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Che Doering, Peter Medley, Jefferson Chen

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The Department acknowledges the traditional owners of country throughout Australia and their continuing connection to land, sea and community. We pay our respects to them and their cultures and to their elders both past and present.

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Authors of this report:

Che Doering –Supervising Scientist, GPO Box 461, Darwin NT 0801, Australia

Peter Medley –Supervising Scientist, GPO Box 461, Darwin NT 0801, Australia

Jefferson Chen –Supervising Scientist, GPO Box 461, Darwin NT 0801, Australia

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Supervising Scientist
Department of the Environment and Energy
GPO Box 461, Darwin NT 0801 Australia

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Executive summary

Gamma dose rates and radon-222 exhalation fluxes are measured at the El Sherana containment every two years to provide ongoing assurance that radioactive waste material buried at the facility does not present an unacceptable radiation health risk to Parks Australia employees or the public. This report presents the measurements from June 2017, the fifth set of measurements since construction of the containment in 2009. Average gamma dose rates and radon-222 exhalation flux densities in 2017 were no different to baseline values in 2007 before the containment was built. Consequently, the levels measured in 2017 would not result in above-background doses to Parks Australia employees or the public above the dose constraint of 30 μSv per year. The implication of these results is that there is currently no unacceptable radiation health risk associated with buried radioactive waste material at the containment.

1 Introduction

The El Sherana containment is a near-surface disposal facility located in the South Alligator River valley in the southern part of Kakadu National Park. It was constructed in the 2009 dry season and contains approximately 22,000 m^3 of radioactively contaminated waste from the remediation of legacy uranium mining and processing sites in the area. Engineering details of the containment are summarised in Doering et al (2011) and Bollhöfer et al (2013, 2015). The uranium mining history of the South Alligator River valley is summarised in Waggitt (2004).

The El Sherana containment is currently in the institutional control period, during which time, public access to the site must be restricted and the site must not be used for other purposes (NHMRC 1993). The site is managed by the Director of National Parks, with regulatory oversight by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). The Supervising Scientist assists the Director of National Parks with radiological monitoring of the site by conducting biennial measurements of gamma dose rates and radon-222 exhalation flux densities.

A dose constraint of 30 $\mu Sv\ y^{-1}$ for both public and occupational exposure has been set for the El Sherana containment based on an assessment of plausible exposure scenarios Bollhöfer et al (2013). The dose constraint represents an upper bound on the expected above-background doses from the containment and a level below which radiation exposures should be optimised (ICRP 2007).

This report presents the results of gamma dose rate and radon exhalation flux density measurements conducted in June 2017 and compares them to previous measurement results, including baseline values measured in 2007. Based on these results, we have determined the potential for above-background radiation doses to workers and the public, and also the acceptability of such exposures in the context of the dose constraint.

2 Methods

2.1 Radon-222 exhalation flux densities

Radon-222 exhalation flux densities were measured over the period 8–14 June 2017. The prevailing meteorological conditions during the measurement period were typical of the tropical Northern Territory dry season, with maximum daytime temperatures around 30°C and zero rainfall.

Brass canisters containing activated charcoal were used for field sampling of radon-222 exhalation flux densities. The canisters were prepared by heating in an oven at 110°C for 48 hours to drive out residual radon-222 adsorbed on the surface of the charcoal. They were then allowed to cool to room temperature and immediately sealed for transport to the field.

Forty six canisters were deployed on and around the containment and their geospatial coordinates recorded using a global positioning system (GPS). The canisters were embedded in the ground surface to a depth of approximately 1 cm to trap exhaling radon-222. Two additional canisters were carried into the field but remained sealed at all times. These canisters were ‘controls’ and used to determine the background activity of radon-222 on the charcoal.

At the end of the sampling period, the canisters were removed from the ground surface and immediately sealed for transport back to the laboratory. They were then counted for a period of 600 s on a sodium iodide detector and the resulting energy spectrum displayed on a multi-channel analyser. The control canisters were also counted. Regions of interest were established around the characteristic photopeaks of the radon-222 decay products lead-214 (242 keV, 295 keV and 352 keV) and bismuth-214 (609 keV). The net count rate of these decay products in the field samples was determined by summing the total counts under each photopeak and then subtracting the arithmetic mean of the total counts under the corresponding regions of interest for the two control canisters. The counting efficiency of the detector was determined to be 10.3% using a sealed canister containing charcoal spiked with a known activity of radium-226, the parent radionuclide of radon-222.

