a concentrated particle is lodged in the lung of a small mammal, it may cause more dose than the standard models will predict for the typical inhalation pathway (Caffrey et al., 2017).

Recommendations:

- Better characterise the levels and extent of radionuclides in the soils and vegetation of the most impacted areas on Alpha and Trimouille Islands.
- Improve the understanding of radionuclide uptake in mammals potentially through further sampling and analysis of mammal tissue/bone, to reduce the uncertainty of dose rate estimates for resident mammal species.
- Given the restricted range on the islands, and the proximity to elevated and persistent radiounuclide levels, improve the understanding of population level exposures. This may include animal movement studies and modelling of exposure-dynamics (e.g. how much of the population is exposed to the highly elevated radionuclide areas over time).
- For those species exposed to higher dose levels, investigate and describe the potential for individual and population effects. This may include a testing program for chromosomal and

physical anomalies in the mala and burrowing bettong populations as well as modelling on the perpetuation of radionuclide impacts intergenerationally.

BACKGROUND

In October 1952, a nuclear weapon with a plutonium core was detonated in the hull of the HMS Plym, which was anchored in shallow waters within the Montebello Islands Archipelago off Western Australia. The 25 kt detonation initially caused a gamma burst, quickly followed by pressure and heat waves. Vaporised and molten materials from the ship, seawater and seafloor sediments were subsumed into a rising thermal cloud. The subsequent radioactive fallout was deposited first onto local waters and islands, then, with less intensity, regionally and ultimately across northern Australia (Butement et al., 1957; Child and Hotchkis, 2013; Lal et al., 2017; Tims et al., 2013; Tims et al., 2016).

This test, code-named "Hurricane", initiated the British nuclear testing program and was the first major atmospheric release of anthropogenic radionuclides in the Southern Hemisphere (Figure 1). Two additional nearby nuclear detonations followed four years later, Mosaic G1 and Mosaic G2, the latter being the largest of all nuclear detonations of the British tests in Australia (the proposed yield was 60 kt, estimates of the actual yield approach 100 kt: Child and Hotchkis, 2013; UNSCEAR, 2000).

In the ~70 years since the testing, many of the short-lived radionuclides have decayed to low levels and are now difficult to detect using standard methods. However, a number of medium- and long-lived radionuclides remain at elevated levels including strontium-90 (^{90}Sr) and plutonium isotopes ($^{239, 240, 241}$Pu). This legacy of radionuclides creates a need for ongoing awareness and monitoring. Government surveys were conducted in the 1960s-1980s (Australian Radiation Laboratory [ARL] Report Series; ARL1979; ARL, 1980; ARL, 1982; ARL, 1983; ARL, 1990). Following the ARL 1990 publication, there was a period in which few Montebello radionuclide data were reported (Child and Hotchkis, 2013; Tims et al., 2013). More recently, new data have been published (Johansen et al. 2019), however, these data were few and focused mainly near the detonation areas.

Despite the efforts of the past, major data gaps exist relevant to types of use and potential exposure risks existing in the Montebello Islands today. One significant data gap is the lack of radionuclide measurements reported for the designated mammal research areas on the islands near the nuclear detonation sites. These islands are being utilised as important refugia for several threatened and endangered Australian mammal species. Knowing the levels of radionuclides at these locations is important for understanding any potential impacts to the mammals themselves, as well as for ensuring development of appropriate health and safety protocols and safe work practices for the human researchers that regularly visit the sites and interact with the soils.

The main goals of this project include filling the data gaps on radionuclide levels at mammal research sites, and providing estimates of current dose rates to site mammals.

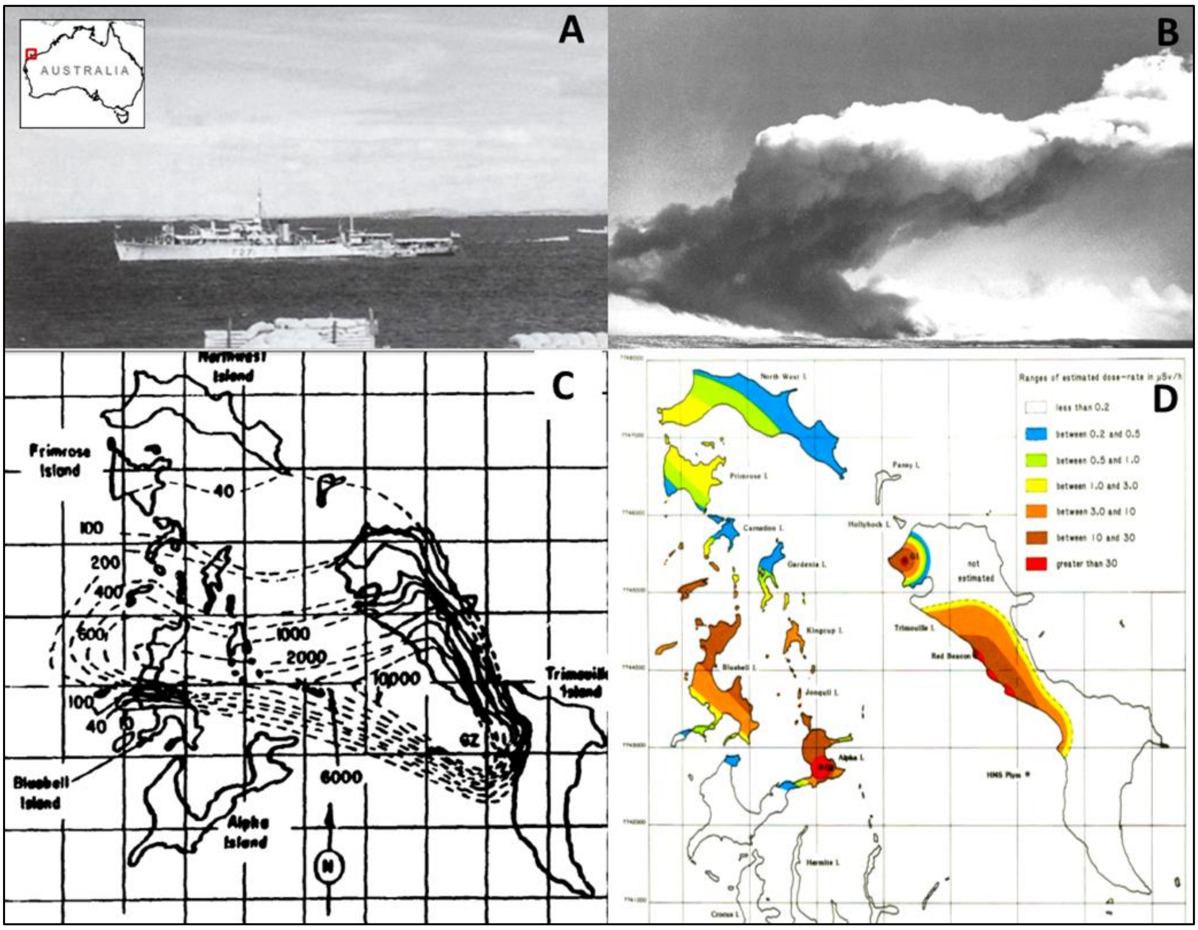


Figure 1. (A) The HMS Plym prior to the Hurricane test in October 1952. (B) The thermal cloud after detonation. (C) The resulting surface dose rate contours at 1 hour (from 40 to 10,000 rad hr^{-1}, approximately 0.4 to 100 Gy hr^{-1}). (D) 1962 gamma dose rate contours from the combined fallout from the Hurricane and Mosaic tests (yellow-to-red increasing gamma emissions; ARL, 1982). Sources are: (A,B) National Archives of Australia; (C) "*Local fallout from nuclear test detonations, compilation of fallout patterns and related test data, foreign nuclear tests.*" US Army Nuclear Defence Laboratory, 1964. Declassified 17 June 1992 by the US Defence Technical Information Center; (D) Australian Radiation Laboratory (ARL), 1982.

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METHODS

Soil Sampling

The field sampling followed standard best practice methods for environmental assessment of radionuclides as described in Johansen et al. (2019). These included:

- Samples of soils were from the surface layer (<10 cm) unless specified otherwise consistent with current IAEA and other international approaches.
- Samples were collected using clean 30 mm PVC tubes (10 cm deep samples). Fresh tubes were used at different locations.
- All samples were composites of a minimum of 3 tube pushes (typically gathered within a few meters of each other at ~120° angles from a centre-point). The 3 samples were mixed in a plastic bag by rotation and shaking with care to avoid stratification or loss. Any excess was eliminated at the sample location.
- Soil depth profiles were gathered at some locations (0-32 cm). These were gathered by digging a large U-shape hole, leaving an undisturbed central section that was progressively sampled downward in 4-cm lifts. Before each sampling, the exposed faces of the soil were shaved to eliminate the potential for cross-contamination.

At mammal research areas, samples were typically gathered at all four corners and near the grid centre (Figures 2, 3). For some grids (where detail across the grid was not needed), fewer samples were gathered, or samples were composited.

On Trimouille Island, the existing mammal survey transects were used to guide sampling at every 200 m across most of the transect with some finer sampling near the transect ends (Figure 4) as well as beach and sediment samples when available. Due to practical time constraints, four (out of ten) transects (5-6, 11-12, 13-14, 19-20) were not sampled.

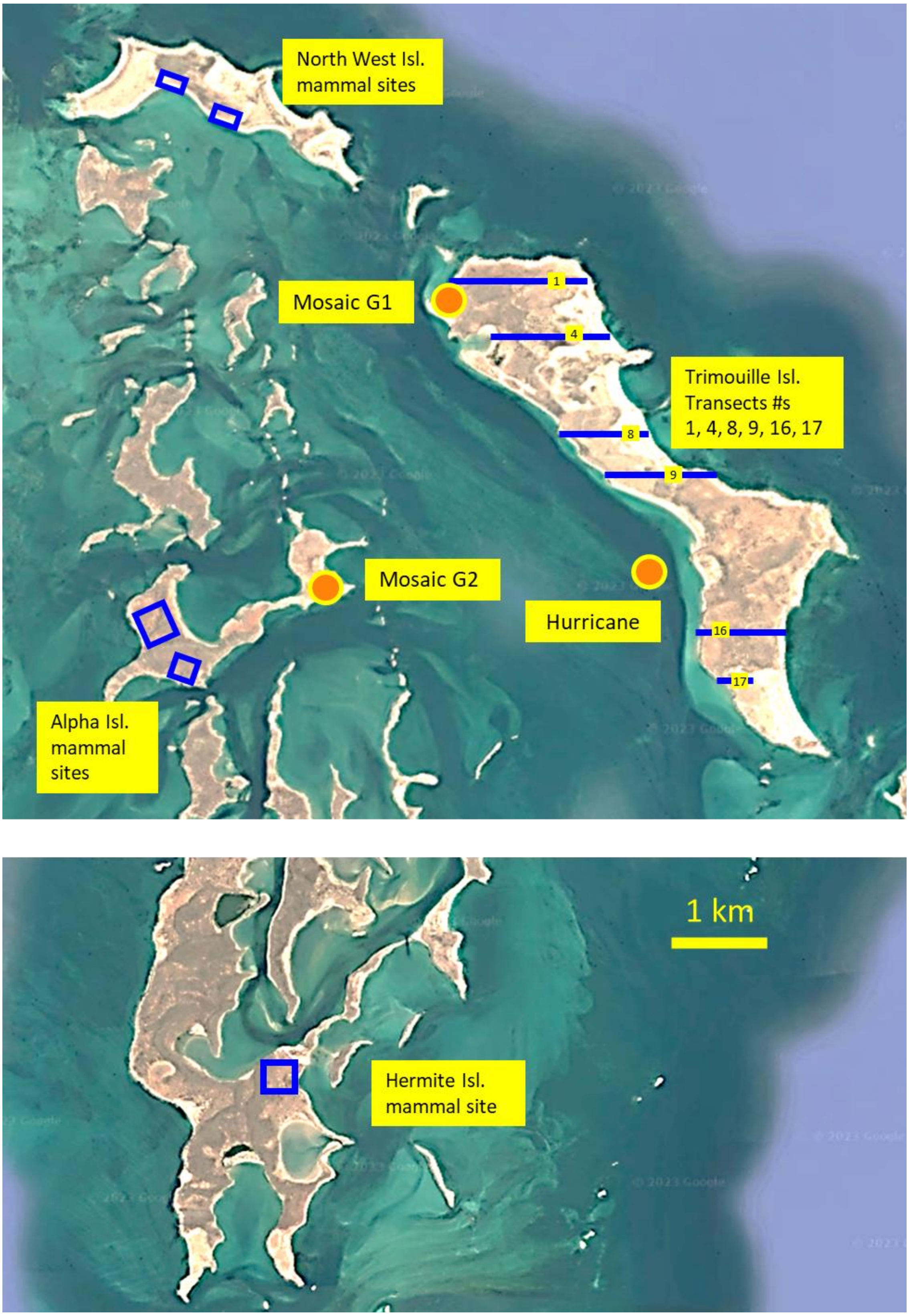


Figure 2. Study locations at mammal research areas (blue) and 1950s test sites (orange) at the Montebello Islands, Western Australia.

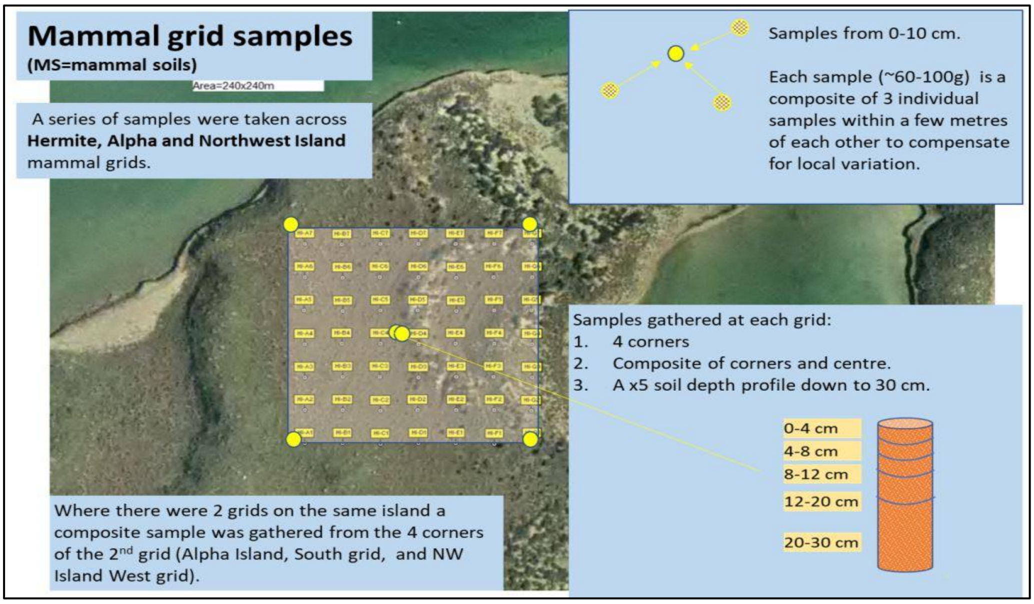


Figure 3. Typical soil sampling design at the mammal research grids (e.g., Hermite Island), Montebello Islands.

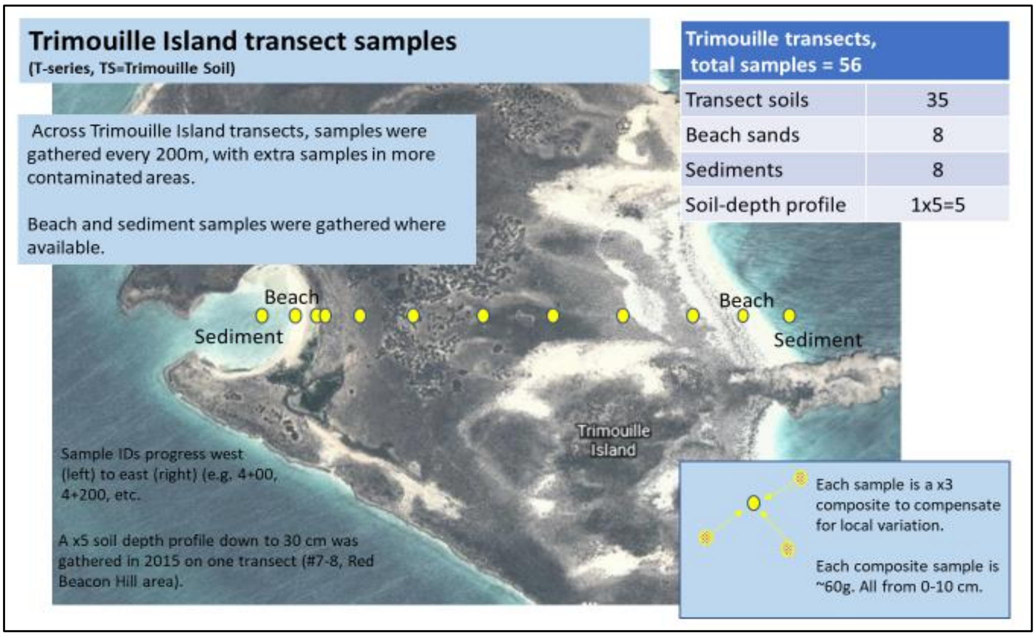


Figure 4. Typical soil sampling design for a Trimouille Island transect (e.g., Transect 3-4), Montebello Islands.

Bone Sampling

Ideally, the activity concentration burdens within mammals could be determined from analysis of fresh tissues collected from the study sites. However, no such sampling was planned for the endangered species populations on the Montebello Islands. The next best alternative is to collect bones from found carcasses at the site. Several key radionuclides are absorbed strongly in bones including Pu isotopes and ^{90}Sr and these substantially remain with the bones until physical removal (e.g., disintegration or other physical processes; Durbin, 1975). It is therefore important to gather only bones that have not degraded physically, and that have not been contaminated by contact with soils. This was accomplished by searching out recently deceased specimens in which the skin/fur/muscles covered the bones, and by selecting those bones positioned away from soils. In some cases, the carcasses were suspended in shrubs/vegetation which helped prevent soil contamination. The collected bones were then assessed for the potential for degradation or contamination and were excluded from the study if deemed unsuitable.

The standard bone sample was one whole femur which provided intact marrow and the approximate mass needed for analysis by alpha-spectrometry. Such samples were analysed for the two hare-wallaby species (spectacled on Hermite Island and rufous on Trimouille Island) and burrowing bettongs (Alpha Island). Control (background) mala bone samples were obtained with the help of the DBCA from Dorre Island (Shark Bay) and the mainland site of Matuwa. Additional comparable bone samples from kangaroo were gathered from Burrup Peninsula.

Radionuclide Analysis

Radionuclide analysis methods are explained in detail in Johansen et al. (2019); some text below is excerpted from these papers and briefly summarised here.

Alpha spectrometry

Surface soils and marine sediments were screened to remove fragments, coarse pebbles and vegetation (>500 µm). The bulk soil was then homogenised, dried, and subsamples (~10 g) were digested using a three-step digestion process: aqua regia reflux (solid:liquid ratio 1:20, 108 °C, 4 hours); open hotplate digestion using hydrofluoric acid; and fusion digestion of residual solids (IAEA, 2010). Any residue remaining after digestion was collected on a filter paper and screened for total radioactivity (ISO, 2009). Radioactivity was not detected above instrument background in these residues indicating adequate dissolution of the sample matrices.

