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11 NELSON PARADE HUNTERS HILL, NEW SOUTH WALES

RADIATION ASSESSMENT (PRELIMINARY FINDINGS)

May 2008

Document Record

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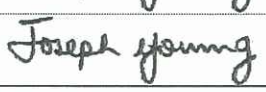
Approved by	Dr. J. G. Young		19/6/08

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1.0 Introduction

The study site is located at 11 Nelson Parade, Hunters Hill (Woolwich) and is an unoccupied residence with a rear garden that faces onto Sydney Harbour. The adjacent block of land to the east is known to have been contaminated by radioactive residues from the processing of uranium ore for extraction of radium by the Radium Hill Company between 1911 and 1916. In recent years there have been several studies of the radioactive contamination of the land.

Australian Radiation Services Pty. Ltd. (ARS) was requested by Environmental Resources Management Australia Pty. Ltd. (ERM) to conduct a preliminary investigation of the current state of the radioactive contamination on the block at the rear of the house, and if contamination was found determine its activity concentration. The total survey area is hereafter referred to as the 'Site'.

This report presents the results of a qualitative external gamma radiation survey performed at the Site and provides preliminary data on the analysis of soil samples collected from the site and a nearby 'background' location for key radionuclides.

The data presented is intended to provide a preliminary indication of the radiation levels identified on the Site and are by no means an exhaustive characterisation of the radioactive contamination present.

2.0 Basic radiation issues

2.1 Radiation and radioactivity

Although many elements or isotopes of elements are stable, some are not. Unstable isotopes transform themselves into a more stable nuclear state by losing energy in the form of ionising radiation. Various types of radiation can be emitted in the spontaneous transformation of the nucleus of an atom. This transformation is called radioactivity. The process of radioactive decay can result in the emission of gamma radiation or beta or alpha particles. Generally, radioactive materials found in the environment will emit one or other of these forms of radiation.

Alpha radiation is a particle in the form of a positively charged helium nucleus. It is a relatively massive particle but only has a short range in air (1 - 2 cm) and can be absorbed completely by paper or skin. Alpha particles can be a significant internal radiation hazard if radionuclides that emit these particles enter the body by inhalation or ingestion and which may lead to significant internal exposures to tissue, such as the lining of the stomach or the lung.

Beta radiation is also particulate in the form of an electron. They are much smaller than alpha particles, are negatively charged, and can penetrate further into materials or tissues. Beta radiation can be completely absorbed by sheets of plastic, glass or metal. They do not normally penetrate beyond the top layer of skin, and the main hazard is from the inhalation or ingestion of beta-emitting materials. Beta-emitting radionuclides are a minor external hazard in most situations.

Gamma radiation is a very high-energy form of electromagnetic radiation like light and is often emitted at the same time as a beta particle. Gamma radiation is very penetrating and only a substantial thickness of dense materials such as steel, lead or tungsten can produce effective shielding. Gamma radiation can therefore produce significant doses to internal organs without inhalation or ingestion and therefore can be a major external radiation hazard.

There are other forms of radiation, such as X-rays and neutrons, that have similar properties to the types described above and can cause similar biological effects. However, these types of radiation are usually emitted by radiation apparatus or sources used in medical or industrial applications.

2.2 Radiation quantities

The rate at which nuclear transformations occur in a radioactive material is termed activity and this is used as a measure of the amount of a radioactive isotope, or radionuclide, that is present. The unit for activity is the becquerel (Bq) and one Bq is equivalent to one nuclear transformation per second. It is common practice to express the concentration of a radionuclide in a radioactive material as either becquerel per gram or kilogram for solids, becquerel per litre for liquids, and becquerel per cubic metre for air or other gases.

When radiation passes through matter it deposits some or all its energy in the material concerned. The amount of energy deposited per unit mass of the material is called absorbed dose and is expressed in a quantity termed the gray (Gy), where 1 Gy equals 1 joule per kilogram. Absorbed dose rate 'free-in-air' ($\mu Gy \cdot h^{-1}$) is a field quantity used in environmental monitoring.