Radon-222 exhalation flux densities were calculated following the method described in Spehr & Johnston (1983) as:

$$J = \frac{R \cdot t_c \cdot \lambda^2 \cdot \exp(\lambda \cdot t_d)}{\varepsilon \cdot a \cdot [1 - \exp(-\lambda \cdot t_s)] \cdot [1 - \exp(-\lambda \cdot t_c)]}$$

where J (Bq m^{-2} s^{-1}) is the average radon-222 flux density, R (s^{-1}) is the net count rate of radon-222 decay products, t_c (s) is the counting period, λ (s^{-1}) is the radon-222 decay constant, t_d (s) is the delay period from the end of sampling to the beginning of counting, ε (s^{-1} Bq^{-1}) is the counting efficiency of the detector, a (m^2) is the area of the open face of the canister when embedded in the ground and t_s (s) is the duration of the sampling period.

2.2 Gamma dose rates

Total gamma counts were measured on 8 June 2017 at each location where charcoal canisters were deployed. The count time was 60 s and the height of the measurement was approximately 1 m above the ground surface. Two RadEye GX meters with an attached Mini Instrument MC70 Geiger Müller tube were used to make the measurements. One meter (GM2) was calibrated by an external laboratory (SafeRadiation) against a certified radiation source and the other meter (GM3) was cross-calibrated to the first. The ratio of counts recorded by meter GM3 to meter GM2 during the cross-calibration was 0.934. This ratio was subsequently used to normalise field counts recorded by GM3 to GM2. Gamma counts recorded by both meters during the field survey were then converted to an absorbed dose rate using:

$$D = \frac{C}{T} \times \frac{1}{14.0} \times \frac{1}{1.21}$$

where:

D (μGy h^{-1}) is the absorbed dose rate;

C (counts) is the number of counts recorded by the meter normalised to GM2;

T (s) is the time over which field counts were recorded;

14.0 (counts s^{-1} per μSv h^{-1}) is the count rate to effective dose rate conversion factor reported on the calibration certificate of GM2; and

1.21 (Sv Gy^{-1}) is the to effective to absorbed dose conversion factor reported on the calibration certificate of GM2.

3 Results and discussion

Figure 1 shows the location and magnitude of the radon-222 exhalation flux density measurements and Figure 2 shows the gamma dose rate measurements. Data underpinning the figures have been provided in Appendix 1.

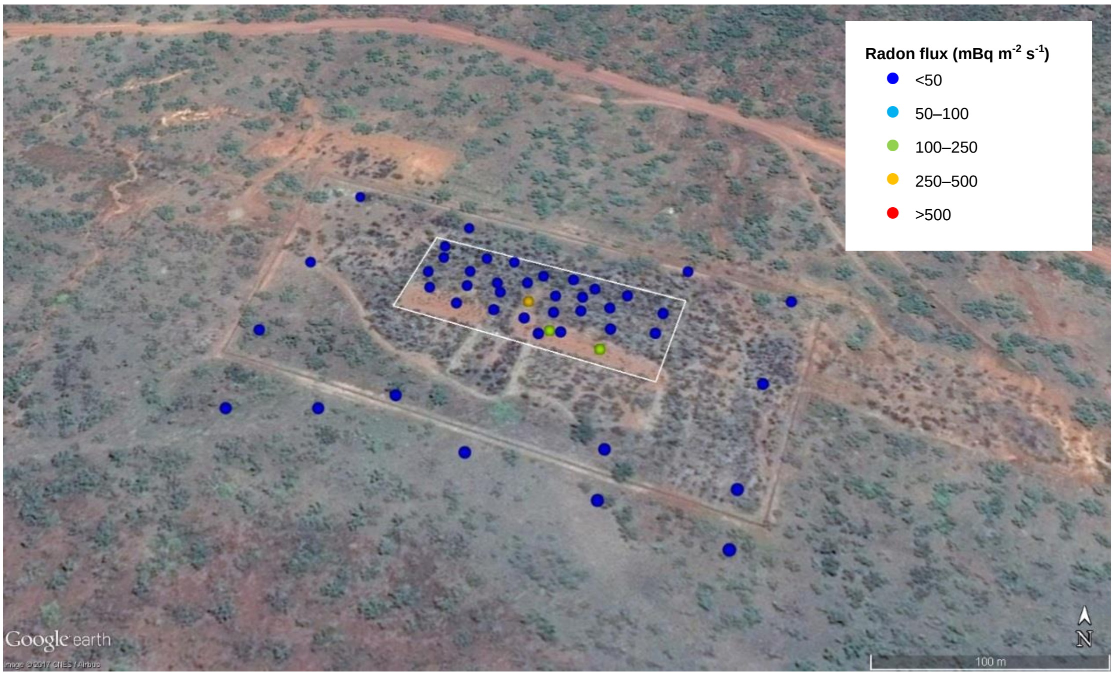

Figure 1 Radon-222 exhalation flux densities at El Sherana containment in 2017. The white rectangle shows the approximate outline of the containment. The fence line of the facility is visible in the image.