Sample digests were spiked with yield tracers ^{232}U (EZA Source 83609-657), ^{229}Th (EZA Cat. No. 7229), ^{242}Pu (NIST SRM 4334I), ^{243}Am (EZA Cat. No. 7243). Samples were chemically processed as described in Harrison et al. (2011). Uranium (^{238}U, ^{234}U), thorium (^{230Th}); to assess for above-background U and Th resulting from the 1950s testing), plutonium ($^{239+240}Pu$, ^{238}Pu) and americium (^{241}Am) were measured by alpha spectrometry on a Canberra Alpha Analyst using Passivated Implanted Planar Silicon (PIPS®) detectors as described in Harrison et al. (2016).

Beta analysis

Digests for beta analysis were conducted as described for alpha spectrometry and stable Sr was used for the control spike. Autochthonous stable Sr concentrations in each sample were measured by ICP-AES and taken into consideration in the Sr yield assessment. Strontium-90 (^{90}Sr) was quantified by Cherenkov counting (L'Annunziata and Kessler, 2012) on a Perkin-Elmer Tri-Carb 3100TR liquid scintillation counter. Instrumentation settings and count methodology are described in Harrison et al. (2011).

Gamma spectroscopy

Gamma-emitting radionuclides in soils and sediments were measured in standard-geometry containers using an ORTEC High-Purity Germanium (HPGe) n-type reduced background detector (relative efficiency of 45%) coupled to an ORTEC DSPEC Pro with MAESTRO software. An equivalent geometry, soil matrix, mixed gamma calibration source (15 x 55 mm, EZA SRS 94204) was used for energy and efficiency calibration across an energy range of 46.5–1836.1 keV. Dried and homogenous samples were counted between 24 – 72 hours each to achieve adequate counting statistics. The detectors were calibrated using a multi gamma calibration standard.

Dose Assessment

Dose Calculation

The dose rates to mammals were estimated under the current best-practice framework (ARPANSA, 2015; ICRP, 2008) using standard approaches for terrestrial organisms (Johansen et al., 2012; Ulanovsky et al., 2008; Vives i Batlle et al., 2007). Dose estimates were calculated using the ERICA-Tool software v 2.0 (Brown et al., 2016).

The scope of this report is limited to the five mammal species that have been placed on the islands:

- *Bettongia lesueur* (burrowing bettong, boodie);
- *Isoodon auratus barrowensis* (golden bandicoot);
- *Lagorchestes conspicillatus)* (spectacled hare-wallaby);
- *Lagorchestes hirsutus* (rufus hare-wallaby; mala);
- and *Pseudomys gouldii* (Shark Bay mouse, djoongari).

Table 1 provides the external exposure geometry input to the ERICA-Tool based on each species typical sizes, nesting/burrowing and feeding habits.

Table 1. Exposure information for the five mammal species of the Montebello Islands considered in this study. Most data are site-specific, sourced mainly from Pers. Coms: C. Sims, DBCA 2023.

		Weight, Body dimensions[1]	Exposure characteristics[2]	locations
Bettongia lesueur (burrowing bettong, boodie)		0.43-1.16kg, Ave=0.82kg (Adults) ERICA Ellipsoid: 0.82 kg, (HWL= 0.082, 0.073, 0.24 m)	Burrows socially. Nocturnal foraging, Digs for food. Home range <2 km. ERICA Occupancy: 0.75 in-soil. 0.25 on-soil.	Alpha Island.
Isoodon auratus barrowensis (golden bandicoot)		0.2 - 0.7 kg, Ave=0.375 kg (Adults) ERICA Ellipsoid: 0.375 kg, (HWL= 0.062, 0.048, 0.22 m)	Burrows, or nests at or above ground. Nocturnal. Omniv. Digs for food. Home range < 0.35 km^2 (M) and <0.12 km^2 (F). ERICA Occupancy: 0.6 in-soil. 0.4 on-soil.	Hermite Island.
Lagorchestes conspicillatus) (spectacled hare-wallaby)		1.3-3.7kg; Ave=2.55kg (Adults) ERICA Ellipsoid: 2.55kg, (HWL= 0.11, 0.10, 0.40 m)	Shelters in scrapes within dense veg at or above ground. Nocturnal. Herbiv. ERICA Occupancy: 0.2 in-soil. 0.8 on-soil.	Hermite Island.
Lagorchestes hirsutus (rufus hare-wallaby; mala)		0.78-1.55kg; Ave=1.25kg (Adults) ERICA Ellipsoid: 1.25 kg, (HWL= 0.10, 0.068, 0.32 m)	Shelters in scrapes, or in single opening burrows. Nocturnal. Herbiv./Graniv. Limited data on home range. ERICA Occupancy: 0.6 in-soil. 0.4 on-soil.	Trimouille Island.
Pseudomys gouldii (Shark Bay mouse, djoongari)		0.027-0.075kg. Ave=0.051kg ERICA Ellipsoid: 0.051 kg, (HWL= 0.039, 0.028, 0.051 m)	Shelters in a nest in a burrow. Nocturnal. Herbiv. (Omniv?) ERICA Occupancy: 0.75 in-soil. 0.25 on-soil.	North West Island.

[1] ERICA Ellipsoid dimensions refer to the standard approach within the ERICA-Tool of representing an organism by an ellipsoid of equivalent mass. HWL = height, width and length of the ellipsoid (m).
[2] ERICA Occupancy refers to the fraction of time spent in a burrow (in-soil) vs on the ground surface.

For external dose rates, the measured activity concentration data from host soils at research study sites were used as input into the ERICA-Tool (Appendix C). Where sufficient data was available, the data were assumed to be lognormally distributed and the geometric means were used. On Trimouille Island, the radionuclide levels varied greatly and therefore five exposure zones were used according to their $^{239.240}$Pu activity concentrations:

- near Mosaic G1
- Zone 1; 0-100 Bq kg^{-1}
- Zone 2; 100-10,000 Bq kg^{-1}
- Zone 3; >10,000
- Maximum (transect 8, nr Red Beacon Hill)

These zones represent exposure scenarios. That is, if an animal spends most of their time on soils with 100-10,000 Bq kg^{-1} Pu, then their dose can be defined for that exposure. The general locations of these zones relate to the activity concentrations shown in Figures 5 and 8. However, the detailed boundaries of these zones are not known due to sparse sampling coverage on Trimouille Island. Additional sampling is needed to more completely define specific locations.

To determine internal dose rates, body burdens were estimated from the available measurements on bones retrieved in 2019 from the study areas (Appendix A). From the results of the radionuclide analysis on bone samples, standard reference bone-to-whole-body ratios (Johansen et al., 2016; Yankovich et al., 2010) were applied to determine the whole-body activity concentrations for input into the dose calculations (Appendix B).

Bone sample results were mostly available for the anthropogenic radionuclides with far fewer results for the U and Th (natural) radionuclides. Where bone sample data were not available, the whole-body burdens were estimated from the measured soil activity concentrations using the standard Concentration Ratio (CR) approach (Hirth et al., 2017; IAEA, 2013). The CR approach is a standard method that is applied widely across the world and is the default method used in the ERICA-Tool software for calculating dose to non-human biota (Brown et al., 2016). However, the CRs are known to vary among species and no species-specific CRs were available for the five species of this study. In such instances, the standard approach is to use the generic CRs for small mammals (available within the ERICA-Tool, and at wildlifetransferdatabase.org) as has been done here.

While the above approach applies best practice, there is inherent variability in data and parameters including; the activity concentration data that varies spatially; the uptake (CR) data which is known to vary among species and individuals; and the bone-to-whole body ratios that are also known to have inherent variability among species and conditions (Beresford, 2010).

RESULTS

Radionuclide levels at mammal research areas

Radionuclide levels across island areas are highly variable. Among the various island research sites, the levels of radionuclides in soils typically ranked (highest-to-lowest): Trimouille >Northwest >Alpha >Hermite (Figure 5). On Trimouille Island, the activity concentrations of key anthropogenic radionuclides typically rank (highest to lowest): $^{239}Pu > ^{137}Cs > ^{90}Sr > ^{240}Pu > ^{238}Pu > ^{241}Am > ^{235}U > ^{152}Eu$. However, variation in ranking exists at different locations, for example in areas impacted by the Mosaic G1 and G2 sites, ^{152}Eu can rank higher than ^{137}Cs.

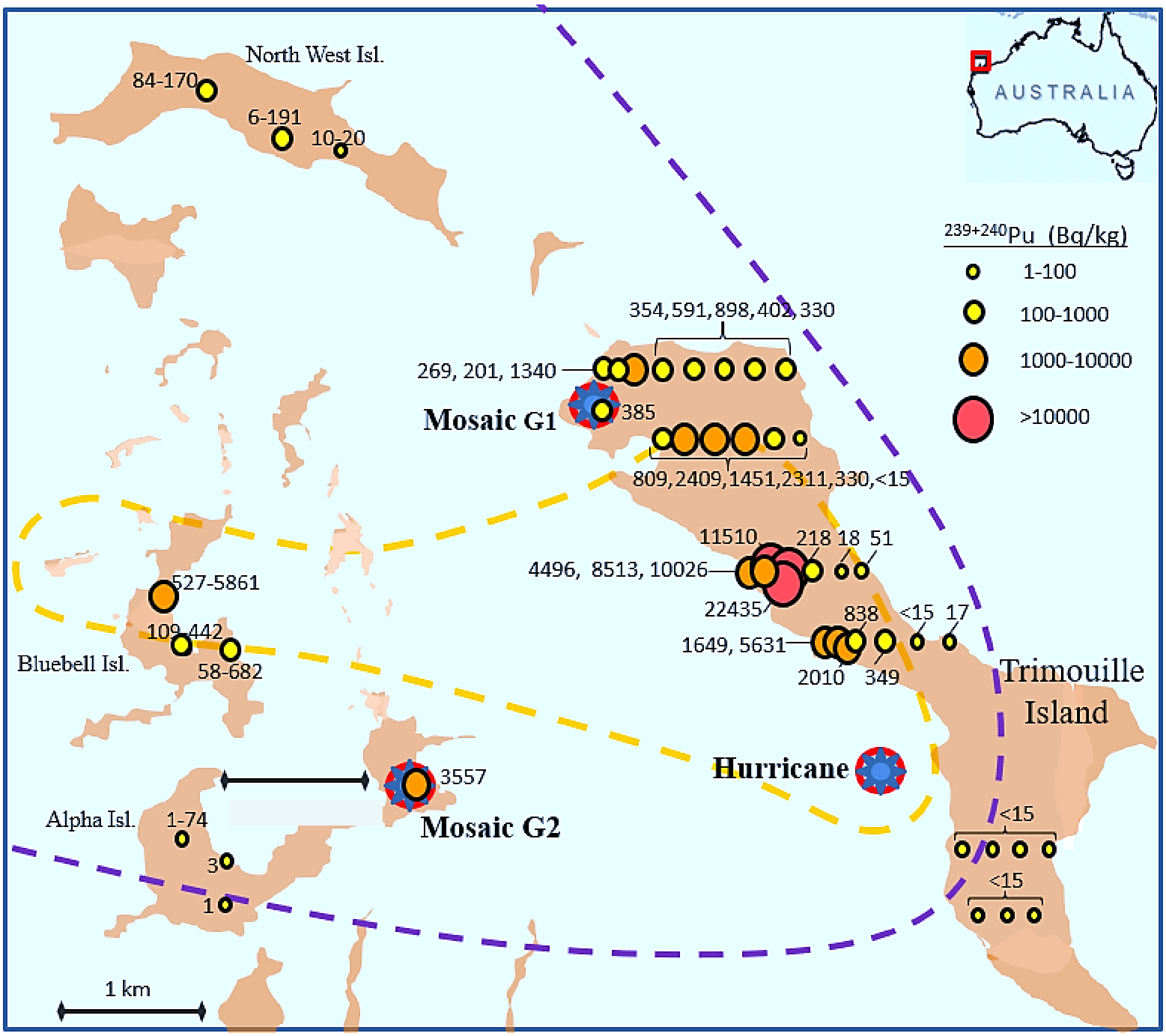


Figure 5. $^{239,240}Pu$ levels (Bq/kg) results of 2015-2019 sampling of soils (see text and data tables for beach sands and sediment data). The purple dashed line indicates the approximate area of elevated 1950s fallout from all three tests (based on 1960-70s data: Figure 1D). The yellow dashed line bounds the approximate area of highest 1952 Hurricane Test deposition (based on 1952 data; Figure 1C).

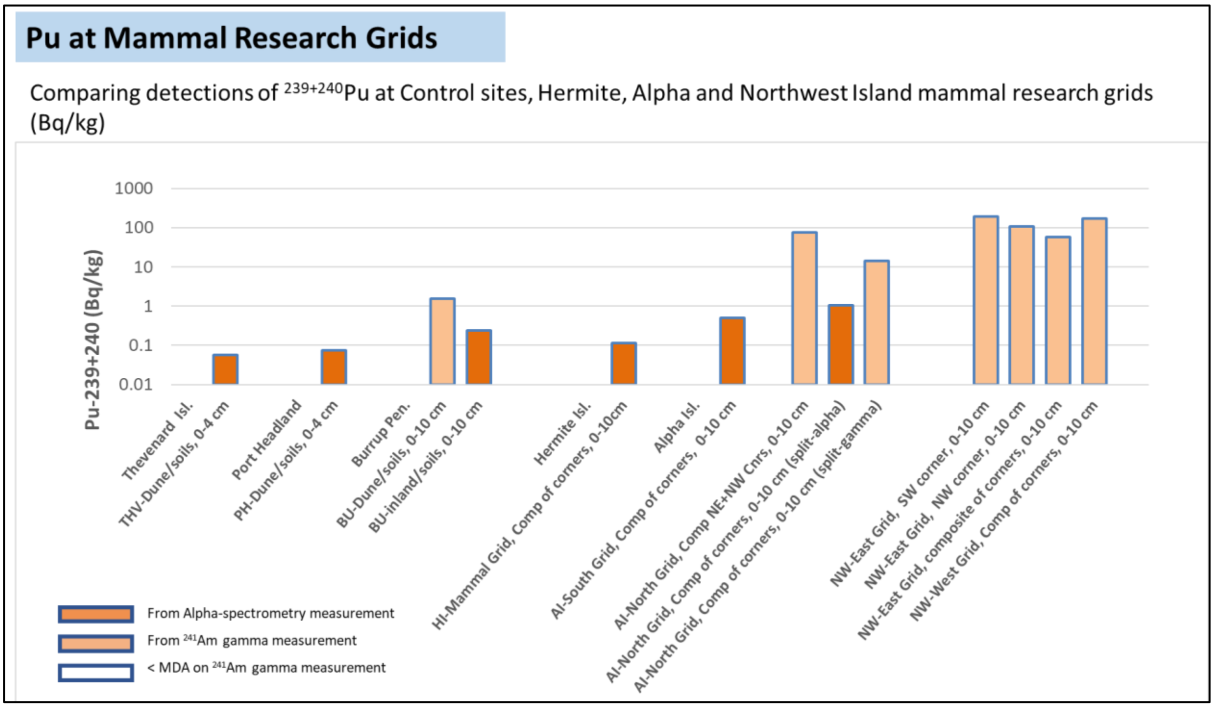


Figure 6. Summary Pu activity concentrations in soils at mammal research areas on Hermite, Alpha and Northwest Islands with comparison to other areas within the Western Australia Pilbara Region (Thevenard Island, Port Hedland, and Burrup Peninsula).

At the Hermite mammal grid site (Figure 2), the Pu in soils is mainly sourced from the tests, however, the levels are relatively low and are not different than the range of background levels from global fallout elsewhere in Australia (soil background ranges from 0.01 to ~1.0 Bq/kg) (Child and Hotchkis, 2013; Hancock et al., 2011; Smith et al., 2016). The sampling on Hermite, and other relatively uncontaminated areas, did not find any new undiscovered areas of contamination and therefore, at these sites, the natural radionuclides of the U and Th series provide more dose than the nuclear test radionuclides.

On Alpha Island, the north mammal grid (Located on western Alpha Island) had substantially higher radionuclide levels than the south mammal grid (on south-western Alpha, Figure 2). At the north grid, the Pu results ranged from about 1 - 74 Bq/kg (between 10 to 100 times higher than typical background levels). The highest levels were at the northernmost corners of the north grid (Figure 6). However, on the eastern end of Alpha Island (Figures 2, 6) much higher radionuclide levels exist near the site of the Mosaic G2 detonation (mean of 3557 Bq/kg, Johansen et al., 2019).

On North West Island, of the two mammal research areas (Figure 2), the higher levels of Pu were at the western grid (174 Bq/kg for the composite of four grid corners) as compared with 57 Bq/kg composite result for the eastern grid (Figure 6). This pattern is consistent with the known trajectory of the Hurricane fallout cloud which travelled from the detonation site northward and westward passing between Alpha Island and North West Island (across Kingcup, Gardenia, Bluebell, and other islands) and therefore deposited more Pu at the western areas of North West Island than on the eastern areas. However, levels varied significantly with one sample from the eastern grid at 191 Bq/kg (Appendix E).

Trimouille Island Pu

In this study, the highest Pu levels in soils of the Montebello Islands exceeded 10,000 Bq/kg and were in samples from the western margin of Trimouille Island (Figures 5, 7). These were from the same general area as the 2015 samples which had >20,000 Bq/kg maximums (Johansen et al., 2019). On Trimouille Island, the transect sampling (west-to-east) across the island provided the largest set of Pu data to date on the island and showed that the activity concentrations in the eastern/southern margins of the island are orders of magnitude lower than in the western/northern areas.

The data of this study greatly improve the understanding of the Pu on Trimouille Island, which has had only limited direct testing for Pu in past studies. Figure 8 is a partially completed map of the Pu levels on Trimouille Island. While this map provides the most extensive set of Pu measurements gathered on the island to date (2019), some key areas of the island with known contamination have yet to be sampled/characterized for Pu (areas marked with "no data").

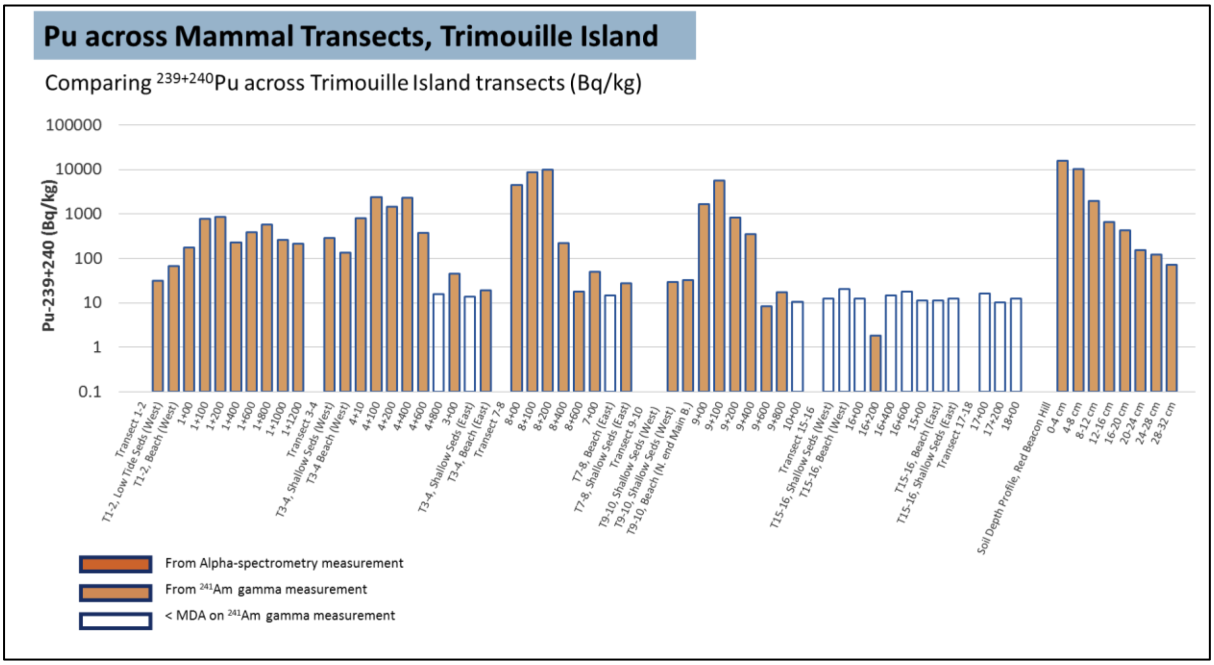


Figure 7. Pu activity concentrations across Trimouille Island transects (all progress west to east), Montebello Islands. See Appendix D for transect information and Appendix E for values and uncertainties. MDA is the minimum detection activity.