Since the different types of ionising radiation interact differently with biological matter and do not have equal biological effects for the same amount of energy deposited in an organ or tissue, another quantity is used to compare the relative harmful effects of radiation on the human body. This quantity is termed the equivalent dose and is expressed in sievert (Sv).

To take into account the different radiosensitivities of different organs and tissues in the body and to assess the overall detriment to the body, radiation doses are expressed as an effective dose, which is the sum of the equivalent doses to individual organs or tissues. The levels of dose to humans arising from environmental or occupational exposures are usually expressed as a fraction of a sievert, namely micro- or milli-sievert (µSv or mSv).

2.3 Natural radiation

Humans are exposed to natural radiation to a greater, or lesser extent, from a number of sources – for example, cosmic radiation from outer space; the presence of uranium, thorium and potassium-40 (^{40}K) in the Earth's crust; and radon gas released from the decay of uranium.

The total average dose to an individual from natural radiation is about 2.4 mSv per year (IAEA 2004A), but varies widely throughout the world depending on altitude at which people live, the local geology, the type of housing lived in, and the food consumed. In some countries the average dose from natural background is in excess of 10 mSv per year. Due to the local geology and our mode of living, average doses in Australia are generally below the worldwide average and closer to 1.7 mSv per year.

Uranium and thorium are dispersed throughout rocks and soils in low concentrations of a few parts per million (ppm). Naturally-occurring uranium-238 and thorium-232 are parents of separate long-lived series of radionuclides of several elements, which decay in succession until stable lead is formed. In addition, radioactive potassium, ^{40}K, is present with stable potassium, which is a common element in the Earth's crust. A number of radionuclides in both natural decay series emit gamma radiation, as does ^{40}K, and this leads to external and internal irradiation of people. The incorporation of these elements into building materials also leads to exposure indoors. Radioactive elements of the uranium and thorium natural series also can be incorporated into food and drinking water, which results in internal exposures to radiation from the consumption of foodstuffs.

Radon and thoron gas are a particularly significant source of exposure to natural radiation, especially radon (^{222}Rn) from the decay of ^{226}Ra from the ^{238}U series. Build-up of radon gas inside houses can lead to an accumulation of radon indoors if a dwelling is not well ventilated. Exposure to radon gas can contribute to more than half the overall dose to individuals from natural sources.

Uranium and thorium are present in some minerals and ores at higher concentrations than are found in soil, but not necessarily at levels that could be exploited for the elements themselves. The processing of these ores can lead to additional radiation exposure of workers and the public during operations or from management of waste materials.

Enhanced levels of natural occurring radionuclides can also occur as a result of the processing of resources such as coal or by the production of oil and gas, where the radionuclides present in the raw materials may be concentrated in various product or waste streams. The management of waste or residues containing naturally occurring radioactive materials, or NORM as it is termed, can also lead to increased exposures of people.

3.0 Scope of the Radiation Assessment

The main purpose of the survey was to determine whether radiation levels on the site were typical of those in the local area and consistent with natural background radiation. The following aspects have been covered within this study:

(i) Characterisation of the external radiation dose rates arising from gamma ray emitting radionuclides on site, by means of a preliminary radiation survey conducted by ARS.

(ii) Characterisation of the radionuclide content of a selection of soil samples collected to a maximum depth of 0.9 m by conducting gamma ray spectrometry.

(iii) Discussion of the results and comparison with local radionuclide concentrations and radiation levels normally expected as a result of natural background radiation.

(iv) Estimation of the external component of the annual effective dose to an individual.

This report only examines the external radiation dose rates from gamma radiation and determines the activity concentration of selected soil samples. In addition to external gamma radiation doses, persons living at the property are likely to be also exposed to additional radiation from the inhalation of radon gas and the inhalation and ingestion of soil material. This report does not attempt to quantify the doses from these additional potential pathways.