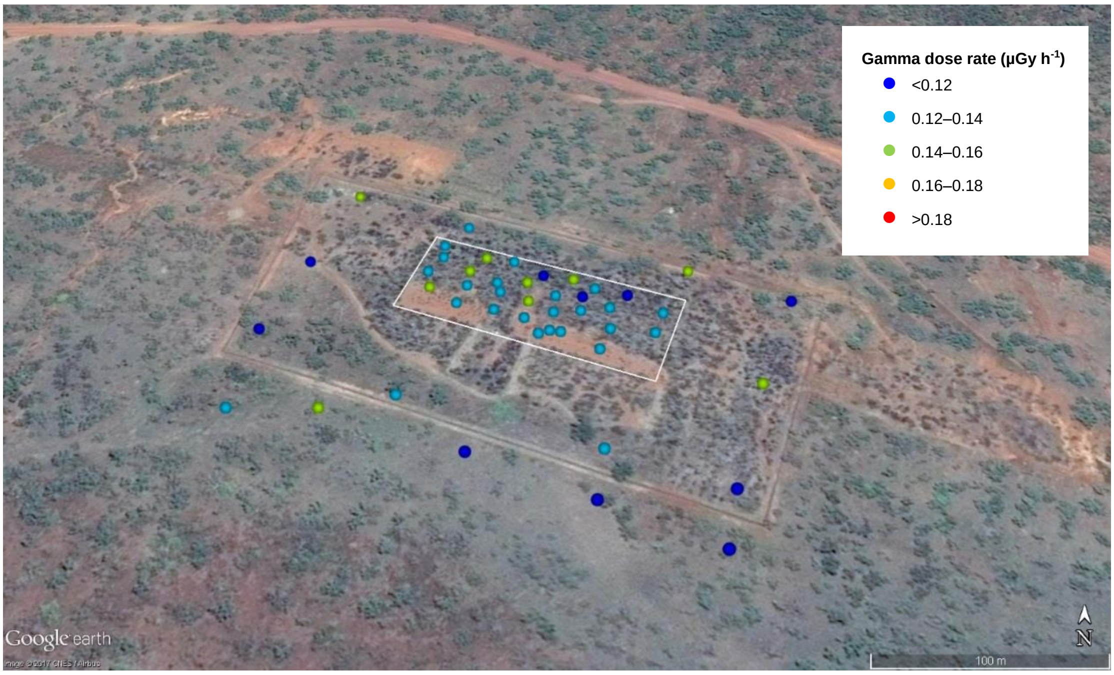

Figure 2 Gamma dose rates at El Sherana containment in 2017. The white rectangle shows the approximate outline of the containment. The fence line of the facility is visible in the image.

Radon-222 exhalation flux densities directly above the containment, off the containment but inside the fenced area and outside the fenced area were generally similar except for three elevated measurements directly above the containment (Figure 1). The arithmetic mean and standard deviation radon-222 exhalation flux density directly above the containment was 29 ± 70 mBq m^{-2} s^{-1} (n = 31), off the containment but inside the fenced area was 12 ± 4 mBq m^{-2} s^{-1} (n = 10) and outside the fenced area was 5.8 ± 3.8 mBq m^{-2} s^{-1} (n = 5). The arithmetic mean value directly above the containment has been skewed by the three elevated measurements. The geometric mean value of 7.1 mBq m^{-2} s^{-1} is perhaps more representative of the average radon-222 exhalation flux density over the total area directly above the containment, as less weight is placed on outliers.

The three locations where elevated radon-222 exhalation flux densities were measured do not correspond with elevated gamma dose rates (Figure 2), suggesting that the sampled radon-222 at these locations may have originated from deeper in the soil profile, possibly from the buried waste itself through cracks in the clay cap. Radon-222 in dry soil has a diffusion length of about 1.5 m (IAEA 2013, Porstendörfer 1994), making it possible for radon-222 generated by the decay of radium-226 in the buried waste to be exhaled from the surface of the containment. By comparison, the gamma signal in air at 1 m above the ground generally comes from radionuclides located in about the top 0.5 m of the soil, with deeper lying radionuclides tending to contribute only a few percent or less (ICRU 1994).