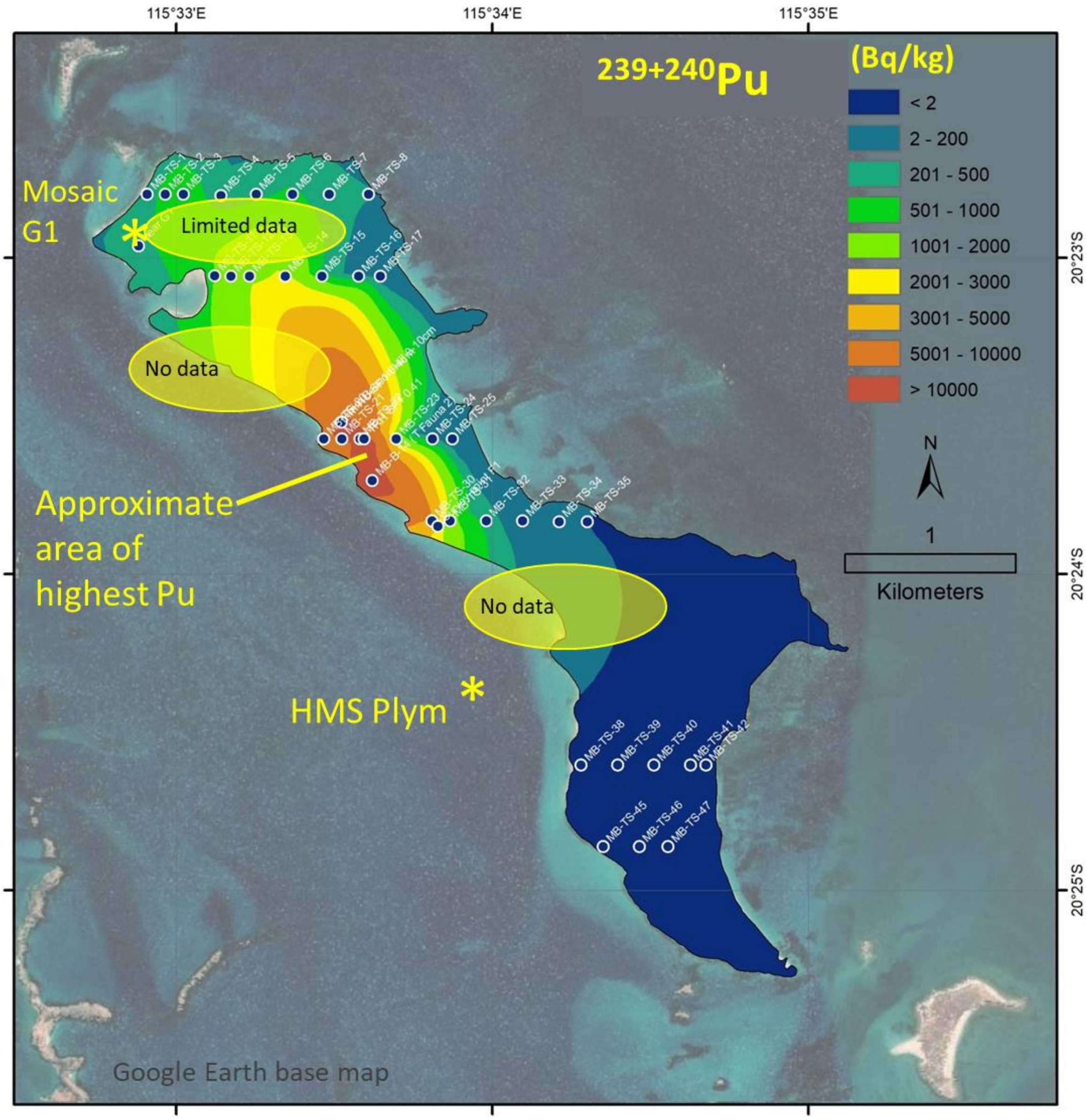


Figure 8. Spatial mapping of Pu activity concentrations on Trimouille Island, Montebello Islands, based on all soils data collected through 2019. The lack of data in some areas prohibits accurate bounding of contours and more data are needed to improve mapping in those areas (e.g., between transects and across southern Trimouille Island).

Despite these gaps, the results indicate that the Pu on Trimouille is highest in the original Hurricane test deposition areas (close to the western shoreline, north of Main Beach, Figure 8). The persistence of Pu in these soils are indicated by the Soil Depth Profile data which shows the Pu is mixed within the top 10 cm of island soils, and that some Pu has penetrated to beyond 30 cm depth (Figure 7, rightmost data). Because of this, most of this buried Pu is not easily mobilised by wind, which accounts for its stability over the past decades. However, the topmost layer is available for ongoing mobilisation, with perhaps some spreading due to winds suggested in Figure 8 (potentially northward from the highest deposition areas). The island soils are subject to frequent high winds and periodic storm events, which can cause scour, erosion and mobilisation of the Pu by wind and water. However, insufficient sampling has been done to quantify the wind remobilisation.

Despite the erosive forces that regularly act on the islands, the Pu persists at relatively high levels in the soils at the original deposition areas. In these areas, the 0-30 cm layer of soil should be considered as an ongoing source of Pu and that the subsequent risk of exposure to wildlife, likely to persist for many decades into the future.

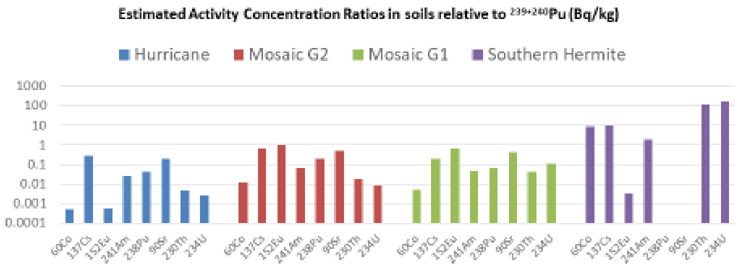
Given that the Pu contamination is persistent and can be mobilised, further sampling is recommended to gain a better understanding of its current distribution, and to monitor how this distribution changes with time, especially in the areas shown in Figure 8 (around the Mosaic G1 site and the gaps to the north and south of the elevated contamination on the western margin of Trimouille Island). These data gaps can be filled by additional soil samples (~30-50), and/or additional field gamma measurements that can be correlated to Pu (hand-held, backpack, or drone detectors with highly sensitive gamma capabilities).

^{137}Cs, ^{90}Sr and other key radionuclides in soils

Describing the radiological contamination in the Montebello Islands presents a major challenge in that the three different nuclear tests produced a range of different radionuclides, and these were deposited in amounts that vary greatly from place to place across the islands. Even when sampling sites in close proximity, activity ratios among the key radionuclides can vary due to differing decay rates over time as well as the presence of hot particles. One basic remedy for this is additional sampling. Until that occurs, we provide here activity ratios based on existing data (Figure 9) which can be used to estimate expected radionuclide levels where measurements do not yet exist or are sparse. In this study, a few data gaps were filled using these ratios (Appendix A). Note that these ratios should be updated over time (due to decay and environmental dilution) and would be improved over time with more measurements.

Projected activity concentration ratios relative to $^{239+240}Pu$

*means were used where data were sufficient. Some ratios are based on limited data and may be improved in the future.



Estimated Activity Concentration Ratios in soils relative to $^{239+240}Pu$ (Bq/kg)										
Hurricane			**Mosaic G2**			**Mosaic G1**			**Southern Hermite**		
60Co	0.001		60Co	0.012		60Co	0.005		60Co	<	8.8
137Cs	0.285		137Cs	0.691		137Cs	0.201		137Cs		9.9
152Eu	0.001		152Eu	0.994		152Eu	0.674		152Eu	<	0.003
241Am	0.027		241Am	0.068		241Am	0.048		241Am		1.92
238Pu	0.041		238Pu	0.201		238Pu	0.070		238Pu		7.95E-05
90Sr	0.195		90Sr	0.513		90Sr	0.431		90Sr		BDL
230Th	0.005		230Th	0.019		230Th	0.042		230Th		120
234U	0.003		234U	0.009		234U	0.107		234U		164

Figure 9. Estimated ratios of activity concentrations in soils relative to $^{239+240}Pu$ (ratios of the Bq/kg of each listed radionuclide to that of the Bq/kg of $^{239+240}Pu$ at the specified locations within the Montebello Islands). The ratios are on a 2015 basis and any future use of these ratios should consider the uncertainty associated with: decay over time, variation due to hot particles, variation due to limited data for some ratios and spatial variation between the specified reference points.

Results from mammal bone samples

Results from the analysis of mammal bone samples indicate high variation in Pu activity concentrations among mammals across the various study sites (Figure 10). The $^{239+240}Pu$ in the bones of mala from the background locations of Dorre Island and Matuwa were similar at 0.00015 Bq/kg and 0.00035 Bq/kg respectively (see Appendix A for uncertainties and other details). In contrast, the kangaroo bone from Burrup Peninsula had three orders of magnitude higher Pu levels (0.18 Bq/kg, rib sample) which was similar to that in the samples from the Hermite island mammal grid (0.11-0.21 Bq/kg for Spectacled Hare-wallaby). Most of the Burrup Peninsula Pu is fallout from the Montebello tests as opposed to world-wide fallout (see bone sample discussion below).

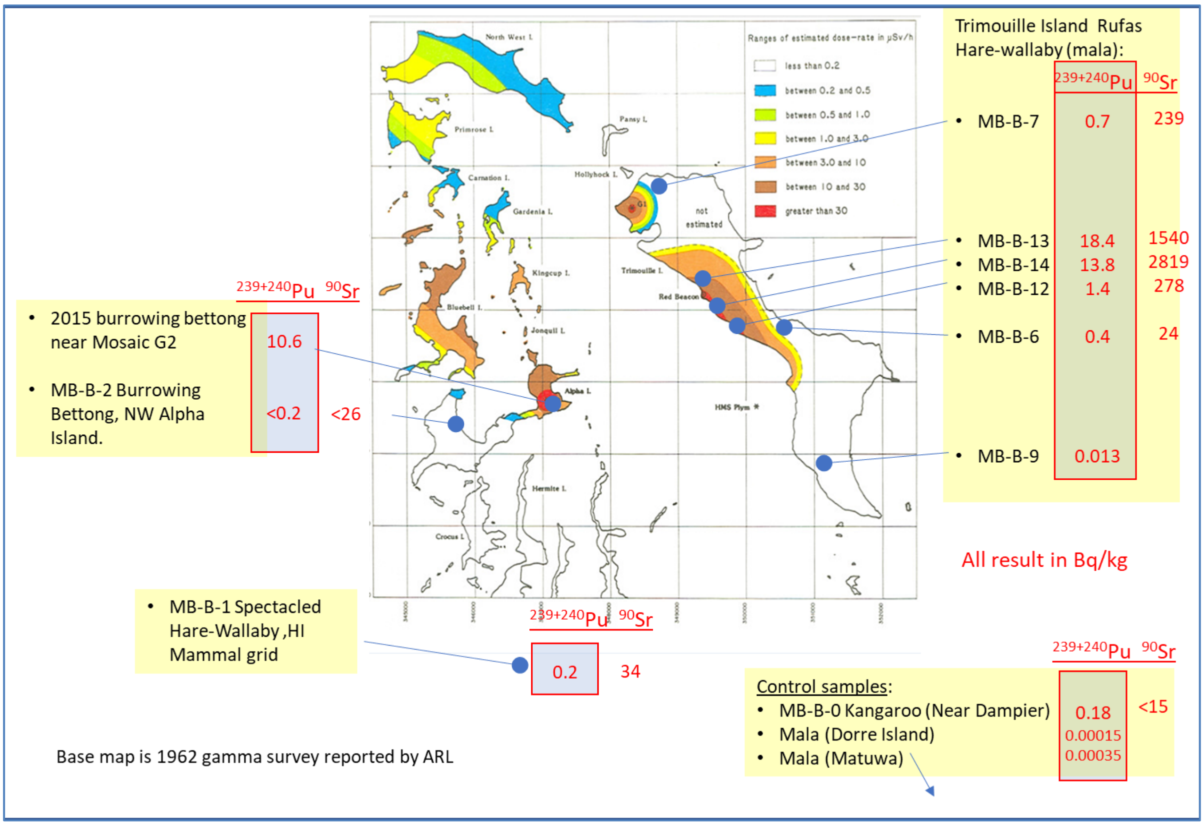


Figure 10. $^{239+240}Pu$ and ^{90}Sr activity concentrations (Bq/kg) in mammal bone samples at the Montebello Islands. See Appendix A for uncertainties and locations.

Like the soils data, the mammal bone data on Alpha and Trimouille Islands varied substantially among locations. On Alpha Island, the bone data align with the soils data in that the levels in samples from near the Mosaic G2 site are orders of magnitude higher than those from the mammal grid on the western portion of the island. On Trimouille Island, the bone data pattern also aligns with the soils data in that the highest activity concentrations in bones are from within, or near, the known area of Hurricane test deposition (Figure 10). The total body burden of any specific mammal depends on the radionuclide levels in the soils where the mammals live/feed, on the mammal behaviours that influence exposure (burrowing, incidental ingestion of soils from eating, grooming, etc.), and the chemical-physical characteristics of each radionuclide. These three factors (radionuclide levels, species exposure characteristics and radionuclide characteristics) are the main determinants of radionuclide uptake and therefore largely determine the potential for radionuclide dose and harmful impacts.

The Pu in all bone samples from within the Montebello Islands had $^{240}Pu/^{239}Pu$ atom ratios that averaged 0.030 (SD=0.14) which confirms it is sourced from three 1950's Montebello nuclear tests which collectively had similar low $^{240}Pu/^{239}Pu$ atom ratios (Johansen et al. 2019). The ratios of the Montebello tests contrast with other possible sources such as regional or global fallout which have much higher ratios (approximately 0.14 and 0.18 respectively, Johansen et al. 2019).

Given its location on the mainland, the bone sample from Burrup Peninsula might be expected to show more influence from global fallout, but its $^{240}Pu/^{239}Pu$ atom ratio of 0.033 indicates that nearly all of its Pu was sourced from the Montebello tests. Greater influence from global/regional fallout is indicated in the bone sample from Matuwa which has a higher atom ratio of 0.079 which is consistent with a mixture of Montebello, Maralinga and other fallout sources. The $^{240}Pu/^{239}Pu$ atom ratio of the Dorre Island mala bone sample (0.036) is lower than expected given its location. This ratio matches the Montebello source signature even though Dorre Island is 560 km to the south and most of the Montebello plumes were known to track northward and eastward instead of southward. Since Dorre Island is further still from another possible Pu source of Maralinga (and also "upwind"), the unusually low atom ratio result at Dorre Island is not explained by the limited data.

Mammal Dose Estimates

Highest doses. The highest doses calculated were at the two areas having the most intense fallout (Table 2, Figure 11): 1) near the Mosaic G2 test site on Alpha Island the estimated dose to burrowing bettongs is 5.8 µGy/hr, about 20 times greater than the background mammal dose rates; and 2) on the western margin of Trimouille Island, in the area of greatest fallout contamination from the Hurricane test the estimated dose to mala is 11.9 µGy/hr, about 40 times greater than the background mammal dose rates.

Dose rates to the burrowing bettongs on Alpha Island and the mala on Trimouille Island vary greatly among locations (Table 2). Dose rate results should be viewed as points along a spectrum of potential doses to individuals on these islands dependent on their location, movement over time, and habits. In this study, we express this variability using two locations on Alpha Island and five locations, or zones, on Trimouille Island. It is likely that such a spectrum includes higher dose rates than predicted here since it is unlikely that our limited sampling found the actual maximum levels in soils or mammal bones.

The main finding of this report is that dose rates in at least two locations (Table 2) are within the 4-40 µGy hr^{-1} DCRL band for mammals (ICRP, 2008) and therefore, have the potential to impact resident burrowing bettong and mala individuals.

From ICRP 108 (2008):

> *A DCRL can therefore be considered as a band of dose rate within which there is likely to be some chance of deleterious effects of ionising radiation occurring to individuals.*

From ARPANSA Guide on Radiological Protection of the Environment (2015):

The DCRLs identify a band of dose rates where a decision-maker may need to consider the potential for deleterious effects of radiation in a particular species, although further considerations might be needed in order to take a fully informed decision.

The "further considerations" suggested in the ARPANSA guide are particularly relevant for the translocated species at the Montebello Islands. Some key considerations are:

- The potential impacts to individuals in the study areas have an oversized importance given that these island populations represent a large proportion of the species' (relatively small) global populations. Any impacts also bring in to question the suitability of these populations (or parts there-of) as harvest sources for contributing to future conservation translocation decisions.
- The DCRL benchmarks should not be viewed as precise thresholds because they rely on an evolving understanding of dose effects (Copplestone et al., 2008; Garnier-Laplace et al., 2008), and they were developed using limited empirical data which does not include data on the species considered here.
- The importance of maternal transfer and intergenerational effects may be amplified in these small and constrained island populations.
- Radiation exposure, and its impacts, has been occurring prior to this assessment. The above dose estimates are on a 2015 basis. Dose rates prior to this would have been greater, and the severity of any impacts would have been greatest in the first years after species translocation because of the higher levels of key dose contributors at that time (e.g., ^{137}Cs, ^{90}Sr). The ^{137}Cs and ^{90}Sr radionuclides have ~30-year half-lives and therefore, dose is decreasing slightly each year. However, given the persistence of some dose contributors (e.g., Pu isotopes), it will be many years until the maximum dose rates decrease below DCRL levels.
- The main uncertainties in this project (discussed below) suggest that the standard approaches used in this assessment may underestimate dose rates and potential population effects to the five species of this study in conditions at the Montebello Islands.

Doses at Montebello and distant background locations. At the two distant background locations (Dorre Isl., Matuwa), the dose to mala (0.33 μGy $hr^{-}1$) was almost completely from natural background with a small increment from anthropogenic fallout (<1.0 %).

On Burrup Peninsula (mainland area, ~130 km east of the Montebello Islands), the dose rates to mammals from anthropogenic radionuclides are about four times higher than those at the distant background locations. Burrup Peninsula is the nearest mainland area directly east of the Montebello Islands and has a clear residual weapons test fallout signature that remains today (Appendix D).

However, the dose added by the Montebello tests to Burrup Peninsula mammals is only incrementally (1.4 %) above the natural background level.

Elsewhere within the Montebello Islands, the dose rates to golden bandicoot and Spectacled Hare-wallaby on Hermite Island are also only incrementally (1.9 – 2.0 %) above the natural background level. The low dose rates on Hermite Island are consistent with the historical record and subsequent investigations (ARL 1990; Johansen et al. 2019) which confirm that relatively small amounts of fallout were deposited southward from the three test sites. Higher fallout levels are documented in the soils northward, including at North West Island, where the dose rates to Shark Bay mouse are noticeably higher (5.5 % above natural background level) than the mammals at Hermite (Table 2), but still well below the 4-40 µGy hr^{-1} DCRLs that would indicate the potential for deleterious effects.