4.0 Methodology and Results

4.1 External gamma radiation on the Site

A survey of the ambient external gamma radiation dose rates was conducted across the rear garden area of the Site. The survey was conducted by taking radiation dose rate measurements at regular distances on a grid pattern (approximately 3 metre by 3 metre) over accessible areas at the rear of the site. A total of 128 external gamma radiation measurements were collected at 27 locations (see Figure 1).

Individual dose rate measurements were performed using an Exploranium GR-130 mini-spectrometer (serial number: 9940, calibrated: 27/7/2007) at a height of approximately one metre above the ground. Each mini-spectrometer contains a NaI detector calibrated to measure dose rates up to approximately 50 $\mu S \cdot h^{-1}$ and an energy compensated GM detector for measuring greater dose rates. At least three readings were taken and averaged with the mini-spectrometer at each location.

In order to obtain absolute absorbed dose rates free-in-air ($nGy \cdot h^{-1}$) a Mini Instruments Ltd. Model 6-80 / MC-71 Environmental Radiation Meter (serial number: 01065, calibrated: 7/4/2008) was used to perform dose measurements at several points in conjunction with the GR-130 mini-spectrometer measurements. The MC-71 energy compensated GM detector was positioned on a stand approximately 1 metre off the ground and the dose rate incident on the detector allowed to integrate on the Model 6-80 Meter for a period of approximately 70 minutes. The Mini 6-80 / MC-71 Meter measurements were used to normalise all GR-130 measurements to give true measures of the absolute absorbed dose rates free-in-air. The results of the external gamma radiation dose rate survey are presented in Table 1.

Figure 1: Approximate survey locations for the rear garden area at 11 Nelson Parade, Hunters Hill, NSW – April 2008.