Gamma dose rates directly above the containment, off the containment but inside the fenced area and outside the fenced area were effectively the same (Figure 2). The arithmetic mean and standard deviation gamma dose rate directly above the containment was 0.13 ± 0.01 μGy h^{-1} (n = 31), off the containment but inside the fenced area was 0.12 ± 0.02 μGy h^{-1} (n = 10) and outside the fenced area was 0.11 ± 0.02 μGy h^{-1} (n = 5).

Table 1 compares the 2017 radon-222 exhalation flux densities directly above the containment to previous measurements, including baseline values from 2007. Radon-222 exhalation flux densities directly above the containment have typically been higher than baseline values and variable between years, though showing a decreasing trend since 2012. The geometric mean of the 2017 measurements was less than the geometric mean baseline value, implying there was no above-background radon-222 exposure pathway to workers or the public at the time of measurements.

Table 1 Summary of biennial radon exhalation flux densities (mBq m^{-2} s^{-1}) on the containment

Year	Arithmetic mean	Arithmetic standard deviation	Geometric mean	Geometric standard deviation	Minimum	Maximum	*n*
2007[a]	14	6	13	1.5	5.0	25	21
2010	29	39	19	2.8	6.2	170	34
2012	240	230	120	2.2	18	750	17
2013	180	150	99	2.1	9.7	530	30
2015	110	90	72	3.0	5.0	350	30
2017	29	70	7.1	4.0	0.19	320	31

[a]Baseline measurements

Variability in radon-222 exhalation flux densities between years may be due to a number of factors, including changes in containment surface soil and vegetation cover and differences in the timing of biennial measurements. The original ~2.5 m thick surface soil layer (or 'growth medium') on the containment was supplemented by an additional 1 m of soil in 2013 and the surface re-contoured following erosion in the previous wet seasons. Vegetation cover on the containment has varied from being bare in 2010 and 2013, to that of dense grass and scrub in 2015. Vegetation cover in 2017 was generally sparse due to a recent fire, though some patches of thick grass were present. Radon-222 measurements in 2015 and 2017 were taken early in the dry season (May and June) and were lower than those in 2010–2013, taken late in the dry season (September and October) (Table 1). Soil moisture content will be higher in the early dry season, immediately following the wet season. Higher soil moisture content is known to result in lower radon-222 exhalation from a substrate (Bollhöfer & Doering 2016), as it impedes the emanation of radon-222 from the soil grain into the soil pore space (IAEA 2013, Porstendörfer 1994).

Table 2 compares the 2017 gamma dose rates directly above the containment to previous measurements, including baseline values from 2007. Gamma dose rates have effectively remained unchanged from baseline values. The implication is that gamma radiation from radionuclides in the buried waste has been effectively attenuated by the clay cap and surface soil layer and that to date there has been no above-background gamma exposure pathway to workers or the public from the containment.

Table 2 Summary of biennial gamma dose rates (µGy h^{-1}) on the containment

Year	Arithmetic mean	Arithmetic standard deviation	Geometric mean	Geometric standard deviation	Minimum	Maximum	*n*
2007[a]	0.12	0.01	0.12	1.1	0.09	0.14	100
2010	0.10	0.01	0.10	1.1	0.08	0.13	230
2012	0.13	0.01	0.13	1.1	0.10	0.17	202
2013	0.13	0.01	0.13	1.1	0.11	0.15	30
2015	0.13	0.01	0.13	1.1	0.10	0.14	30
2017	0.13	0.01	0.13	1.1	0.11	0.15	31

[a]Baseline measurements

No dose modelling using the 2017 measurements was conducted, as the results indicated there was effectively no above-background radon-222 or gamma exposure pathway to workers or the public. Thus, the outcome of dose modelling using the measurement results would be a zero dose.

4 Conclusion

Average radon-222 exhalation flux densities and gamma dose rates at the El Sherana containment in 2017 were effectively no different to baseline values from 2007. The conclusion is that there was no above-background radon-222 or gamma exposure pathway to workers or the public at the time of measurements and there would be no exceedance of the occupational or public dose constraint of 30 µSv y^{-1} for the containment. Measurements of radon-222 exhalation flux densities and gamma dose rates at the containment should continue into the future to provide ongoing assurance of the performance of the facility and to ensure that workers and the public remain protected against radiation exposure from the buried waste.