Nuclear test vs background radionuclides. The estimated dose rates to island mammals (Table 2, Figure 11) indicate highly varied exposures to the nuclear test radionuclides (consistent with their respective locations relative to the test sites and fallout areas). For species in locations away from the nuclear test sites and fallout plume, such as the Golden Bandicoot on Hermite Island, most dose came from the natural U and Th series with a relatively small proportion from the nuclear test radionuclides (2%). In contrast, species closer to these areas, such as the mala at the highest exposure area of Trimouille Island, almost all dose (97%) was from the nuclear test radionuclides. The dose from the U and Th series radionuclides were exclusively from natural background at most sites. However, at two locations, additional U and Th series radionuclides were deposited from the tests (Mosaic G2 and Hurricane tests; Figure 11).

Internal vs external dose. Dose is often separated into “internal dose” which derives from the radionuclides taken up into the body, and “external dose” which is from radionuclides in surrounding media (soils in this study). Of the dose from nuclear test radionuclides, the internal dose contribution (ranged between 60%-97%) exceeded the external dose (ranged between 3%-40%) (Figure 12). This finding is consistent with those at other comparable exposure sites (Chernobyl and Maralinga; Beresford et al., 2020; Johansen et al., 2016) where most dose to mammals is from internal exposure.

Among the study sites, the highest percentage of external dose (40 %) was for the burrowing bettongs at the more highly contaminated areas of Alpha Island which mainly reflects the burrowing bettong’s high percentage of time spent in burrows (subject to external radiation from surrounding soils).

Table 2. Estimated dose rates (μGy hr^{-1}) for mammal species of this study at the Montebello Islands. Refer to Figure 5 for island locations and zones. Trim = Trimouille Island.

	U&Th Series Total	Anthrop. External	Anthrop. Internal	Anthrop. Total	Total
Background (distant)-Mala	0.30	0.0002	0.0010	0.0011	0.30
Background (regional)-Small Mammal	0.30	0.0002	0.0043	0.0045	0.30
Golden Bandicoot (Hermite Island)	0.31	0.0004	0.0060	0.0065	0.32
Spectacled Hare-Wallaby (Hermite Island)	0.30	0.0003	0.0061	0.0064	0.31
Shark Bay Mouse (North West Island)	0.31	0.0037	0.0150	0.0188	0.33
Burrowing Bettong (N. mammal grid, west Alpha Island)	0.30	0.014	0.021	0.035	0.34
Burrowing Bettong (near Mosaic G2, east Alpha Island)	0.89	1.90	3.08	4.92	5.81
Mala (Trim, max)	0.38	1.62	9.89	11.51	11.89
Mala (Trim, Z3)	0.30	0.17	1.52	1.68	2.00
Mala (Trim, Z2)	0.30	0.063	0.30	0.36	0.66
Mala (Trim, Z1)	0.30	0.001	0.016	0.017	0.32
Mala (Trim, near Mosaic G1)	0.30	0.090	0.22	0.31	0.61

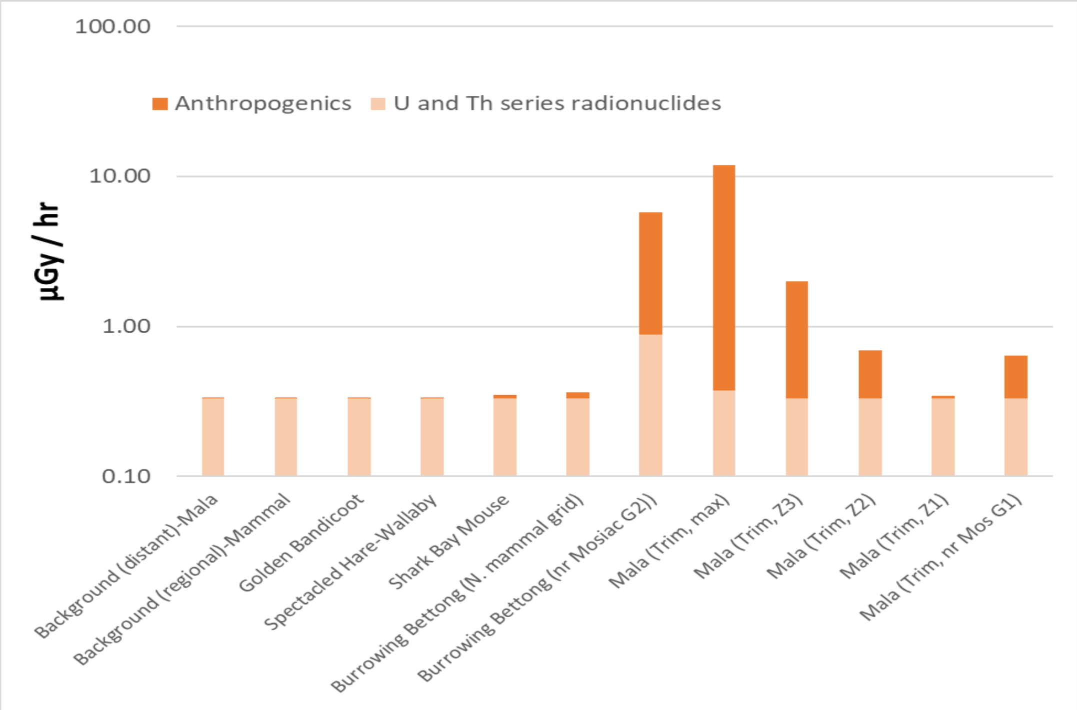


Figure 11. Mammal dose estimates from this study at the Montebello Islands. Anthropogenic radionuclides are (^{241}Am, ^{137}Cs, ^{152}Eu, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{90}Sr, ^{235}U). U and Th series radionuclides are mainly from natural sources. However, some U and Th levels are increased near the test sites. For island locations and zones refer to Figure 5.

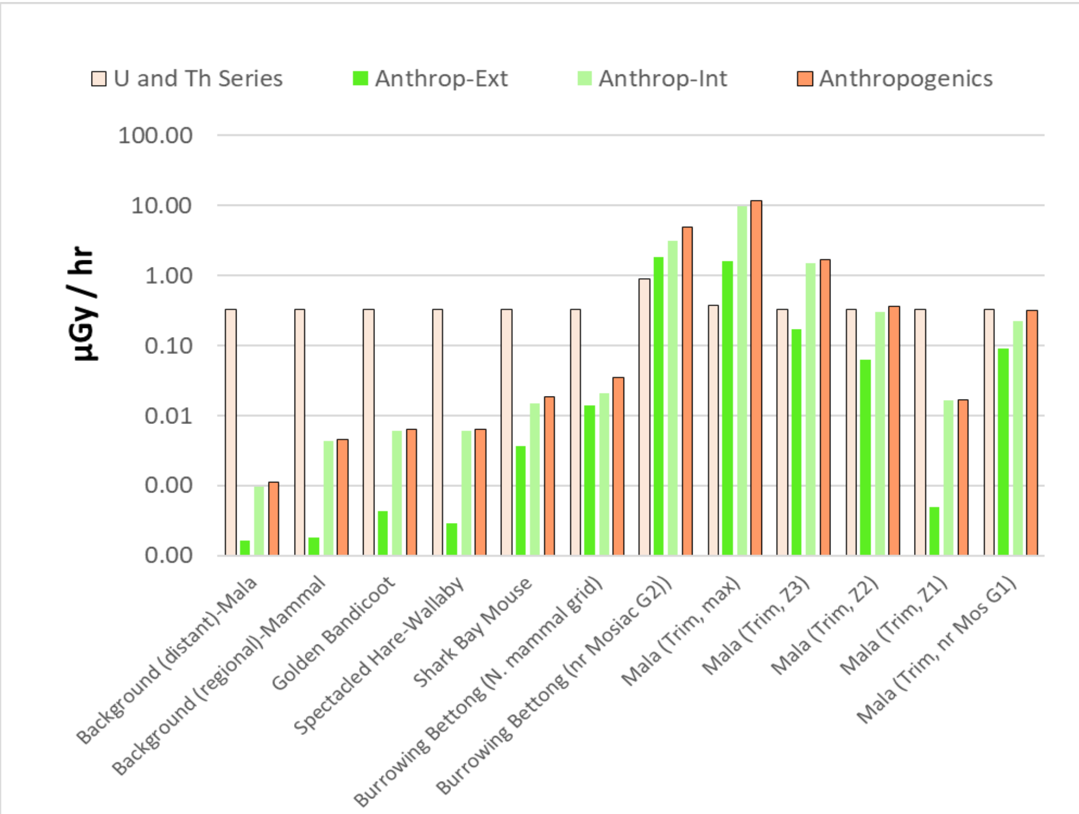


Figure 12. Relative contribution of anthropogenic vs U and Th Series radionuclides to mammal species at the Montebello Islands. For island locations and zones refer to Figure 5.

Key uncertainties

- It is unlikely that our limited sampling found the actual maximum radionuclide levels in soils or mammalian bones. Also, there has been insufficient sampling to define the boundaries of the areas of highest contamination. Therefore, it is likely that dose rates to mammals are higher than those predicted here.
- The soil-to-animal uptake factors used in this study (CRs) may underestimate the radionuclide body burdens in the Montebello Islands mammals. We used standard CRs (e.g., ERICA defaults for small mammals). However, data suggests that the soil-organism uptake amounts are higher in Australia (Hirth et al., 2017; Johansen and Twining, 2010; Rea et al., 2021), relative to the CR defaults which are strongly linked to temperate environments. In this study, bone samples were used where available, but few data meant that CRs were used as well to fill data gaps.
- In addition, there are physiological differences in many Australian animals that could influence radionuclide exposure. For example, in most mammals, early development takes place within the placenta; whereas marsupial joeys are born relatively early and finish development within-pouch. It could be that the marsupial joeys, which are situated closer to the contaminated soils and less shielded by the parent body mass, have greater exposure during their critical development stages. Therefore, it is possible that the exposure risk to the species on Trimouille and Alpha Islands is underestimated by the internationally derived DCRL benchmarks. More detailed species-specific dose and effects data is necessary to gain a greater understanding of how the mammals in the Montebello Islands respond to radiological exposure.
- The standard dose calculation and DCRL consideration do not specifically account for radioactive particles, which may increase dose in some situations. The ANSTO sampling in 2015 found numerous radiological particles in deposition areas (Figure 13a, 13b). In some soil samples, particles were the dominant form of radionuclides (Figure 13, Johansen et al., 2022). The particles from the Hurricane Test (Figure 13b) tend to be smaller and are therefore of greater concern for mammal exposure as these particles are likely to be within the respirable range (<5 µm), which, if inhaled, may become lodged in the lungs (here we assume that the <5um range for humans also applies to the mala, burrowing bettongs and other resident mammals of the islands although data on this is limited (Caffrey et al., 2017).

While the long-term fate of these particles has yet to be determined, the Mosaic G2 particles appear to have greater potential to remain in particle form compared to the Hurricane particles based on their higher Si and Ca content (Johansen et al., 2022). It may be that the Hurricane particles will dissipate and release their radionuclides in more respirable form sooner, but that is yet to be determined.

In this dose assessment, the various exposures from radioactive particles are not inherently modelled within the ERICA-Tool and therefore the dose rates predicted here may be understated. Key exposure pathways of concern are; inhalation of particles absorbed in dust, ingestion of particles absorbed in dust, and skin/external exposure of developing joeys which may come into contact with particles in soils/dust while in the pouch or during forays on contaminated soils.

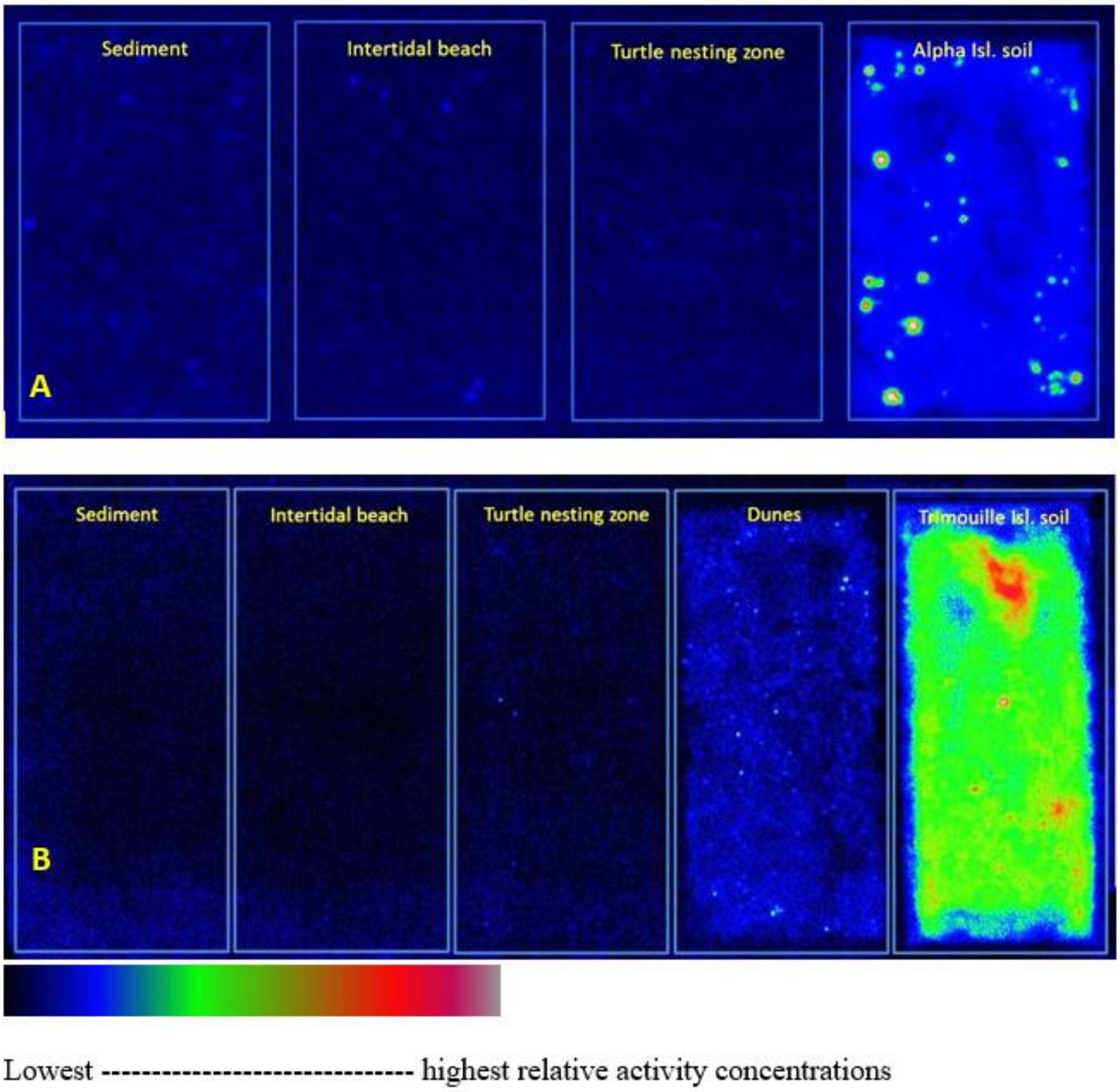


Figure 13a and 13b. PSL Autoradiography of sediment-sand-soil panels of 5 g samples each at the Montebello Islands. Top (A) is from near the Mosaic G2 site at Alpha Island, bottom (B) is from near HMS Plym site to the Red Beacon Hill area of Trimouille Island (from Johansen et al. 2019).

Discussion on the potential for population impacts. Overall, there is not yet enough information available to determine whether negative population-level impacts will occur to the island mammals as a result of radionuclide exposures. Using some approaches (such as averaging the activity concentration levels over large areas) would suggest that no population impacts will occur. However, there are considerations for this site that are exceptional in terms of very small and threatened populations, and their confinement on small islands along with the elevated radionuclide levels. The following text discusses some aspects of this topic mainly for the purposes of providing a context for any future work.

On Trimouille and Alpha Islands, where areas of elevated contamination exist, all individuals of the populations are essentially "fenced" in proximity to the areas of high contamination. This boundary limitation is not considered in most biota dose evaluations where mammals may roam over larger areas and may therefore only encounter a radiologic waste site for brief periods. Or, in typical mainland settings, territorial mammals may have only a small chance of establishing a home range on a contamination site when there are many other sites to choose from elsewhere. However, within the limited areas on Trimouille and Alpha Islands, it is more probable that an individual's movement will intersect with the high-contamination areas. The overall exposure and susceptibility of these populations is therefore higher than would happen in a typical mainland terrestrial setting.

Important for the above consideration are the movement patterns of the mala and burrowing bettong, including the dispersal of juveniles and establishing/replacement of territories. While details of such movement for the study species on these island settings are not yet known, they could be highly important to dose outcomes. If, for example, an individual would live its entire life on the southern end of Trimouille Island and always mate with similar exclusive individuals, then they and their offspring would not likely show genetic markers for any radiation damage occurring in the northern part of the island (Figure 10). However, it is likely that over time, some individuals born in less contaminated areas will translocate to the highly contaminated areas. Likewise, some of those born in the highly contaminated areas would translocate outward into the surrounding population and carry with them any radiation effects (e.g., genetic markers indicating radiation damage). The outward spread of radiation markers would occur intergenerationally as some radiation damage to DNA is known to be passed from parents to offspring (Raskosha et al., 2023; Wang et al., 2023).

The existence of genetic markers radiation damage in mammals at the Montebello Islands was not evaluated in the study and has not been reported to our knowledge. The detection of radiological effects in mammal populations requires specific testing for chromosomal or physical anomalies. It also requires consideration of the potential for multi stressor impacts (e.g., radiological dose effects in concert with other stressors such as drought, cyclones or disease).

RECOMMENDATIONS

- Better characterise the levels and extent of radionuclides in the soils and vegetation of the most impacted areas on Alpha and Trimouille Islands.
- Improve the understanding of radionuclide uptake in mammals. This can be accomplished through further sampling and analysis of mammal tissues/bones, to reduce the uncertainty of dose rate estimates for resident mammal species.
- Given the restricted range on the islands, and the proximity to elevated and persistent radionuclide levels, improve the understanding of, population level exposures. This may include animal movement studies (e.g., VHF or satellite telemetry) (Beaugelin-Seiller et al., 2020; Hinton et al., 2015) and modelling of exposure-dynamics (how much of the population is exposed to the highly elevated radionuclide areas over time).
- For those species exposed to higher dose levels, investigate and describe the potential for individual and population effects. This may include a testing program for chromosomal and physical anomalies in the mala and burrowing bettong populations as well as modelling on the perpetuation of radionuclide impacts intergenerationally.

CONCLUSIONS

This study highlights that throughout the Montebello Islands group, the translocated mammals are taking up, into their bodies, plutonium and other long-lived radionuclides that remain from the nuclear testing in the 1950s. At most locations, the exposures to these radionuclides are below the levels that are expected to cause harm. However, in some locations, namely areas on Trimouille and Alpha Islands, the exposures are at much higher levels and may cause harm. Of concern is that any deleterious effects occurring in individuals at a location on an island may spread throughout the broader population via animal movement and intergenerational transfer over time. It is not yet known if such spreading of effects is occurring or whether there may be long-term health impacts on the confined populations. Further sampling of soils and mammal tissues, along with genetic, demographic and movement studies, is needed to understand this risk better and implement suitable and effective ongoing management of these threatened, isolated populations.

ACKNOWLEDGEMENTS

The study would not have been possible without funding for sample analysis provided by the Western Australian Government Department of Biodiversity, Conservation and Attractions.

Michael Corry and Alexandra Boyd provided valuable review comments on drafts of this report.