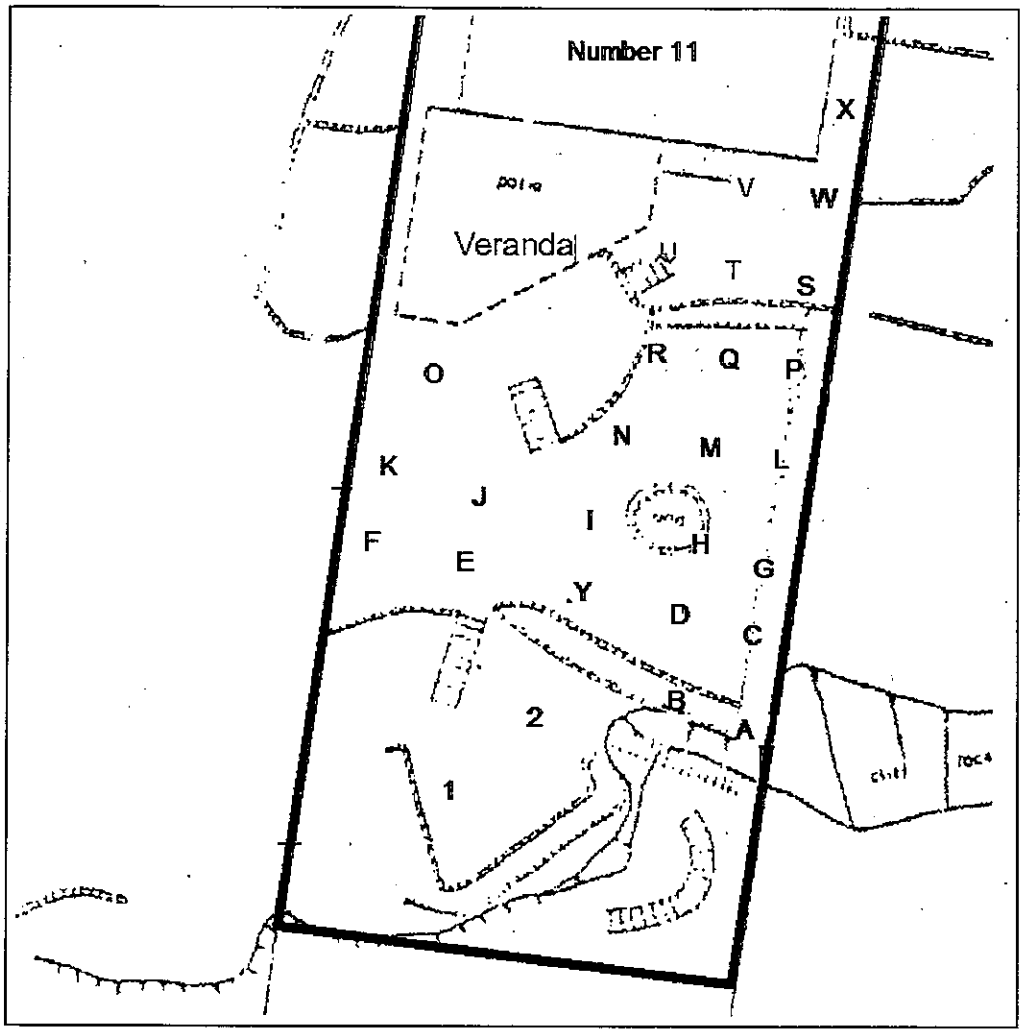

Table 1: Normalised absorbed dose rate free-in-air ($\mu Gy \cdot h^{-1}$) survey data for the rear garden area at 11 Nelson Parade, Hunters Hill, NSW – April 2008.

Location	Normalised Absorbed Dose Rate free-in-air* ($\mu Gy \cdot h^{-1}$)
1	0.21
2	0.22
A	0.40
B	0.25
C	0.96
D	0.56
E	0.48
F	0.30
G	1.19
H	0.40
I	0.36
J	0.27
K	0.34
L	1.12
M	0.36
N	0.28
O	0.27
P	1.26
Q	0.25
R	0.22
S	0.65
T	0.30
U	0.23
V	0.24
W	0.86
X	1.61
Y	0.57

* Results are not corrected for ambient background radiation.

The average external gamma radiation dose rate across the site was 0.52 $\mu Gy \cdot h^{-1}$, with a range of ~0.21 to ~1.61 $\mu Gy \cdot h^{-1}$ for the grid location measurements. Of particular interest from the survey was that the measurement locations where the highest dose rates were identified as being beside the eastern boundary of the site (ARS grid reference: A, C, G, L, P, S, W and X).

4.2 External gamma radiation levels off-site

External gamma radiation levels were assessed at a location off-Site to provide an estimate of what the background radiation levels would be in the local area, without any influence from those sites once used by the Radium Hill Company.

A nearby recreational area known as 'Kellys Bush' containing dense natural bush-land area and walking tracks was identified as a suitable background location. . The area was at least 200 metres from the Nelson Parade residential properties used by the Radium Hill Company. Measurements were conducted at a location chosen at random within the bushland. The surface soil appeared to be representative of the natural environmental surrounding.

A methodology identical to that discussed in Section 4.1 was adopted using the GR-130 mini-spectrometer and Mini Instruments Ltd. Model 6-80 / MC-71 Environmental Radiation Meter. Time restraints meant that the measurements were limited to a 12-minute integration.

The measured absorbed dose rate free-in-air was 0.12 ± 0.01 $\mu Gy \cdot h^{-1}$.

The radiation levels measured are consistent with normal background dose rates, and are comparable with the median radiation levels in Australia of 0.093 $\mu Gy \cdot h^{-1}$ (UNSCEAR 2000).

4.3 Radionuclide content of soil

Soils samples were collected from the Site from hand augered boreholes and surface samples. Sample locations chosen by ERM were predominantly along the eastern boundary, where the highest ambient dose equivalent rates had been identified by ARS. Of the samples collected, six (6) were chosen for analysis, namely at positions HA2, HA3, HA4 and HA5 (see Table 2). These samples were chosen, primarily to identify and quantify those radionuclides in the soil giving rise to the elevated gamma radiation dose rates approximately 1 m above the surface. Samples collected originated from the ground surface and sub-surface up to a maximum depth of 0.9 m.

One soil sample was collected from Kellys Bush location where background radiation measurements were conducted.