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Appendix 1 Gamma and radon-222 measurements

Table A1 Gamma counts (cpm) and dose rates (µGy h^{-1}) and radon-222 exhalation flux densities (mBq m^{-2} s^{-1}) measured on and around the El Sherana containment in June 2017

Easting	Northing	Gamma counts	Gamma meter	Dose rate	Radon-222
On containment					
228802	8506249	148	GM2	0.15 ± 0.01	320 ± 4
228800	8506237	136	GM2	0.13 ± 0.01	8.0 ± 0.7
228783	8506243	124	GM2	0.12 ± 0.01	5.1 ± 0.7
228786	8506256	128	GM2	0.13 ± 0.01	6.9 ± 0.7
228784	8506263	120	GM2	0.12 ± 0.01	4.4 ± 0.7
228793	8506279	125	GM2	0.12 ± 0.01	3.8 ± 0.7
228777	8506282	151	GM2	0.15 ± 0.01	15 ± 1
228768	8506272	156	GM2	0.15 ± 0.01	8.2 ± 0.7
228767	8506261	133	GM2	0.13 ± 0.01	9.3 ± 0.9
228762	8506248	136	GM2	0.13 ± 0.01	44 ± 1
228746	8506260	145	GM2	0.14 ± 0.01	26 ± 1
228744	8506272	132	GM2	0.13 ± 0.01	4.8 ± 0.7
228752	8506283	137	GM2	0.13 ± 0.01	8.5 ± 0.9
228752	8506292	122	GM2	0.12 ± 0.01	6.3 ± 0.8
228876	8506240	129	GM2	0.13 ± 0.01	1.7 ± 0.7
228871	8506226	118	GM2	0.12 ± 0.01	2.7 ± 0.7
228857	8506253	110	GM2	0.11 ± 0.01	1.2 ± 0.7
228847	8506244	122	GM2	0.12 ± 0.01	3.5 ± 0.6
228847	8506229	132	GM2	0.13 ± 0.01	2.0 ± 0.5
228841	8506215	122	GM2	0.12 ± 0.01	220 ± 3
228820	8506227	122	GM2	0.12 ± 0.01	14 ± 1
228831	8506242	120	GM2	0.12 ± 0.01	1.4 ± 0.6
228832	8506252	110	GM2	0.11 ± 0.01	0.2 ± 0.6
228839	8506258	124	GM2	0.12 ± 0.01	2.0 ± 0.6
228827	8506265	151	GM2	0.15 ± 0.01	3.8 ± 0.6
228817	8506253	119	GM2	0.12 ± 0.01	8.6 ± 0.9
228816	8506241	122	GM2	0.12 ± 0.01	5.6 ± 0.8
228814	8506228	134	GM2	0.13 ± 0.01	140 ± 2
228808	8506226	135	GM2	0.13 ± 0.01	8.8 ± 0.7
228810	8506268	116	GM2	0.11 ± 0.01	2.6 ± 0.6
228801	8506263	147	GM2	0.14 ± 0.01	15 ± 1

Table A1 (continued)

Easting	Northing	Gamma counts	Gamma meter	Dose rate	Radon-222
Off containment					
228947	8506248	96	GM3	0.10 ± 0.01	9.7 ± 0.9
228924	8506191	138	GM3	0.15 ± 0.01	8.1 ± 0.9
228765	8506307	124	GM3	0.13 ± 0.01	11 ± 1
228696	8506335	141	GM3	0.15 ± 0.01	20 ± 1
228675	8506280	97	GM3	0.10 ± 0.01	20 ± 1
228656	8506229	109	GM3	0.11 ± 0.01	12 ± 1
228736	8506184	115	GM3	0.12 ± 0.01	10 ± 1
228842	8506152	110	GM3	0.12 ± 0.01	9.4 ± 0.9
228904	8506129	97	GM3	0.10 ± 0.01	10 ± 1
228892	8506271	136	GM3	0.14 ± 0.01	10 ± 1
Outside fence					
228651	8506175	124	GM3	0.13 ± 0.01	9.5 ± 0.9
228698	8506175	133	GM3	0.14 ± 0.01	6.5 ± 0.8
228774	8506149	82	GM3	0.09 ± 0.01	1.1 ± 0.7
228838	8506123	82	GM3	0.09 ± 0.01	2.5 ± 0.7
228897	8506098	109	GM3	0.11 ± 0.01	9.3 ± 0.9