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Appendix A. Radiological Analysis results on 2019 mammal bone samples from the Montebello Islands.

STUDY SAMPLE DESCRIPTION		Lat	Long	Method	Pu-239+240			Pu-238			^{241}Am			^{90}Sr			U-238			U-235			U-233+234		
	Field study name				(Bq/kg)	+/-		(Bq/kg)	+/-		(Bq/kg)	at 5% (1s)		Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-	
Background/contol																									
Dorre Island, Mala femur	BKG-1	-25.1000	113.1000	AMS	0.00015		0.00002																		
Matuwa, Mala femur	BKG-2 ANI	-26.2000	121.5000	AMS	0.00035		0.00003																		
Burrup Pen., Kangaroo-rib	MB-B-0-B	-20.5709	116.7989	A-spec	0.18	+/-	0.05				0.8	+/-	0.1		<	15	1.4	+/-	0.1	0.17	+/-	0.05	1.5	+/-	0.2
Burrup Kang, (vert)	MB-B-0-A	-20.5709	116.7989	AMS	0.003		0.00008																		
Hermite Isl																									
HI Mamm Grid, Spectacled H-W femur	MB-B-1	-20.4854	115.5290	AMS	0.109		0.002																		
HI Mamm Grid, Spectacled H-W femur	MB-B-1	-20.4854	115.5290	A-spec	0.21	+/-	0.1	0.18	+/-	0.05	0.5	+/-	0.1	34	+/-	7	1.1	+/-	0.1		<	0.10	1.5	+/-	0.2
HI Claret Bay, Spectacled H-W femur	MB-B-4	-20.4963	115.5307	AMS	0.00024		0.00002																		
Alpha Isl																									
AI N. Mamm Grid, Boodie femur (F1&2)	MB-B-2B	-20.4100	115.5218	AMS	0.081		0.002		<	0.3	0.6	+/-	0.1		<	26									
AI ~30m from GZ 2015, Boodie femur		-20.4060	115.5358	A-spec	10.600		0.262																		
Trimouille Isl																									
Trim. Z1, Mala femur	MB-B-9 (T	-20.4144	115.5734	AMS	0.013		0.0003																		
Trim. Z1, Mala femur	MB-B-6 (T	-20.3968	115.5699	A-spec	0.4	+/-	0.1		<	0.1	0.27	+/-	0.04	24	+/-	2	0.49	+/-	0.06		<	0.04	0.62	+/-	0.07
Trim. Z2 Mala femur	MB-B-7 (T	-20.3790	115.5502	A-spec	0.7	+/-	0.1		<	0.08	0.3	+/-	0.1	239	+/-	5	0.67	+/-	0.08	0.11	+/-	0.03	0.84	+/-	0.09
Trim. Z2, Mala femur	MB-B-12 (	-20.3965	115.5627	A-spec	1.4	+/-	0.2		<	0.2	0.9	+/-	0.1	278	+/-	11	2.6	+/-	0.3	0.24	+/-	0.08	2.8	+/-	0.3
Trim. Z3, Mala femur	MB-B-13 (	-20.3911	115.5577	A-spec	18.4	+/-	0.7	0.8	+/-	0.1	0.8	+/-	0.1	1540	+/-	12	1.4	+/-	0.2		<	0.1	1.7	+/-	0.2
Trim. Z3, Mala femur	MB-B-14 (	-20.3943	115.5601	A-spec	13.8	+/-	0.8	0.7	+/-	0.2	1.4	+/-	0.2	2819	+/-	20	2.4	+/-	0.3	0.3	+/-	0.1	2.7	+/-	0.3
Trim. Mosaic G1 2015, Mala F-end				AMS	1.02		0.017																		

Appendix B. Whole-body activity concentration estimates (Bq/kg fw) organised for input into the ERICA-Tool for internal dose calculation of mammals at the Montebello Islands. From measured bone results (using Yankovich et al, 2012, and Johansen et al. 2016 tissue-to-whole-body ratios) with Concentration Ratios from soil measurements used when tissues samples were not available.

Data organised for ERICA												
Whole body Bq/kg estimates for ERICA												
(best estimate using Bones samples if available, then Concentration Ratios)												
		Distant Background	Regional Background	Hermite Isl.	North West Isl.	Alpha Isl.	Alpha Isl.	Trimouille Isl.	Trimouille Isl.	Trimouille Isl.	Trimouille Isl.	Trimouille Isl.
Anthropo genics		(Dorre Isl., Matuwa, Rottnest Isl.)	(Burrup Pen.)	(mammal grid)	(W. mammal grid)	(N. mammal grid)	(nr Mosaic G2)	(maximum)	(Zone 3, Soil Pu>10,000 Bq/kg)	(Zone 2, Soil Pu >100<10,000 Bq/kg)	(Zone 1, Soil Pu <100 Bq/kg)	(nr Mosiac G1)
	Am241	0.0001	0.06	0.04	0.12	0.05	10.71	21.68	0.09	0.05	0.02	0.6
	Cs137	2.12	2.12	2.97	10.55	8.27	5985	22230	2167	868	6.56	265.1
	Eu152	0.00	0.00	0.01	0.13	0.73	75.50	0.56	0.36	0.02	0.001	4.5
	Pu238	6.5E-06	0.0047	0.04	0.01	0.01	0.53	1.23	0.19	0.01	0.005	0.04
	Pu239	4.6E-05	0.033	0.05	0.16	0.06	2.22	30.80	3.62	0.24	0.10	0.6
	Pu240	1.7E-05	0.012	0.01	0.02	0.01	0.41	2.94	0.40	0.03	0.01	0.1
	Sr90	0.8344	0.834	1.65	6.07	22.85	2357	6043	1521	189	17.23	200.8
	U235	0.0008	0.0008	0.0023	0.0052	0.03	0.16	0.42	0.06	0.02	0.01	0.1
Naturals			Montebello Islands/ Regional Background									
(from CRs., except U238,U234 from bones)												
	Pb210	0.7524	0.75									
	Po210	1.7226	1.72									
	Ra224	0.5162	0.52									
	Ra226	0.8544	0.85									
	Ra228	0.5162	0.52									
	Th228	0.00638	0.01									
	Th230	0.01111	0.0111									
	Th232	0.00638	0.0064									
	Th234	0.02665667	0.03									
	U234	0.00284	0.0028									
	U238	0.309298	0.31									

Appendix C. Soil activity concentration (Bq/kg dw) at the Montebello Islands, derived from Appendix D and organised for input into the ERICA-Tool for external dose calculation.

SOILS (Bq/kg dry mass)	Background (Islands- Thevenard, Eaglehawd, Burrup Pen., Rottnest)	Hermite (mammal grid)	North West (mammal grids)	Alpha (mammal grid)	Alpha (high, nr Modaic G2)	Trimouille (high)	Trimouille (Z3)	Trimouille (Z2)	Trimouille (Z1)	Trimouille (nr Mosiac G1)
Am241	0.18	0.21	4.49	0.26	397	803	600	71	2.36	23
Cs137	0.74	1.04	3.70	2.90	2100	7800	760	305	2.30	93
Eu152	0.000	0.39	5.31	29.38	3020	22	14	1	0.03	180
Pu238	0.04	0.02	5.90	0.31	611	881	881	41	1.81	27
Pu239	0.05	0.10	114.30	24.94	3280	22000	12666	780	26.02	409
Pu240	0.02	0.00	12.70	4.79	643	2100	1550	96	3.18	57
Sr90	0.55	1.09	4.02	15.14	1561	4002	2604	156	5.21	133
U235	0.29	0.80	1.83	1.08	57	149	94	6	0.19	0.11
Pu239+240\	0.07	0.59	127.00	29.68	3923	22435	14216	876	29	385

	Islands Back	Mos	Trimouille	average
Pb210	20	20	19.8	19.8
Po210	20	20	19.8	19.8
Ra224	6	15	27	15.8
Ra226	10	57	11.5	25.9
Ra228	6	15	27	15.8
Th228	6	15	27	15.8
Th230	10	57	84.5	50.4
Th232	6	15	27	15.8
Th234	24	21	36.25	27.2
U234	28	21	45	31.2
U238	24	21	36.25	27.2

Appendix D. Radionuclide sample locations within the Montebello Islands, and other locations in Western Australia, including descriptions and Sample IDs. Samples are 0-10cm soils unless indicated.

STUDY SAMPLE DESCRIPTION	**Sample ID**	**Lat.**	**Long.**
Thevenard Island			
THV-Dune/soils, 0-4 cm	THV-1	-21.4535	115.0023
Port Headland			
PH-Dune/soils, 0-4 cm	MB-C-45	-20.32388	118.66181
PH-Dune/soils, 4-12 cm	MB-C-46-47	-20.32388	118.66181
PH-Dune/soils, 12-20 cm	MB-C-48	-20.32388	118.66181
PH-Dune/soils, 0-4 cm	MB-C-45	-20.32388	118.66181
Burrup Peninsula			
BU-Beach, 0-10 cm	MB-C-37	-20.57045	116.79341
BU-Camp, 0-10 cm	MB-C-38	-20.56981	116.79356
BU-Dune/soils, 0-10 cm	MB-C-39	-20.56978	116.79294
BU-inland/soils, 0-10 cm	MB-C-40	-20.56555	116.7921
Hermite Isl			
HI-Mammal Grid, Comp of corners, 0-10cm	MB-MS-1	-20.48659	115.52956
HI-Mammal Grid, Comp of corners, 0-10cm	MB-MS-1 recount	-20.48659	115.52956
HI-Mammal grid (centre), 0-10cm	MB-MS-2	-20.48659	115.52956
HI-Mammal Grid (centre), SDP 0-4cm	MB-MS-3	-20.48659	115.52956
HI-Mammal Grid (centre), SDP 4-12cm	MB-MS-4-5	-20.48659	115.52956
HI-Mammal Grid (centre), SDP 12-20cm	MB-MS-6	-20.48659	115.52956
HI-Comp (comp 4 corners), 0-10cm (alpha)	MB-MS-1	-20.48659	115.52956
Home Lagoon			
HI-Home Lagoon	MB-C-10	-20.44412	115.54078
HI-HL-sediment, 0-10cm	MB-C-11	-20.44405	115.54131
HI-HL-beach (0-10cm)	MB-C-12	-20.44391	115.54177
HI-HL-camp (0-10cm)	MB-C-13	-20.44391	115.54211
HI-HL-dune/soils,(0-10cm)	MB-C-14	-20.44391	115.54211
HI-HL-dune/soils, SDP 0-4cm	MB-C-15-16	-20.44391	115.54211
HI-HL-dune/soils, SDP 4-12cm	MB-C-17	-20.44391	115.54211
HI-HL-dune/soils, SDP 12-20cm	MB-C-13	-20.44391	115.54211
Whisky bay (Renewal Is)			
WB-sediments (0-10cm)	MB-C-1	-20.47229	115.54609
WB- beach sands, 0-10cm	MB-C-2	-20.47216	115.54554
WB-Camp (0-10cm)	MB-C-3	-20.47312	115.54546
MB-C-4 Camp dune soils-WB	MB-C-4	-20.4732	115.54458

WB-Dune/soils, SDP 0-4cm	MB-C-5	-20.4732	115.54458
WB-Dune/soils, SDP 4-12cm	MB-C-6-7	-20.4732	115.54458
WB-Dune/soils, SDP 12-20cm	MB-C-8	-20.4732	115.54458
WB-Camp dune soils (0-10cm) (alpha)	MB-C-4	-20.4732	115.54458
Alpha Isl.			
AI-Boodie grid SE Cnr (0-10cm) same as camp soils/dune	MB-C-22	-20.41064	115.52281
AI-Boodie grid SW Cnr (0-10cm)	MB-MS-12	-20.41056	115.52023
AI-Boodie grid NE+NW Cnrs combined (0-10cm)	MB-MS-13-14	-20.40779	115.51865
AI-North Mammal Grid (corners), 0-10cm	MB-MS-12-14	-20.40765	115.52163
AI-North grid, Comp (0-10 cm) (alpha)	MB-MS-12-14	-20.40765	115.52163
AI-South Grid (corners), 0-10cm	MB-MS-15	-20.4129	115.5228
AI-South Grid (corners), 0-10cm (alpha)	MB-MS-15	-20.4129	115.5228
Chartreuse Bay Camp			
AI-CB-Shallow sediments	MB-C-19	-20.41018	115.52407
AI-CB-Dune/soils (0-10cm)	MB-C-22	-20.41064	115.52281
AI-CB-Dune/soils (0-4cm)	MB-C-23	-20.44391	115.54211
AI-CB-Dune/soils (4-12cm)	MB-C-24-25	-20.44391	115.54211
AI-CB-Dune/soils (12-20cm)	MB-C-26	-20.44391	115.54211
AI-CB-Dune/soils (0-10cm) (alpha)	MB-C-22	-20.44391	115.54211
Northwest Isl.			
NW-East Grid, SE corner, 0-10 cm	MB-MS-8	-20.36658	115.52813
NW-East Grid, SW corner, 0-10 cm	MB-MS-9	-20.36601	115.52642
NW-East Grid, NW corner, 0-10 cm	MB-MS-10	-20.36586	115.52843
NW-East Grid, Comp. of corners, 0-10 cm	MB-C-31	-20.3658	115.5276
NW-East Grid, Comp. of corners, 0-10 cm (alpha)	MB-MS-8-10 (composite)	-20.3658	115.5276
NW-West Grid, Comp of corners, 0-10 cm	MB-MS-8-10 (composite)	-20.3658	115.5276
NW-West Grid, Comp of corners, 0-10 cm (alpha)	MB-MS-11	-20.3622	115.5222
MB-MS-11 NW-W-Comp	MB-MS-11	-20.3622	115.5222
NW-sediment, 0-10cm	MB-C-28	-20.36655	115.52556
NW-beach (0-10cm)	MB-C-29	-20.36675	115.53082
NW-Camp (0-10cm)	MB-C-30	-20.36663	115.53088
NW-dune/soils,(0-10cm)	MB-C-31	-20.36588	115.531
NW-dune/soils,(0-10cm) (alpha)	MB-C-31	-20.36588	115.531
Bluebell Island			

BI-North-Beach	MB-C-59	-20.39334	115.52032
BI-North-Camp	MB-C-60	-20.39327	115.52013
BI-North-Dune/soils	MB-C-61	-20.39246	115.52011
BI-North-Dune/soils-2 (alpha)	MB-C-61	-20.39246	115.52011
BI-Middle-Shallow sediments	MB-C-50	-20.39634	115.52101
BI-Middle-Beach	MB-C-51	-20.39661	115.52061
BI-Middle-Camp	MB-C-52	-20.39696	115.52065
BI-Middle-Dune/soils	MB-C-53	-20.39679	115.51982
BI-Middle-Dune/soils-2 (alpha)	MB-C-53	-20.39679	115.51982
BB-South-Beach	MB-C-62	-20.39751	115.52399
BB-South-Camp	MB-C-63	-20.39745	115.52385
BB-South-Dune/soils	MB-C-64	-20.39713	115.52364
BB-South-Dune/soils-2 (alpha)	MB-C-64	-20.39713	115.52364
<u>Trimouille Island.</u> Samples are 0-10cm soils unless indicated. Transect 1 is at north end of island. All points along transects progress West to East (e.g., station 4 is on west. So that transect progresses eastward 4+00, 4+10, 4+100, etc.)			
Transect 1-2 Low Tide Seds (West)	MB-TS-MBLTS		
Transect 1-2 Beach (West)	MB-TS-0		
1+00	MB-TS-1	-20.37999	115.54847
1+100	MB-TS-2	-20.37999	115.54942
1+200	MB-TS-3	-20.37999	115.55037
1+400	MB-TS-4	-20.37999	115.5523
1+600	MB-TS-5	-20.37999	115.55421
1+800	MB-TS-6	-20.37999	115.55614
1+1000	MB-TS-7	-20.37999	115.55807
1+1200	MB-TS-8	-20.37999	115.56015
Transect 3-4 Low Tide Seds (West)	MB-TS-9	-20.38513	115.55118
Transect 3-4 Beach (West)	MB-TS-10	-20.38509	115.55175
4+10	MB-TS-11	-20.38428	115.55203
4+100	MB-TS-12	-20.3843	115.55288
4+200	MB-TS-13	-20.3843	115.55385
4+400	MB-TS-14	-20.3843	115.55574
4+600	MB-TS-15	-20.3843	115.55768
4+800	MB-TS-16	-20.3843	115.55961
3+00	MB-TS-17	-20.3843	115.56076
Transect 3-4 Low Tide Seds (East)	MB-TS-18	-20.3832	115.56159
Transect 3-4 Beach (East)	MB-TS-19	-20.38316	115.56124
8+00	MB-TS-20	-20.39288	115.55777
8+100	MB-TS-21	-20.39288	115.55873
8+200	MB-TS-22	-20.39288	115.55969

8+400	MB-TS-23	-20.39288	115.56161
8+600	MB-TS-24	-20.39288	115.56352
7+00	MB-TS-25	-20.39288	115.56456
Transect 7-8 Beach (East)	MB-TS-26	-20.39209	115.56521
Transect 7-8 Low Tide Seds (East)	MB-TS-27	-20.39161	115.56558
Transect 9-10 Low Tide Seds (West)	MB-TS-28	-20.39815	115.56255
North end or Main Beach (from 2015 data)		-20.39766	115.56275
9+00	MB-TS-29	-20.39721	115.56253
9+100	MB-TS-30	-20.39721	115.56348
9+200	MB-TS-31	-20.39721	115.56443
9+400	MB-TS-32	-20.39721	115.56635
9+600	MB-TS-33	-20.39721	115.56827
9+800	MB-TS-34	-20.39725	115.57019
10+00	MB-TS-35	-20.39725	115.57168
Transect 15-16 Low Tide Seds (West)	MB-TS-36	-20.41016	115.57061
Transect 15-16 Beach (West)	MB-TS-37	-20.41016	115.57092
16+00	MB-TS-38	-20.41009	115.57135
16+200	MB-TS-39	-20.41009	115.57327
16+400	MB-TS-40	-20.41009	115.5752
16+600	MB-TS-41	-20.41009	115.57712
15+00	MB-TS-42	-20.41009	115.57793
Transect 15-16 Beach (East)	MB-TS-43	-20.41249	115.57827
Transect 15-16 Low Tide Seds (East)	MB-TS-44	-20.41251	115.57849
17+00	MB-TS-45	-20.41438	115.57251
17+200	MB-TS-46	-20.41438	115.57442
18+00	MB-TS-47	-20.41439	115.57594
Soil Depth Profile from Red Beacon Hill			
TRH SP1 0-4	TRH SP1 0-4	-20.39207	115.5587
TRH SP1 4-8	TRH SP1 4-8	-20.39207	115.5587
TRH SP1 8-12	TRH SP1 8-12	-20.39207	115.5587
TRH SP3 12-16	TRH SP3 12-16	-20.39207	115.5587
TRH SP4 16-20	TRH SP4 16-20	-20.39207	115.5587
TRH SP5 28-32	TRH SP5 28-32	-20.39207	115.5587
TRH SP6 20-24	TRH SP6 20-24	-20.39207	115.5587
TRH SP7 24-28	TRH SP7 24-28	-20.39207	115.5587

Appendix E. Radionuclide Activity Concentrations at the Montebello Islands, and other locations in Western Australia (three tables below). Data are on a September 2020 basis. Ratios of ^{241}Am to ^{230,240}Pu are from Figure 12 and Johansen et al., 2019). The key radionuclides in this study include:

- ^{90}Sr, strontium-90
- ^{137}Cs, cesium-137
- ^{152}Eu, ^{154}Eu, europium-152, 154
- U-238 series includes: thorium-234, 230, uranium-234,238, Radium -226
- Th-232 series includes: thorium-232, radium -228, thorium 228
- Pu, plutonium-239,240
- ^{241}Am, americium-241