Each sample was prepared for analysis by drying, grinding and homogenising. A portion of each sample was transferred to a standard plastic container and analysed by high-resolution gamma ray spectrometry at the ARS Laboratory.

In addition to the samples analysed at ARS, three (3) duplicate samples were sent to a second laboratory for analysis (National Radiation Laboratory, New Zealand which is NATA accredited), as a quality control measure.

The analysis results of all samples is provided in Table 2.

Table 2: Radionuclide content ($Bq \cdot kg^{-1}$) of surface soil from the Site and Kellys Bush – April 2008.

Soil Sample Location (depth in metre)	Radionuclide Activity (becquerel per kilogram dry weight)[a,b,c]						
		uranium (^{238}U) series				thorium (^{232}Th) series	
	K-40	U-238 (as Th-234)	Th-230	Ra-226	Pb-210	Ra-228	Th-228
Kellys Bush	85 ± 8	24 ± 8	-	23 ± 2	45 ± 9	43 ± 3	44 ± 3
Kellys Bush[d]	5.8 ± 2	16.8 ± 5.6	-	25.5 + 2.1	41.3 ± 5.5	50.8 ± 3.8	52.0 ± 5.6
HA2 (0.2 - 0.6)	< 50	2400 ± 200	5200 ± 800	2100 ± 100	1800 ± 100	130 ± 20	110 ± 10
HA3 (0 – 0.1)	140 ± 50	1600 ± 120	3600 ± 990	1650 ± 80	1250 ± 100	90 ± 30	82 ± 10
HA3 (0 – 0.1)[d]	100 ± 17	1260 ± 370	-	1778 ± 91	1141 ± 90	99.9 ± 7.6	102 ± 15
HA4 (0.3 – 0.4)	< 140	2400 ± 200	5100 ± 1700	2800 ± 200	1900 ± 200	120 ± 40	100 ± 20
HA4 (0.7)	< 130	2300 ± 200	4700 ± 1500	1800 ± 100	1500 ± 200	140 ± 30	120 ± 10
HA4 (0.9)	< 90	7500 ± 300	9200 ± 1300	2900 ± 200	2100 ± 200	210 ± 40	180 ± 20
HA4 (0.9)[d]	107 ± 21	6100 ± 1800	-	3210 ± 170	1850 ± 150	212 ± 15	232 ± 18
HA5 (0 - 0.1)	< 170	1300 ± 300	7600 ± 2100	9000 ± 400	7800 ± 400	190 ± 40	140 ± 20

Note:
a. Activities are in becquerel (Bq) per kilogram dry weight. One becquerel equals one nuclear transformation per second.
b. Less than (<) values indicate the limit of detection for each radionuclide for the measurement system.
c.. The reported uncertainty in each result is the expanded uncertainty calculated using a coverage factor of 2.
d. Results of duplicates samples sent to the NATA accredited National Radiation Laboratory of New Zealand for an independent analysis.

The soil analysis indicates that radionuclide concentrations of the soil sample collected at 'Kellys Bush' are consistent with the range of typical concentrations found in soil worldwide of 16 - 110 $Bq \cdot kg^{-1}$ for U-238 and 17-60 $Bq \cdot kg^{-1}$ for Ra-226 (UNSCEAR 2000).

In the "control" sample taken at the Kellys Bush location, the concentrations of the long-lived radionuclides of the respective uranium and thorium series are in radioactive equilibrium, with the exception of lead-210, which is slightly elevated due to washout of this radionuclide present naturally in the atmosphere. Also, in uncontaminated soil, it is common to find a slightly higher thorium-232 content compared to that of uranium-238 (UNSCEAR 2000). The results for the Kellys Bush sample confirm this.

The analytical results for samples collected on the Site indicate the presence of significantly elevated levels of long-lived lived radionuclides of the uranium-238 series. This would be consistent with contamination from the residues of uranium ore processing to extract radium, as was historically undertaken in adjacent areas. Levels in soil from the Site are consistently higher than radionuclide concentrations from a sample collected from Kellys Bush, and the global average for uranium-238 and decay products in soil.

Results also indicate that the elevated levels were not limited to surface soil samples and were identified in samples collected at depth, in this study to a maximum of 0.9 metres (sample 'HA4 (0.9)').

The radioactive concentrations of uranium-238, thorium-230 and radium-226 in some of the soil samples from the Site demonstrate a significant degree of disequilibria between these radionuclides, which is evidence that their origin is more likely associated with tailings from the processing of uranium than being a natural occurrence. For example, in sample HA4 (0.9) the U-238, Th-230 and Ra-226 concentrations are 7000, 9200 and 2900 $Bq \cdot kg^{-1}$, respectively, whereas in sample HA5 (0-0.1), the values are 1300, 7600 and 9000 $Bq \cdot kg^{-1}$, respectively.

Results of samples sent to NRL for analysis are in good agreement with the results of samples analysed at the ARS laboratory.

5.0 Discussion

5.1 External gamma radiation exposure

Radiation measurements conducted at the site have indicated that average surface dose rates on the Site arising from external gamma radiation (0.52 $\mu Gy \cdot h^{-1}$) are a factor of approximately four (4) times greater than background levels measured at the nearby Kellys Bush (0.12 $\mu Gy \cdot h^{-1}$). The highest levels were identified at locations closest to the adjacent lot, number 9 Nelson Parade.

ARS were instructed that the NSW Department of Health has proposed to remediate the soil contamination on No. 7 and No. 9 Nelson Parade to ensure background levels of contamination are no higher than 0.35 $\mu Gy \cdot h^{-1}$ on those sites (GHD, 2002). Radiation measurements conducted by ARS indicate that absorbed dose rates recorded at 14 of the 27 locations on the Site at No. 11 are greater than 0.35 $\mu Gy \cdot h^{-1}$.

Based on the range of absorbed dose rates measured "free-in-air" of 0.21 to 1.61 $\mu Gy \cdot h^{-1}$ an effective dose from external gamma radiation as a result of the contribution from contamination on the site can be estimated. If we consider natural background levels, as identified at Kellys Bush of 0.12 $\mu Gy \cdot h^{-1}$, this equates to an absorbed dose rate above natural background radiation level for the area of 0.09 – 1.49 $\mu Gy \cdot h^{-1}$ for the Site (i.e. outside area).

Measurements within the house erected on No.11 were conducted by ANSTO in 2008 under the direction of NSW Health and NSW DECC (ANSTO, 2008). The average of 'radiation dose rates' recorded inside the building were approximately 0.30 $\mu Sv \cdot h^{-1}$. Under the assumption reported values are 'ambient dose equivalent rates', this equates to an average absorbed dose rate of approximately 0.25 $\mu Gy \cdot h^{-1}$, or if corrected for background levels measured by ARS at Kellys Bush, approximately 0.13 $\mu Gy \cdot h^{-1}$.

For estimating effective doses from exposure to sources of natural radiation inside or outside buildings a conversion factor of 0.7 $Sv \cdot Gy^{-1}$ should be used (UNSCEAR, 2000). Additionally, considerations need to be given to expected occupancy of residents inside and outside the house. Standard practice is to assume an 0.8 indoor and 0.2 outdoor ratio (UNSCEAR, 2000).

Considering the absorbed dose rates measured by ARS, and those reported inside the house by ANSTO, and assumed UNSCEAR occupancy factors, the calculated annual effective dose to an individual is in the

range 0.7 – 2.5 mSv (above background) as a result of external gamma ray exposure from the sources of contamination on the site.

5.2 Internal radiation exposure

In any dose assessment, consideration must be given to an individuals internal dose component which may be significant. Exposure to dust may result in the inhalation of airborne radionuclide's associated with the dust, which would lead to an internal exposure. Significant levels of dust will arise as a result of activities that involve the disturbance of the surface soil, and if dry windy conditions prevail. Additionally an internal dose is possible by ingestion if there is the transfer of material to the mouth, or it is passed into the blood stream though cuts or abrasions in the skin, or to a lesser extent by absorption through the skin layer. An individual's internal dose will depend on activity concentrations of radionuclide's present, among other factors.