	Pu-239+240			Estimated Pu from Am: Est. Pu-239+240 (from Am241)			Pu-238			^{241}Am				^{137}Cs activity	at 661.7 keV			^{60}Co			
	Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		Bq/kg	at 59	+/-	MDA	Bq/kg	+/-		MDA	Bq/kg	+/-		MDA
Thevenard Isl.																					
THV-Dune/soils, 0-4 cm											<	0.4		0.7	±	0.1	0.47				
THV-Dune/soils, 0-4 cm	0.07	+/-	0.02				0.04	+/-	0.02	0.2	+/-	0.03									
Port Headland																					
PH-Dune/soils, 0-4 cm										-			0.62	-		-	0.74	-		-	0.7
PH-Dune/soils, 4-12 cm										-			0.86	-		-	0.96	-		-	1.2
PH-Dune/soils, 12-20 cm										-			0.55	-		-	0.54	-		-	0.7
PH-Dune/soils, 0-4 cm	0.07	+/-	0.02					<	0.03	0.2	+/-	0.03									
Burrup Pen.																					
BU-Beach, 0-10 cm										-			0.80	3.3		0.30	0.91	-		-	0.9
BU-Camp, 0-10 cm										-			0.87	-		-	1.08	-		-	1.1
BU-Dune/soils, 0-10 cm				1.5	+/-	0.3				1.3	±	0.23		0.8	±	0.1	0.65				
BU-inland/soils, 0-10 cm	0.24	+/-	0.03				0.04	+/-	0.01	0.2	+/-	0.03									
Hermite Isl.																					
HI-Mammal Grid, Comp of corners, 0-10cm											<	0.33			<	0.3					
HI-Mammal Grid, Comp of corners, 0-10cm											<	0.47			<	0.7					
HI-Mammal grid (centre), 0-10cm											<	0.46			<	0.5					
HI-Mammal Grid (centre), SDP 0-4cm											<	0.32			<	0.47					
HI-Mammal Grid (centre), SDP 4-12cm											<	0.34		0.4	±	0.1	0.36				
HI-Mammal Grid (centre), SDP 12-20cm											<	0.36			<	0.5					
HI-Comp (comp 4 corners), 0-10cm (A-spc)	0.11	+/-	0.03					<	0.04	0.2	+/-	0.04									
Home Lagoon																					
HI-HL-sediment, 0-10cm											<	0.30			<	0.27					
HI-HL-beach (0-10cm)										-		-	0.30	-		-	0.60	-		-	0.6
HI-HL-camp (0-10cm)										-		-	0.38	-		-	0.54	-		-	0.6
HI-HL-dune/soils,(0-10cm)										-		-	0.59	-		-	0.90	-		-	0.8
HI-HL-dune/soils, SDP 0-4cm											<	0.55		3.2	±	0.81	0.39				
HI-HL-dune/soils, SDP 4-12cm											<	0.28			<	0.4					
HI-HL-dune/soils, SDP 12-20cm											<	0.48			<	0.6					
MB-C-13 Camp dune soils (0-10 cm) (A-spc)	0.51	+/-	0.05				0.07	+/-	0.02	0.2	+/-	0.03									
Renewal Island-Whisky bay Camp																					
WB-sediments (0-10cm)										-		-	0.63	-		-	0.76	-		-	0.9
WB- beach sands, 0-10cm											<	0.47			<	0.62					
WB-Camp (0-10cm)										-		-	0.40	-		-	0.53	-		-	0.5
MB-C-4 Camp dune soils-WB										-		-	0.72	-		-	1.17	-		-	1.1
WB-Dune/soils, SDP 0-4cm											<	0.27			<	0.3					
WB-Dune/soils, SDP 4-12cm											<	0.56			<	0.7					
WB-Dune/soils, SDP 12-20cm											<	0.49			<	0.7					
WB-Camp dune soils (0-10cm) (alpha)	1.15	+/-	0.08				0.09	+/-	0.02	0.2	+/-	0.04									
Alpha Island																					
AI-Boodie grid SE Cnr (0-10cm) same as camp soils/dune										-		-	0.72	-		-	0.91	-		-	0.7
AI-Boodie grid SW Cnr (0-10cm)										-		-	0.46	-		-	0.69	-		-	0.8
AI-Boodie grid NE+NW Cnrs combined (0-10cm)				74	+/-	3.7				7.1	±	0.35		1.4	+/-	0.32	0.68	-		-	0.7
AI-North Mammal Grid (corners), 0-10cm				14	+/-	1.1				1.3	±	0.10		0.6	±	0.1	0.38				
AI-North grid, Comp (0-10 cm) (alpha)	1.03	+/-	0.09					<	0.1	0.3	±	0.04									
AI-South Grid (corners), 0-10cm										-		-	0.78	-		-	0.95	-		-	0.8
AI-South Grid (corners), 0-10cm (alpha)	0.51	+/-	0.08					<	0.09	0.2	±	0.04									
Chartreuse Bay Camp																					
AI-CB-Shallow sediments				12	+/-	2.0				1.1	±	0.19		-		-	0.72	-		-	0.7
AI-CB-Dune/soils (0-10cm)										-		-	0.72	-		-	0.91	-		-	0.7
AI-CB-Dune/soils (0-4cm)											<	0.52		1.3	±	0.41	0.27				
AI-CB-Dune/soils (4-12cm)											<	0.37			<	0.42					
AI-CB-Dune/soils (12-20cm)											<	0.43		2.9	±	0.92	0.43				
AI-CB-Dune/soils (0-10cm) (alpha)	2.4	+/-	0.1				0.31	+/-	0.04	0.3	+/-	0.04									

				Estimated Pu from Am																	
	Pu-239+240			Est. Pu-239+240 (from Am241)			Pu-238			^{241}Am				^{137}Cs activity	at 661.7 keV			^{60}Co			
	Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		Bq/kg	at 5!	+/-	MDA	Bq/kg	+/-		MDA	Bq/kg	+/-		MDA
Northwest Island																					
NW-East Grid, SE corner, 0-10 cm				49	+/-	5.9				2.5	±	0.30		-		-	0.64	-		-	0.6
NW-East Grid, SW corner, 0-10 cm				191	+/-	9.6				9.7	±	0.48		2.6		0.44	0.92	-		-	1.1
NW-East Grid, NW corner, 0-10 cm				106	+/-	8.5				5.4	±	0.43		2.1		0.25	0.70	-		-	0.7
										-		-		-		-	0.88	-		-	0.8
NW-East Grid, Comp. of corners, 0-10 cm				57	+/-	2.9				2.9	±	0.15		1.2	±	0.1	0.56				
NW-East Grid, Comp. of corners, 0-10 cr	6.0	+/-	0.2				0.38	+/-	0.03	0.6	+/-	0.06									
NW-West Grid, Comp of corners, 0-10 cm				170	+/-	10.2				8.6	±	0.52		3.7		0.30	0.74	-		-	0.7
NW-West Grid, Comp of corners, 0-10 cı	84	+/-	2				5.9	+/-	0.3	5.1	+/-	0.25									
NW Island Camp																					
NW-sediment, 0-10cm				22	+/-	4.4				1.1	±	0.22		-		-	0.78	-		-	0.8
NW-beach (0-10cm)				12	+/-	3.1				0.6	±	0.16		-		-	0.45	-		-	0.5
NW-Camp (0-10cm)				10	+/-	3.3				0.5	±	0.17		-		-	0.53	-		-	0.2
NW-dune/soils,(0-10cm)										-		-	0.68	-		-	0.88	-		-	0.8
NW-dune/soils,(0-10cm) (alpha)	20.5	+/-	0.6				1.32	+/-	0.09	1.1	+/-	0.07									
Bluebell Island																					
BI-North-Beach				299	+/-	15.0				12.7	±	0.63		3.1	+/-	0.31	0.63	-		-	0.8
BI-North-Camp				527	+/-	26.3				22.3	±	1.11		36.2	+/-	1.81	0.69	-		-	0.7
BI-North-Dune/soils				4456	+/-	222.8				188.6	±	9.43		1260.3	+/-	63.02	1.25	3.43	+/-	0.4	0.9
BI-North-Dune/soils-2 (alpha)	5861	+/-	166				286	+/-	11	209.3	+/-	6.40									
BI-Middle-Shallow sediments				225	+/-	11.2				9.5	±	0.48		-		-	0.78	-		-	0.8
BI-Middle-Beach				419	+/-	21.0				17.7	±	0.89		-		-	0.82	-		-	0.6
BI-Middle-Camp				109	+/-	8.7				4.6	±	0.37		-		-	0.70	-		-	0.2
BI-Middle-Dune/soils				442	+/-	22.1				18.7	±	0.94		42.9	+/-	2.14	1.18	-		-	1.0
BI-Middle-Dune/soils-2 (alpha)	252	+/-	7				23.1	+/-	0.9	11.8	+/-	0.54									
BI-South-Beach				174	+/-	10.4				7.4	±	0.44		1.1	+/-	0.24	0.51	-		-	0.5
BI-South-Camp				682	+/-	34.1				28.9	±	1.44		3.1	+/-	0.22	0.58	-		-	0.5
BI-South-Dune/soils				59	+/-	6.5				2.5	±	0.28		2.7	+/-	0.24	0.64	-		-	0.7
BI-South-Dune/soils-2 (alpha)	58	+/-	2				8.4	+/-	0.3	3.7	+/-	0.17									

			Estimated Pu from Am																
	Pu-239+240		Est. Pu-239+240 (from Am241)			Pu-238		^{241}Am				^{137}Cs activity	at 661.7 keV			^{60}Co			
	Bq/kg	+/-	Bq/kg	+/-		Bq/kg	+/-	Bq/kg	at 5	+/-	MDA	Bq/kg	+/-		MDA	Bq/kg	+/-		MDA
Trimouille Island																			
T1-2, Sediments(West)			**49**	+/-	6.8			**1.6**	±	0.23		**2.3**	+/-	0.25	0.68	-		-	0.6
T1-2, Beach (West)			**103**	+/-	6.2			**3.5**	±	0.21		**1.6**	+/-	0.30	0.57	-		-	0.5
1+00			**269**	+/-	13.4			**9.1**	±	0.46		**11.6**	+/-	0.58	0.58	-		-	0.4
1+100			**1201**	+/-	60.0			**40.7**	±	2.04		**36.4**	+/-	1.82	0.52	-		-	0.6
1+200			**1340**	+/-	67.0			**45.4**	±	2.27		**33.0**	+/-	1.65	1.06	-		-	1.1
1+400			**354**	+/-	17.7			**12.0**	±	0.60		**22.1**	+/-	1.11	0.80	-		-	0.7
1+600			**591**	+/-	29.5			**20.0**	±	1.00		**16.9**	+/-	0.84	0.58	-		-	0.7
1+800			**898**	+/-	44.9			**30.4**	±	1.52		**51.4**	+/-	2.57	0.79	-		-	0.7
1+1000			**402**	+/-	20.1			**13.6**	±	0.68		**15.9**	+/-	0.79	0.75	-		-	0.7
1+1200			**330**	+/-	16.5			**11.2**	±	0.56		**2.7**	+/-	0.24	0.58	-		-	0.5
Transect 3-4																			
T3-4, Shallow Seds (West)			**287**	+/-	17.2			**9.7**	±	0.58		**2.5**	+/-	0.25	0.66	-		-	0.7
T3-4 Beach (West)			**133**	+/-	9.3			**4.5**	±	0.32		**4.4**	+/-	0.35	0.60	-		-	0.6
4+10			**809**	+/-	40.5			**27.4**	±	1.37		**6.3**	+/-	0.38	0.82	-		-	1.0
4+100			**2409**	+/-	120.4			**81.7**	±	4.08		**85.2**	+/-	4.26	0.65	-		-	0.7
4+200			**1451**	+/-	72.6			**49.2**	±	2.46		**11.0**	+/-	0.55	0.77	-		-	0.7
4+400			**2311**	+/-	115.5			**78.3**	±	3.92		**224.2**	+/-	11.21	0.73	-		-	0.6
4+600			**380**	+/-	19.0			**12.9**	±	0.64		**9.5**	+/-	0.47	0.90	-		-	1.1
4+800								-			0.52	**1.9**	+/-	0.49	0.77	-		-	0.2
3+00			**46**	+/-	7.3			**1.6**	±	0.25		**2.3**	+/-	0.23	0.63	-		-	0.5
T3-4, Shallow Seds (East)								-			0.47	-		-	0.49	-		-	0.5
T3-4, Beach (East)			**19**	+/-	5.4			**0.7**	±	0.18		-		-	0.87	-		-	1.2
Transect 7-8																			
8+00			**4496**	+/-	224.8			**152.4**	±	7.62		**2044.5**	+/-	102.23	1.35	**2.30**	+/-	0.3	0.5
8+100			**8513**	+/-	425.6			**288.6**	±	14.43		**3296.0**	+/-	164.80	1.69	**5.14**	+/-	0.8	1.0
8+200			**10026**	+/-	501.3			**339.9**	±	16.99		**3543.6**	+/-	177.18	1.46	**5.38**	+/-	0.8	1.0
8+400			**218**	+/-	13.1			**7.4**	±	0.44		**96.6**	+/-	4.83	0.68	-		-	0.6
8+600			**18**	+/-	4.7			**0.6**	±	0.16		**4.8**	+/-	0.43	0.76	-		-	0.8
7+00			**51**	+/-	10.2			**1.7**	±	0.34		**9.4**	+/-	0.56	0.79	-		-	0.4
T7-8, Beach (East)								-			0.49	-		-	0.62	-		-	0.6
T7-8, Shallow Seds (East)			**27**					**0.9**	±	0.26		**0.9**	+/-	0.25	0.77	-		-	0.9
Transect 9-10																			
T9-10, Shallow Seds (West)								-			0.51	**1.3**	+/-	0.20	0.58	-		-	0.7
T9-10, Beach (N. end Main B., 2015)																			
9+00			**1649**	+/-	82.4			**55.9**	±	2.79		**446.0**	+/-	22.30	0.83	**1.16**	+/-	0.16	0.7
9+100			**5631**	+/-	281.6			**190.9**	±	9.54		**2647.0**	+/-	132.35	1.29	**3.22**	+/-	0.23	0.7
9+200			**838**	+/-	41.9			**28.4**	±	1.42		**295.5**	+/-	14.77	0.90	-		-	1.1
9+400			**349**	+/-	17.5			**11.8**	±	0.59		**112.2**	+/-	5.61	0.80	-		-	0.6
9+600								-			0.46	**3.7**	+/-	0.26	0.68	-		-	0.6
9+800			**17**	+/-	5.0			**0.6**	±	0.17		**4.3**	+/-	0.22	0.47	-		-	0.6
10+00								-			0.36	**1.6**	+/-	0.17	0.52	-		-	0.5
Transect 15-16																			
T15-16, Shallow Seds (West)								-			0.42	-		-	0.58	-		-	0.3
T15-16, Beach (West)								-			0.69	-		-	0.84	-		-	0.9
16+00								-			0.43	-		-	0.65	-		-	0.6
16+200								-			0.59	**0.8**	+/-	0.22	0.68	-		-	0.9
16+400								-			0.50	-		-	0.64	-		-	0.7
16+600								-			0.60	-		-	0.81	-		-	0.9
15+00								-			0.38	-		-	0.39	-		-	0.6
T15-16, Beach (East)								-			0.38	-		-	0.44	-		-	0.6
T15-16, Shallow Seds (East)								-			0.42	-		-	0.45	-		-	0.6
Transect 17-18																			
17+00								-			0.55	-		-	0.66	-		-	0.9
17+200								-			0.34	-		-	0.54	-		-	0.6
18+00								-			0.42	-		-	0.68	-		-	0.9
Soil Depth Profile, Red Beacon Hill																			
0-4 cm			**15774**	+/-	788.7			**534.7**	±	26.74		**6062.7**	+/-	303.14	3.15	**6.36**	+/-	0.64	1.2
4-8 cm			**10317**	+/-	515.9			**349.7**	±	17.49		**5304.2**	+/-	265.21	2.58	**4.35**	+/-	0.43	1.2
8-12 cm			**1983**	+/-	99.2			**67.2**	±	3.36		**931.5**	+/-	46.57	1.31	-		-	1.4
12-16 cm			**665**	+/-	33.2			**22.5**	±	1.13		**275.0**	+/-	13.75	0.85	-		-	0.5
16-20 cm			**428**	+/-	21.4			**14.5**	±	0.72		**152.1**	+/-	7.60	0.58	-		-	0.7
20-24 cm			**72**	+/-	6.5			**2.4**	±	0.22		**23.5**	+/-	1.17	0.61	-		-	0.5
24-28 cm			**153**	+/-	10.7			**5.2**	±	0.36		**65.9**	+/-	3.29	0.74	-		-	0.7
28-32 cm			**122**	+/-	14.6			**4.1**	±	0.49		**33.5**	+/-	1.68	0.67	-		-	0.8

Appendix E (continued)