The analysis of soil samples from the Site clearly indicated the presence of significantly elevated concentrations of radionuclide's in the soils (see Table 2). It was noted that some results are very high, in particular radium-226 concentrations for sample HA5 (0-0.1) which were a factor approximately 400 times greater than those in a sample collected from Kellys Bush.

At this stage, there is insufficient radionuclide concentration data to calculate the internal contribution to the total effective dose an individual would be likely to receive as result of the radionuclide's present on Site. As the data from this study demonstrate, there is significant disequilibria between uranium series radionuclide's and direct dose assessment is not possible without considerations of the radionuclide distributions present. Future use of the land (i.e. swimming pool excavation, vegetables grown in a garden) also needs to be considered.

5.3 Other considerations

Radon emanation from surface soils should also be considered. The release of radon is dependent on a number of site-specific factors apart from the radium content and chemical and physical characteristics of the soil. The condition of the surface is important, for example uncovered or covered, wet or dry etc. Also site specific dispersion meteorological conditions such as the prevailing wind directions and speeds, incidence and duration of inversions, are also important factors. The contamination of groundwater and its impact on the site may need to be considered.

Consideration needs to also be given to the fact that surface soils may be removed in the future, unearthing underlying soils, which may have a different radionuclide content to surface soils. Without an accurate profile of the extent of the contamination below the surface an accurate dose assessment cannot be made. The limited samples collected at depth however, do indicate the presence of elevated radionuclide concentrations below the soil surface.

Other considerations include the impact of highly contaminated soils supposedly present on the neighbouring block No. 9. (EGIS 1999). Major disturbance of this land in any future development, or its proposed use (i.e. if it was to be stripped of vegetation yet remain unsealed) could impact on doses to personnel residing at the No. 11 property.

5.4 Annual dose limits

The national effective dose limit for members of public from all sources of radiation excluding occupational and medical exposures is 1 mSv per annum, above contributions from natural background radiation (ARPANSA 2002). This limit includes the contribution from internal and external radiation exposure.

This annual limit however, applies to exposure to a member of the public as a result of 'existing' radiation practices. In instances where exposure and exposure pathways are already present due to previous practices, the process of 'intervention' is the only action available (ARPANSA, 2002), and the 1 mSv limit should not be applied directly. This Site is one such site where intervention applies. Justification (the interventions action should do more good than harm) and optimisation (net benefit to be maximised) of the remediation process needs to be considered. The '1 mSv limit' should be used as guideline in the justification process and the extent of remediation that should be carried out.

The concept of 'lasting exposure' is discussed elsewhere (HPA 2006) which considers the potential for long-term exposure to members of the public as a result of land contamination, and may be applicable for this residence, and assist in determining the appropriateness of the '1 mSv limit'.

6.0 Conclusions

- An assessment has been made of both ambient external gamma radiation dose rates and of the radionuclide content of soils on the study Site.
- The absorbed dose rate "free-in-air" from external gamma radiation at 14 of the 27 measurement locations exceeded 0.35 $\mu Gy \cdot h^{-1}$. This is the criteria adopted by the NSW Department of Health for the cleanup of No. 7 and No. 9 Nelson Parade (GHD,2002).
- The majority of soil samples taken and analysed indicate activity concentrations significantly greater than those levels normally encountered in soils. Radionuclide's and associated concentrations were consistent with waste from the processing of uranium ore and were similar to that detected on adjacent sites (as reported in EGIS,1999).
- The effective dose to an individual residing on the site may be within the range 0.7 – 2.5 mSv (above background) as a result of contamination on No.11, from external gamma ray exposure alone.
- This report has not assessed the additional exposure that may be incurred by inhalation of radon gas or from ingestion or inhalation of soil material from the disturbance of surface soils.
- Even without the additional data, the evidence suggests the site is unfit for long-term human habitation without remediation.

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