	U-238			U-235			U-233+234			^{90}Sr			^{152}Eu			MDA	^{154}Eu				^{234}Th (proxy for ^{238}U)			
													activi	at 122 keV			activi	at 123 keV			activity	at 63.3 keV		
on gamma	Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		MDA	Bq/kg	+/-		MDA	Bq/kg	+/-		
Thevenard Isl.																								
THV-Dune/soils, 0-4 cm														<	0.8			<	0.6		23.7	±	3.1	4.6
THV-Dune/soils, 0-4 cm	25	+/-	1	1.1	+/-	0.1	29	+/-	2		<	111												
Port Headland																								
PH-Dune/soils, 0-4 cm													-		-	0.9	-		-	0.6	13.1	+/-	3.0	7.0
PH-Dune/soils, 4-12 cm													-		-	1.2	-		-	0.8	12.3	+/-	2.8	9.0
PH-Dune/soils, 12-20 cm													-		-	0.8	-		-	0.5	10.5	+/-	2.4	6.3
PH-Dune/soils, 0-4 cm	2.8	+/-	0.2	0.15	+/-	0.03	3.2	+/-	0.2		<	7												
Burrup Pen.																								
BU-Beach, 0-10 cm													-		-	1.1	-		-	0.6	35.7	+/-	3.9	8.6
BU-Camp, 0-10 cm													-		-	1.2	-		-	0.8	29.4	+/-	4.4	10.0
BU-Dune/soils, 0-10 cm														<	1.1			<	0.8		70.2	±	6.2	10.5
BU-inland/soils, 0-10 cm	14.6	+/-	0.9	0.7	+/-	0.1	17	+/-	1		<	8												
Hermite Isl.																								
HI-Mammal Grid, Comp of corners, 0-10cm														<	0.7			<	0.5		16.3	±	2.3	3.9
HI-Mammal Grid, Comp of corners, 0-10cm														<	1.1			<	0.8		23.7	±	4.0	7.3
HI-Mammal grid (centre), 0-10cm														<	1.1			<	0.8		16.4	±	1.3	6.3
HI-Mammal Grid (centre), SDP 0-4cm														<	0.69			<	0.37		63.6	±	8.6	3.6
HI-Mammal Grid (centre), SDP 4-12cm														<	0.8			<	0.6		14.3	±	0.7	4.4
HI-Mammal Grid (centre), SDP 12-20cm														<	0.8			<	0.6		14.2	±	1.0	4.6
HI-Comp (comp 4 corners), 0-10cm (A-spc)	17.8	+/-	1.0	0.77	+/-	0.08	20	+/-	1		<	154												
Home Lagoon																								
HI-HL-sediment, 0-10cm														<	0.57			<	0.40		42.2	±	4.7	3.1
HI-HL-beach (0-10cm)													-		-	0.7	-		-	0.5	24.5	+/-	2.4	5.6
HI-HL-camp (0-10cm)													-		-	0.6	-		-	0.4	27.9	+/-	2.8	5.4
HI-HL-dune/soils,(0-10cm)													-		-	0.9	-		-	0.7	26.3	+/-	3.2	7.5
HI-HL-dune/soils, SDP 0-4cm														<	1.01			<	0.68		40.9	±	15.0	6.3
HI-HL-dune/soils, SDP 4-12cm														<	0.6			<	0.5		19.3	±	2.5	3.6
HI-HL-dune/soils, SDP 12-20cm														<	1.1			<	0.8		19.7	±	1.3	6.1
MB-C-13 Camp dune soils (0-10 cm) (A-spc)	22	+/-	1	1.2	+/-	0.1	26	+/-	1		<	234												
Renewal Island-Whisky bay Camp																								
WB-sediments (0-10cm)													-		-	0.8	-		-	0.6	26.4	+/-	2.9	6.8
WB- beach sands, 0-10cm														<	0.98			<	0.80		78.6	±	11.2	3.6
WB-Camp (0-10cm)													-		-	0.5	-		-	0.4	26.1	+/-	2.6	4.4
MB-C-4 Camp dune soils-WB													-		-	0.9	-		-	0.8	33.4	+/-	3.7	8.1
WB-Dune/soils, SDP 0-4cm														<	0.6			<	0.5		25.0	±	2.5	3.4
WB-Dune/soils, SDP 4-12cm														<	1.3			<	0.9		23.9	±	1.4	6.5
WB-Dune/soils, SDP 12-20cm														<	1.2			<	0.9		23.3	±	3.9	7.0
WB-Camp dune soils (0-10cm) (alpha)	26	+/-	1	1.4	+/-	0.1	29	+/-	2		<	267												
Alpha Island																								
AI-Boodie grid SE Cnr (0-10cm) same as camp soils/dune													-		-	1.0	-		-	0.7	19.3	+/-	3.1	7.1
AI-Boodie grid SW Cnr (0-10cm)													-		-	0.7	-		-	0.4	25.1	+/-	2.8	6.8
AI-Boodie grid NE+NW Cnrs combined (0-10cm)													-		-	0.7	-		-	0.5	20.2	+/-	2.6	6.6
AI-North Mammal Grid (corners), 0-10cm														<	0.7			<	0.5		21.6	±	1.4	4.0
AI-North grid, Comp (0-10 cm) (alpha)	21	+/-	1	1.1	+/-	0.1	24	+/-	1		<	56												
AI-South Grid (corners), 0-10cm													-		-	1.1	-		-	0.7	23.9	+/-	2.6	8.3
AI-South Grid (corners), 0-10cm (alpha)	17.3	+/-	1.0	0.77	+/-	0.08	19	+/-	1		<	313												
Chartreuse Bay Camp																								
AI-CB-Shallow sediments													-		-	0.7	-		-	0.4	29.2	+/-	2.9	5.9
AI-CB-Dune/soils (0-10cm)													-		-	1.0	-		-	0.7	19.3	+/-	3.1	7.1
AI-CB-Dune/soils (0-4cm)														<	0.57			<	0.40		52.0	±	10.3	5.2
AI-CB-Dune/soils (4-12cm)														<	0.51			<	0.54		41.7	±	8.2	5.1
AI-CB-Dune/soils (12-20cm)														<	0.71			<	0.69		41.7	±	6.9	4.3
AI-CB-Dune/soils (0-10cm) (alpha)	21	+/-	1	1.3	+/-	0.1	24	+/-	1		<	56												

	U-238			U-235			U-233+234			^{90}Sr			^{152}Eu			MDA	^{154}Eu				^{234}Th (proxy for ^{238}U)			
													activi	at 122 keV			activi	at 123 keV			activity	at 63.3 keV		
on gamma	Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		Bq/kg	+/-		MDA	Bq/kg	+/-		MDA	Bq/kg	+/-		
NW Island Camp																								
NW-sediment, 0-10cm													-		-	0.8	-		-	0.6	**29.9**	+/-	3.3	6.9
NW-beach (0-10cm)													-		-	0.5	-		-	0.4	**24.0**	+/-	2.4	4.4
NW-Camp (0-10cm)													-		-	0.6	-		-	0.3	**21.6**	+/-	2.2	5.4
NW-dune/soils,(0-10cm)													-		-	1.0	-		-	0.6	**25.3**	+/-	3.3	7.0
NW-dune/soils,(0-10cm) (alpha)	**24**	+/-	1	**1.4**	+/-	0.1	**27**	+/-	1		<	62												
Bluebell Island																								
BI-North-Beach													-		-	0.7	-		-	0.5	**20.0**	+/-	2.8	6.5
BI-North-Camp													-		-	0.8	-		-	0.5	**27.0**	+/-	2.7	6.6
BI-North-Dune/soils													-		-	1.7	-		-	1.3	**24.7**	+/-	5.2	12.4
BI-North-Dune/soils-2 (alpha)	**21**	+/-	2	**1.4**	+/-	0.5	**22**	+/-	2	167.0	+/-	31.0												
BI-Middle-Shallow sediments													-		-	0.8	-		-	0.6	**36.1**	+/-	3.6	6.5
BI-Middle-Beach													-		-	0.8	-		-	0.6	**20.2**	+/-	2.2	5.3
BI-Middle-Camp													-		-	0.7	-		-	0.5	**27.8**	+/-	2.8	6.2
BI-Middle-Dune/soils													-		-	1.0	-		-	0.6	**19.8**	+/-	2.2	6.9
BI-Middle-Dune/soils-2 (alpha)	**21**	+/-	2	**1.2**	+/-	0.2	**23**	+/-	2		<	73												
BI-South-Beach													-		-	0.5	-		-	0.4	**18.3**	+/-	1.8	4.3
BI-South-Camp													**0.8**	+/-	0.2	0.7	-		-	0.5	**21.1**	+/-	2.1	4.6
BI-South-Dune/soils													-		-	0.8	-		-	0.6	**26.7**	+/-	3.2	7.0
BI-South-Dune/soils-2 (alpha)	**20**	+/-	1	**0.9**	+/-	0.1	**23**	+/-	1		<	55												

	U-238		U-235		U-233+234		^{90}Sr			^{152}Eu			MDA	^{154}Eu			MDA	^{234}Th (proxy for ^{238}U)			
										activi	at 122 keV			activi	at 123 keV			activity	at 63.3 keV		
on gamma	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-	Bq/kg	+/-		Bq/kg	+/-		MDA	Bq/kg	+/-		MDA	Bq/kg	+/-		
Trimouille Island																					
T1-2, Sediments(West)										-		-	0.7	-		-	0.6	**22.6**	+/-	2.5	5.8
T1-2, Beach (West)										-		-	0.6	-		-	0.4	**26.2**	+/-	2.6	4.7
1+00										-		-	1.2	-		-	0.4	**24.4**	+/-	2.4	4.3
1+100										**4.4**	+/-	0.4	0.7	-		-	0.5	**21.6**	+/-	2.2	4.6
1+200										**2.5**	+/-	0.3	1.1	-		-	0.8	**21.6**	+/-	2.4	7.5
1+400										-		-	0.8	-		-	0.6	**22.7**	+/-	2.9	6.7
1+600										-		-	0.6	-		-	0.4	**23.2**	+/-	2.3	5.5
1+800										-		-	0.9	-		-	0.6	**22.7**	+/-	2.5	6.2
1+1000										-		-	0.7	-		-	0.6	**21.7**	+/-	2.2	5.9
1+1200										-		-	0.7	-		-	0.5	**23.1**	+/-	3.0	6.4
Transect 3-4																					
T3-4, Shallow Seds (West)										-		-	0.8	-		-	0.6	**24.1**	+/-	2.7	6.2
T3-4 Beach (West)										-		-	0.6	-		-	0.4	**22.8**	+/-	2.3	5.2
4+10										-		-	0.9	-		-	0.5	**21.3**	+/-	2.1	6.8
4+100										**1.3**	+/-	0.2	0.8	-		-	0.5	**27.2**	+/-	2.7	5.6
4+200										-		-	0.7	-		-	0.4	**23.5**	+/-	2.3	5.6
4+400										**1.1**	+/-	0.2	0.7	-		-	0.5	**23.1**	+/-	2.3	5.8
4+600										-		-	1.0	-		-	0.5	**21.6**	+/-	2.4	7.4
4+800										-		-	0.7	-		-	0.5	**23.5**	+/-	2.3	5.1
3+00										-		-	0.7	-		-	0.5	**26.1**	+/-	2.9	6.2
T3-4, Shallow Seds (East)										-		-	0.6	-		-	0.4	**26.7**	+/-	2.7	5.1
T3-4, Beach (East)										-		-	0.9	-		-	0.6	**27.2**	+/-	3.0	6.5
Transect 7-8																					
8+00										-		-	1.5	-		-	1.1	**24.1**	+/-	4.3	12.2
8+100										-		-	2.3	-		-	1.5	-		-	18.9
8+200										-		-	2.2	-		-	1.7	**29.4**	+/-	5.3	17.0
8+400										-		-	0.7	-		-	0.5	**27.5**	+/-	2.7	6.1
8+600										-		-	0.7	-		-	0.4	**23.2**	+/-	2.3	5.2
7+00										-		-	0.8	-		-	0.5	**29.7**	+/-	3.0	6.3
T7-8, Beach (East)										-		-	0.7	-		-	0.5	**23.9**	+/-	2.4	5.2
T7-8, Shallow Seds (East)										-		-	0.7	-		-	0.6	**22.1**	+/-	2.7	6.6
Transect 9-10																					
T9-10, Shallow Seds (West)										-		-	0.6	-		-	0.5	**24.8**	+/-	3.0	6.2
T9-10, Beach (N. end Main B., 2015)																					
9+00										-		-	0.8	-		-	0.5	**24.1**	+/-	2.4	6.4
9+100										-		-	1.6	-		-	0.9	**28.6**	+/-	5.1	14.0
9+200										-		-	1.2	-		-	0.8	**31.4**	+/-	4.4	9.7
9+400										-		-	0.7	-		-	0.4	**25.1**	+/-	2.8	6.3
9+600										-		-	0.7	-		-	0.4	**23.9**	+/-	2.4	5.6
9+800										-		-	0.5	-		-	0.4	**22.1**	+/-	2.4	5.3
10+00										-		-	0.5	-		-	0.4	**21.5**	+/-	2.1	4.6
Transect 15-16																					
T15-16, Shallow Seds (West)										-		-	0.5	-		-	0.4	**23.0**	+/-	2.3	4.4
T15-16, Beach (West)										-		-	1.0	-		-	0.7	**24.2**	+/-	3.6	7.9
16+00										-		-	0.8	-		-	0.4	**22.3**	+/-	2.2	6.3
16+200										-		-	0.8	-		-	0.5	**24.8**	+/-	2.5	6.1
16+400										-		-	0.7	-		-	0.5	**23.1**	+/-	2.5	6.1
16+600										-		-	0.9	-		-	0.6	**27.0**	+/-	2.7	6.0
15+00										-		-	0.6	-		-	0.4	**21.9**	+/-	2.2	4.9
T15-16, Beach (East)										-		-	0.5	-		-	0.4	**22.2**	+/-	2.2	4.7
T15-16, Shallow Seds (East)										-		-	0.5	-		-	0.4	**26.8**	+/-	2.7	5.0
Transect 17-18																					
17+00										-		-	0.9	-		-	0.6	**28.6**	+/-	2.9	6.8
17+200										-		-	0.5	-		-	0.4	**22.6**	+/-	2.3	4.2
18+00										-		-	0.7	-		-	0.5	**21.8**	+/-	2.2	5.2
Soil Depth Profile, Red Beacon Hill																					
0-4 cm										-		-	3.7	-		-	2.8	-		-	31.6
4-8 cm										-		-	3.5	-		-	2.6	-		-	29.9
8-12 cm										-		-	1.5	-		-	0.8	**26.8**	+/-	5.4	12.0
12-16 cm										-		-	0.8	-		-	0.5	**25.8**	+/-	2.8	6.8
16-20 cm										-		-	0.7	-		-	0.5	**23.9**	+/-	2.6	6.3
20-24 cm										-		-	0.7	-		-	0.4	**20.3**	+/-	2.0	5.4
24-28 cm										-		-	0.9	-		-	0.6	**23.0**	+/-	2.8	6.7
28-32 cm										-		-	0.9	-		-	0.6	**24.3**	+/-	2.4	7.5

Appendix E (continued)

	^{214}Pb (proxy for ^{226}			MDA	^{214}Bi (proxy for ^{226}Ra)				^{210}Pb				^{212}Pb (proxy for ^{228}Th)				^{40}K			
	activity	at 351.9 keV			activit	at 609.3 keV			activit	at 46.5 keV			activit	at 238.6 keV			activit	at 1460.8 keV		
	Bq/kg	+/-		MDA c	Bq/kg	+/-		MDA	Bq/kg	+/-		MDA c	Bq/kg	+/-		MDA	Bq/kg	+/-		MDA c
Thevenard Isl.																				
THV-Dune/soils, 0-4 cm	**9.4**	±	0.4	1.3	**9.6**	±	0.5	1.4	**19.8**	±	2.7	8.2	**6.5**	±	0.6	0.5	**49.5**	±	3.0	5.87
THV-Dune/soils, 0-4 cm																				
Port Headland																				
PH-Dune/soils, 0-4 cm	**4.9**	+/-	0.8	1.4	**5.6**	+/-	1.1	1.8	**21.2**	+/-	2.3	7.0	**13.5**	+/-	1.3	1.0	**773.6**	+/-	77.4	24.60
PH-Dune/soils, 4-12 cm	**5.6**	+/-	0.8	1.7	**4.6**	+/-	1.0	2.2	**-**	+/-		11.1	**16.6**	+/-	1.7	1.3	**784.6**	+/-	78.5	32.70
PH-Dune/soils, 12-20 cm	**5.8**	+/-	0.6	1.2	**7.1**	+/-	0.9	1.6	**-**	+/-		6.7	**12.5**	+/-	1.3	0.9	**811.2**	+/-	81.1	15.40
PH-Dune/soils, 0-4 cm																				
Burrup Pen.																				
BU-Beach, 0-10 cm	**18.7**	+/-	1.9	2.0	**18.1**	+/-	1.8	2.4	**43.1**	+/-	4.3	9.0	**32.8**	+/-	3.3	1.2	**572.3**	+/-	57.2	30.30
BU-Camp, 0-10 cm	**7.1**	+/-	0.9	1.9	**6.9**	+/-	1.1	2.4	**17.2**	+/-	3.1	9.6	**12.0**	+/-	1.2	1.4	**331.1**	+/-	33.1	37.20
BU-Dune/soils, 0-10 cm	**43.4**	±	0.6	1.9	**44.4**	±	0.7	2.2	**66.3**	±	3.2	15.3	**78.2**	±	2.7	0.8	**108.6**	±	59.0	9.09
BU-inland/soils, 0-10 cm																				
Hermite Isl.																				
HI-Mammal Grid, Comp of corners, 0-10cm	**15.9**	±	0.4	1.1	**15.8**	±	0.5	1.2	**25.2**	±	2.7	8.3	**5.8**	±	0.4	0.5	**34.9**	±	2.6	5.34
HI-Mammal Grid, Comp of corners, 0-10cm	**17.7**	±	0.4	1.8	**16.8**	±	0.5	2.1	**26.9**	±	2.1	13.7	**4.6**	±	0.2	0.8	**33.1**	±	2.5	8.50
HI-Mammal grid (centre), 0-10cm	**15.9**	±	0.4	1.8	**16.3**	±	0.4	2.0	**23.9**	±	1.9	12.5	**4.4**	±	0.5	0.7	**35.2**	±	2.5	6.95
HI-Mammal Grid (centre), SDP 0-4cm	**7.1**	±	1.7	1.0	**12.6**	±	3.8	2.0	**36.8**	±	6.0	3.3	**6.1**	±	0.9	0.5		<		
HI-Mammal Grid (centre), SDP 4-12cm	**19.6**	±	1.6	1.2	**15.2**	±	0.5	1.4	**22.4**	±	1.5	8.4	**4.5**	±	0.4	0.6	**34.6**	±	2.2	5.91
HI-Mammal Grid (centre), SDP 12-20cm	**15.1**	±	0.3	1.4	**15.6**	±	0.4	1.5	**16.6**	±	1.4	9.0	**4.7**	±	0.2	0.6	**34.6**	±	2.3	6.45
HI-Comp (comp 4 corners), 0-10cm (A-spc)																				
Home Lagoon																				
HI-HL-sediment, 0-10cm	**6.4**	±	1.7	0.9	**4.2**	±	2.2	1.6	**19.8**	±	5.0	3.0	**4.5**	±	0.5	0.4		<	16.1	
HI-HL-beach (0-10cm)	**11.7**	+/-	1.2	1.4	**11.5**	+/-	1.2	1.8	**12.7**	+/-	2.2	5.4	**2.2**	+/-	0.4	0.8	**-**			15.75
HI-HL-camp (0-10cm)	**13.5**	+/-	1.4	1.2	**13.0**	+/-	1.3	1.3	**18.7**	+/-	2.1	4.9	**3.0**	+/-	0.4	0.7	**-**			14.67
HI-HL-dune/soils,(0-10cm)	**12.6**	+/-	1.3	1.8	**13.7**	+/-	1.5	2.5	**27.2**	+/-	4.1	8.8	**2.6**	+/-	0.5	1.2	**-**			30.72
HI-HL-dune/soils, SDP 0-4cm	**8.8**	±	2.1	1.3	**14.0**	±	5.3	2.9	**55.5**	±	7.9	4.2	**5.9**	±	0.9	0.6		<	30.2	
HI-HL-dune/soils, SDP 4-12cm	**13.8**	±	0.4	1.1	**13.7**	±	0.3	1.2	**22.8**	±	2.5	7.4	**2.7**	±	0.3	0.4	**19.8**	±	1.4	5.11
HI-HL-dune/soils, SDP 12-20cm	**14.4**	±	0.4	1.6	**13.9**	±	0.7	2.0	**13.7**	±	1.6	10.8	**2.8**	±	0.2	0.7	**19.1**	±	1.8	8.09
MB-C-13 Camp dune soils (0-10 cm) (A-spc)																				
Renewal Island-Whisky bay Camp																				
WB-sediments (0-10cm)	**-**		-	1.6	**-**		-	2.0	**16.8**		-	7.3	**-**		-	1.1	**-**		-	20.99
WB- beach sands, 0-10cm		<	1.5			<				<			**12.4**	±		1.0		<		
WB-Camp (0-10cm)	**7.0**	+/-	0.7	1.2	**7.8**	+/-	0.9	1.5	**14.0**	+/-	1.5	4.7	**1.5**	+/-	0.4	0.8	**-**			14.86
MB-C-4 Camp dune soils-WB	**9.0**	+/-	1.2	2.0	**8.8**	+/-	1.5	2.5	**16.9**	+/-	4.1	9.3	**2.2**	+/-	0.6	1.3	**-**			34.66
WB-Dune/soils, SDP 0-4cm	**9.5**	±	0.2	1.0	**9.3**	±	0.2	1.2	**16.9**	±	1.2	7.2	**1.9**	±	0.3	0.4	**9.7**	±	1.0	4.32
WB-Dune/soils, SDP 4-12cm	**7.7**	±	0.3	1.7	**7.9**	±	0.4	2.1	**22.4**	±	3.8	11.9	**2.1**	±	0.5	0.8		<	8.3	
WB-Dune/soils, SDP 12-20cm	**8.9**	±	0.3	1.8	**8.1**	±	0.4	2.3	**15.5**	±	1.8	13.2	**2.0**	±	0.2	0.8		<	7.9	
WB-Camp dune soils (0-10cm) (alpha)																				
Alpha Island																				
AI-Boodie grid SE Cnr (0-10cm) same as cam	**13.4**	+/-	1.3	1.8	**15.9**	+/-	1.7	2.6	**17.1**	+/-	3.4	7.3	**2.6**	+/-	0.5	1.1	**-**			33.60
AI-Boodie grid SW Cnr (0-10cm)	**21.0**	+/-	2.1	1.6	**20.5**	+/-	2.1	2.0	**26.3**	+/-	2.6	6.1	**5.9**	+/-	0.6	1.0	**51.2**	+/-	8.7	18.50
AI-Boodie grid NE+NW Cnrs combined (0-10c	**20.5**	+/-	2.1	1.5	**22.1**	+/-	2.2	1.7	**32.4**	+/-	3.2	6.9	**5.3**	+/-	0.5	0.9	**-**			17.16
AI-North Mammal Grid (corners), 0-10cı	**18.2**	±	0.4	1.2	**18.4**	±	0.4	1.4	**25.1**	±	2.7	8.1	**4.6**	±	0.4	0.5	**29.1**	±	1.9	5.57
AI-North grid, Comp (0-10 cm) (alpha)																				
AI-South Grid (corners), 0-10cm	**21.2**	+/-	2.1	2.1	**23.7**	+/-	2.4	2.8	**29.4**	+/-	3.8	8.8	**7.5**	+/-	0.8	1.3	**70.0**	+/-	14.7	33.50
AI-South Grid (corners), 0-10cm (alpha)																				
Chartreuse Bay Camp																				
AI-CB-Shallow sediments	**12.4**	+/-	1.2	1.5	**10.7**	+/-	1.1	1.8	**19.6**	+/-	2.7	6.5	**2.6**		0.5	1.0	**-**			25.50
AI-CB-Dune/soils (0-10cm)	**13.4**	+/-	1.3	1.8	**15.9**	+/-	1.7	2.6	**17.1**	+/-	3.4	7.3	**2.6**		0.5	1.1	**-**			33.60
AI-CB-Dune/soils (0-4cm)	**8.9**	±	1.6	1.1	**10.8**	±		2.5	**37.1**	±	5.7	4.1	**6.6**	±	0.9	0.6		<	24.2	
AI-CB-Dune/soils (4-12cm)	**8.5**	±	3.0	1.3	**11.2**	±	3.3	2.4	**53.9**	±	12.2	4.4	**6.4**	±	1.0	0.6		<	28.8	
AI-CB-Dune/soils (12-20cm)	**8.5**	±	2.7	1.4	**14.1**	±	5.3	2.8	**45.4**	±	10.3	5.3	**6.5**	±	0.8	0.6		<	28.8	
AI-CB-Dune/soils (0-10cm) (alpha)																				

	^{214}Pb (proxy for ^{226}			MDA	^{214}Bi (proxy for ^{226}Ra)				^{210}Pb				^{212}Pb (proxy for ^{228}Th)				^{40}K			
	activity	at 351.9 keV			**activit**	at 609.3 keV			**activit**	at 46.5 keV			**activit**	at 238.6 keV			**activit**	at 1460.8 keV		
	Bq/kg	+/-		MDA c	**Bq/kg**	+/-		MDA	**Bq/kg**	+/-		MDA c	**Bq/kg**	+/-		MDA	**Bq/kg**	+/-		MDA c
<u>Northwest Island</u>			0.0				0.0				0.0				0.0				0.0	
NW-East Grid, SE corner, 0-10 cm	**8.3**	+/-	0.9	1.6	**8.1**	+/-	1.1	2.1	**15.9**	+/-	3.0	6.9	**-**			0.9	**-**			18.18
NW-East Grid, SW corner, 0-10 cm	**8.1**	+/-	1.1	1.9	**8.0**	+/-	1.3	2.2	**24.7**	+/-	3.5	8.2	**-**			1.2	**-**			32.71
NW-East Grid, NW corner, 0-10 cm	**10.1**	+/-	1.0	1.4	**9.9**	+/-	1.0	1.8	**20.7**	+/-	2.5	5.9	**-**			1.0	**-**			18.43
	8.5	+/-	1.1	1.9	**8.3**	+/-	1.2	2.2	**15.0**	+/-	2.7	6.3	**-**			1.1	**-**			31.70
NW-East Grid, Comp. of corners, 0-10 cr	**9.6**	±	0.3	1.6	**9.2**	±	0.3	1.8	**18.5**	±	1.6	11.0	**1.1**	±	0.1	0.6	**6.8**	±	1.2	6.42
NW-East Grid, Comp. of corners, 0-10 cm (alpha)																				
NW-West Grid, Comp of corners, 0-10 c	**6.8**	+/-	0.9	1.6	**8.3**	+/-	1.0	1.8	**24.1**	+/-	3.1	7.1	**-**			1.1	**-**			20.14
NW-West Grid, Comp of corners, 0-10 cm (alpha)																				
NW Island Camp																				
NW-sediment, 0-10cm	**5.4**	+/-	0.9	1.7	**5.7**	+/-	1.2	2.2	**8.7**	+/-	2.1	5.8	**-**			1.1	**-**			20.78
NW-beach (0-10cm)	**9.4**	+/-	0.9	1.0	**10.0**	+/-	1.0	1.4	**15.7**	+/-	2.0	4.7	**-**			0.7	**-**			13.40
NW-Camp (0-10cm)	**11.3**	+/-	1.1	1.2	**12.8**	+/-	1.3	1.6	**17.6**	+/-	2.1	5.3	**1.7**	+/-	0.4	0.8	**-**			15.74
NW-dune/soils,(0-10cm)	**8.5**	+/-	1.1	1.9	**8.3**	+/-	1.2	2.2	**15.0**	+/-	2.7	6.3	**-**			1.1	**-**			31.70
NW-dune/soils,(0-10cm) (alpha)																				
<u>Bluebell Island</u>																				
BI-North-Beach	**13.2**	+/-	1.3	1.4	**14.1**	+/-	1.4	1.9	**24.0**	+/-	2.4	6.0	**2.8**	+/-	0.4	0.9	**-**			17.08
BI-North-Camp	**15.9**	+/-	1.6	1.5	**15.8**	+/-	1.6	2.0	**38.7**	+/-	3.9	7.7	**3.5**	+/-	0.5	1.0	**-**			19.26
BI-North-Dune/soils	**22.0**	+/-	2.2	2.7	**25.3**	+/-	2.5	2.9	**50.4**	+/-	6.5	15.6	**9.8**	+/-	1.0	1.8	**58.7**	+/-	7.6	17.60
BI-North-Dune/soils-2 (alpha)																				
BI-Middle-Shallow sediments	**13.9**	+/-	1.4	1.7	**13.7**	+/-	1.4	2.0	**24.4**	+/-	2.4	7.0	**2.7**	+/-	0.5	1.0	**-**			26.85
BI-Middle-Beach	**11.6**	+/-	1.2	1.5	**10.4**	+/-	1.0	1.6	**15.2**	+/-	2.1	6.1	**1.9**	+/-	0.4	1.0	**-**			20.33
BI-Middle-Camp	**15.4**	+/-	1.5	1.4	**16.1**	+/-	1.6	1.8	**21.7**	+/-	2.4	5.9	**2.7**	+/-	0.4	1.0	**-**			18.18
BI-Middle-Dune/soils	**17.0**	+/-	1.7	1.8	**18.0**	+/-	1.8	2.3	**19.3**	+/-	2.9	6.7	**3.8**	+/-	0.5	1.1	**-**			30.84
BI-Middle-Dune/soils-2 (alpha)																				
BI-South-Beach	**11.9**	+/-	1.2	1.0	**12.3**	+/-	1.2	1.4	**15.9**	+/-	1.8	4.7	**2.7**	+/-	0.4	0.7	**29.7**	+/-	6.2	13.60
BI-South-Camp	**15.4**	+/-	1.5	1.3	**15.7**	+/-	1.6	1.7	**24.3**	+/-	2.4	5.4	**2.1**	+/-	0.4	0.8	**34.9**	+/-	8.4	15.30
BI-South-Dune/soils	**18.5**	+/-	1.9	1.5	**19.2**	+/-	1.9	2.2	**30.3**	+/-	3.6	7.8	**2.9**	+/-	0.5	1.0	**-**			16.60
BI-South-Dune/soils-2 (alpha)																				

	^{214}Pb (proxy for ^{226}			MDA	^{214}Bi (proxy for ^{226}Ra)				^{210}Pb				^{212}Pb (proxy for ^{228}Th)				^{40}K			
	activity	at 351.9 keV			activit	at 609.3 keV			activit	at 46.5 keV			activit	at 238.6 keV			activit	at 1460.8 keV		
	Bq/kg	+/-		MDA c	Bq/kg	+/-		MDA	Bq/kg	+/-		MDA c	Bq/kg	+/-		MDA	Bq/kg	+/-		MDA c
Trimouille Island																				
T1-2, Sediments(West)	**5.8**	+/-	0.8	1.5	**6.1**	+/-	1.2	2.0	**10.5**	+/-	1.4	6.1	-			1.0	-			18.80
T1-2, Beach (West)	**11.1**	+/-	1.1	1.2	**12.6**	+/-	1.3	1.4	**15.7**	+/-	2.0	4.9	-			0.7	-			13.70
1+00	**11.5**	+/-	1.1	1.0	**12.3**	+/-	1.2	1.4	**18.9**	+/-	2.1	5.2	-			0.7	-			13.13
1+100	**10.5**	+/-	1.0	1.1	**10.1**	+/-	1.0	1.5	**19.2**	+/-	1.9	5.4	**1.5**	+/-	0.3	0.7	-			13.40
1+200	**9.5**	+/-	0.9	1.5	**9.6**	+/-	1.4	2.3	**17.8**	+/-	2.7	8.4	-			1.2	-			30.73
1+400	**15.4**	+/-	1.5	1.5	**16.9**	+/-	1.7	2.1	**19.7**	+/-	2.9	7.4	**3.5**	+/-	0.5	1.0	**33.6**	+/-	8.4	17.90
1+600	**13.2**	+/-	1.3	1.5	**11.0**	+/-	1.1	1.7	**21.2**	+/-	2.3	5.8	**1.8**	+/-	0.4	0.8	-			15.97
1+800	**12.4**	+/-	1.2	1.9	**11.1**	+/-	1.4	2.3	**20.8**	+/-	2.5	7.7	-			1.1	-			17.68
1+1000	**10.8**	+/-	1.1	1.5	**10.5**	+/-	1.2	2.1	**19.1**	+/-	2.5	6.2	**1.6**	+/-	0.4	1.0	-			18.76
1+1200	**10.8**	+/-	1.1	1.4	**9.5**	+/-	1.0	1.6	**23.1**	+/-	3.2	7.1	-			0.9	-			15.48
Transect 3-4																				
T3-4, Shallow Seds (West)	**6.0**	+/-	0.7	1.3	**7.0**	+/-	1.1	1.9	**16.3**	+/-	2.8	6.7	-			1.0	-			19.24
T3-4 Beach (West)	**7.0**	+/-	0.8	1.5	**6.2**	+/-	0.7	1.5	**10.2**	+/-	2.2	5.6	-			0.8	-			16.42
4+10	**6.9**	+/-	1.0	1.6	**6.5**	+/-	1.2	2.0	**20.0**	+/-	3.4	7.9	-			1.1	-			28.20
4+100	**11.3**	+/-	1.1	1.2	**11.9**	+/-	1.2	1.9	**29.7**	+/-	3.6	8.1	**1.5**	+/-	0.4	0.9	-			14.15
4+200	**8.4**	+/-	0.9	1.5	**8.7**	+/-	0.9	1.6	**15.2**	+/-	2.7	6.7	-			0.9	-			15.06
4+400	**8.1**	+/-	0.8	1.4	**8.2**	+/-	0.9	1.5	**18.3**	+/-	2.0	5.9	**1.7**	+/-	0.4	0.9	-			14.65
4+600	**6.4**	+/-	1.0	1.7	**10.4**	+/-	1.5	2.4	**15.7**	+/-	3.6	8.5	-			1.2	-			31.71
4+800	**6.9**	+/-	0.7	1.2	**5.6**	+/-	0.7	1.6	**15.3**	+/-	3.4	7.3	-			0.9	-			15.43
3+00	**7.7**	+/-	0.8	1.3	**8.8**	+/-	1.1	1.9	**9.8**	+/-	1.8	5.7	-			0.9	-			16.86
T3-4, Shallow Seds (East)	**9.0**	+/-	0.9	1.1	**7.9**	+/-	0.9	1.5	**11.1**	+/-	2.2	5.6	-			0.8	-			16.23
T3-4, Beach (East)	**-**		-	1.5	**-**		-	2.0	**-**		-	7.5	-			1.1	-			29.74
Transect 7-8																				
8+00	**13.4**	+/-	1.5	3.5	**12.3**	+/-	1.2	2.5	**21.6**	+/-	4.5	14.5	-			2.1	-			16.05
8+100	**15.9**	+/-	2.4	4.8	**13.1**	+/-	2.3	4.0	**24.2**	+/-	6.0	19.6	-			2.7	-			15.77
8+200	**10.3**	+/-	1.5	4.7	**13.0**	+/-	2.2	4.1	**-**	+/-		21.3	-			3.1	-			19.35
8+400	**11.1**	+/-	1.1	1.6	**11.3**	+/-	1.1	1.8	**14.6**	+/-	2.2	6.1	-			0.9	-			16.24
8+600	**9.2**	+/-	0.9	1.2	**9.7**	+/-	1.1	1.6	**17.5**	+/-	2.6	6.2	-			0.9	-			23.46
7+00	**10.7**	+/-	1.1	1.6	**10.2**	+/-	1.1	1.9	**13.1**	+/-	2.0	6.1	-			1.0	-			15.87
T7-8, Beach (East)	**6.3**	+/-	0.8	1.5	**6.2**	+/-	0.9	1.8	**11.5**	+/-	2.6	6.3	-			1.0	-			17.79
T7-8, Shallow Seds (East)	**3.3**	+/-	0.7	1.5	**3.7**	+/-	1.0	1.9	**16.2**	+/-	2.6	6.9	-			1.1	-			21.75
Transect 9-10																				
T9-10, Shallow Seds (West)	**6.2**	+/-	0.6	1.2	**8.3**	+/-	1.1	1.8	**12.1**	+/-	3.4	7.3	-			0.9	-			15.21
T9-10, Beach (N. end Main B., 2015)																				
9+00	**9.9**	+/-	1.0	1.6	**10.2**	+/-	1.0	1.7	**20.5**	+/-	3.1	8.0	-			1.1	-			14.78
9+100	**10.5**	+/-	1.6	3.7	**12.5**	+/-	1.5	2.9	**-**	+/-		15.5	-			2.2	-			15.31
9+200	**9.4**	+/-	0.9	1.8	**14.5**	+/-	1.4	2.5	**19.1**	+/-	4.2	10.1	-			1.4	-			30.89
9+400	**13.1**	+/-	1.3	1.6	**13.1**	+/-	1.3	1.7	**16.4**	+/-	2.0	6.1	-			0.9	-			12.80
9+600	**14.2**	+/-	1.4	1.3	**15.3**	+/-	1.5	1.7	**19.5**	+/-	2.5	6.2	-			0.9	-			23.41
9+800	**16.8**	+/-	1.7	1.2	**15.9**	+/-	1.6	1.3	**24.0**	+/-	2.4	5.4	**1.7**	+/-	0.4	0.7	**25.4**	+/-	6.4	12.40
10+00	**16.6**	+/-	1.7	1.0	**19.3**	+/-	1.9	1.4	**20.7**	+/-	2.1	4.7	**3.0**	+/-	0.4	0.7	**27.7**	+/-	7.2	13.50
Transect 15-16																				
T15-16, Shallow Seds (West)	**9.8**	+/-	1.0	1.2	**9.8**	+/-	1.0	1.5	**15.0**	+/-	1.9	4.8	-			0.7	-			14.39
T15-16, Beach (West)	**7.6**	+/-	1.0	1.7	**8.6**	+/-	1.5	2.4	**13.4**	+/-	3.2	7.7	-			1.2	-			31.05
16+00	**16.1**	+/-	1.6	1.8	**15.4**	+/-	1.5	2.1	**22.0**	+/-	3.5	7.8	**2.2**	+/-	0.4	1.0	-			16.83
16+200	**11.3**	+/-	1.1	1.4	**11.5**	+/-	1.2	1.8	**26.0**	+/-	3.1	7.3	**2.4**	+/-	0.4	1.0	-			19.77
16+400	**10.5**	+/-	1.1	1.3	**11.8**	+/-	1.2	1.7	**22.1**	+/-	2.4	5.9	**1.8**	+/-	0.4	0.9	-			17.38
16+600	**6.9**	+/-	0.8	1.4	**8.3**	+/-	1.2	1.9	**17.8**	+/-	2.5	6.2	-			1.0	-			27.72
15+00	**8.3**	+/-	0.8	0.9	**8.0**	+/-	0.8	1.3	**11.6**	+/-	1.7	4.4	-			0.7	-			12.14
T15-16, Beach (East)	**9.5**	+/-	1.0	1.1	**8.5**	+/-	0.8	1.3	**13.4**	+/-	1.7	4.4	-			0.7	-			13.75
T15-16, Shallow Seds (East)	**8.8**	+/-	0.9	1.3	**8.9**	+/-	1.0	1.5	**8.7**	+/-	1.7	4.4	-			0.7	-			14.09
Transect 17-18																				
17+00	**12.1**	+/-	1.2	1.7	**12.7**	+/-	1.4	2.2	**25.3**	+/-	2.5	7.5	-			1.1	-			29.33
17+200	**11.3**	+/-	1.1	1.0	**12.9**	+/-	1.3	1.5	**18.0**	+/-	1.8	4.5	**1.4**	+/-	0.4	0.7	-			13.61
18+00	**10.2**	+/-	1.0	1.2	**11.4**	+/-	1.1	1.6	**10.0**	+/-	1.9	6.1	-			0.9	-			23.61
Soil Depth Profile, Red Beacon Hill																				
0-4 cm	**12.4**	+/-	2.7	8.9	**15.3**	+/-	3.7	7.2	**-**	+/-		37.4	-			5.8	-			26.36
4-8 cm	**13.4**	+/-	3.1	7.6	**11.8**	+/-	2.7	5.9	**-**	+/-		33.3	-			4.9	-			25.01
8-12 cm	**10.1**	+/-	1.0	2.2	**10.6**	+/-	1.3	2.3	**-**	+/-		12.7	-			1.6	-			28.88
12-16 cm	**9.6**	+/-	1.0	1.3	**8.2**	+/-	0.8	1.5	**13.1**	+/-	2.2	7.3	-			0.9	-			12.75
16-20 cm	**9.4**	+/-	0.9	1.3	**9.2**	+/-	0.9	1.5	**12.0**	+/-	2.4	6.5	-			0.9	-			14.61
20-24 cm	**10.7**	+/-	1.1	1.1	**11.0**	+/-	1.1	1.4	**10.0**	+/-	2.0	5.7	**1.8**	+/-	0.3	0.7	-			12.52
24-28 cm	**9.2**	+/-	0.9	1.5	**10.2**	+/-	1.0	1.7	**11.7**	+/-	3.5	8.1	-			1.0	-			23.77
28-32 cm	**11.8**	+/-	1.2	1.8	**8.8**	+/-	0.9	1.7	**11.6**	+/-	2.7	8.6	-			1.0	-			15.66