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Radiation Consultancy & Training Services

Health Physics Report on

Radiological Survey of Nelson Parade, Hunters Hill - Stages 1 and 2

For NSW Dept Health and NSW DECC

8th June 2009

By Robert Blackley
Radiation Consultancy & Training Services
External Radiation Services
Australian Nuclear Science & Technology Organisation

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1 Executive Summary

In November and December 2008 and in March 2009, the Australian Nuclear Science & Technology Organisation (ANSTO) carried out two stages of a comprehensive radiological survey of Nelson Parade and surrounding areas in Hunters Hill, NSW. This report assesses the spatial extent of radiological contamination in Nelson Parade and surrounding areas and provides the basis for estimating the potential exposure to members of the public.

For the majority of sites surveyed, levels were found to be consistent with natural background. Elevated levels of radioactivity were measured in the areas immediately adjacent to the site of the former radium extraction plant in Nelson Parade. Elevated levels of radioactivity were also detected from the surface of numerous roads in the area, including Nelson Parade, as a result of the historical use of waste slag from the former Tin Smelter located at Kelly's Bush in the preparation of the road base.

This report details the areas surveyed, the potential exposure levels arising from external gamma radiation and, where it has been possible to quantify, the internal exposure from inhalation of radioactive dusts and the ingestion of particles and foodstuffs. Radon levels inside residential buildings were measured, with all results being below the recommended action levels for potential remediation. Core samples of soil were also taken at areas of elevated radioactivity to determine a depth profile of the contamination.

From the results of the survey and dose estimates, there is not sufficient justification for the remediation of the sites covered by the survey on radiological safety grounds. However, this conclusion does not consider non-radiological and social impacts.

2 Introduction

In the early part of last century, the Radium Hill Company established a processing works in the area of Nelson Parade at Hunters Hill in NSW for the purposes of extracting radium from uranium-bearing ore for medical and other uses. The uranium came from Radium Hill in South Australia and was shipped to the site in Hunters Hill. The Radium Hill Company went bankrupt and the plant was closed in June 1915, leaving some residual materials. When the potential hazards from these residual materials were recognised in the 1950's, the soil and associated material was relocated to one area, predominately the current Lots 7 and 9 on Nelson Parade. Over the years there have been a number of studies undertaken on the extent of the contaminated areas, consequent potential risks to members of the public and recommendations made on the potential remediation of Lots 7 and 9.

In addition to the radium extraction plant, from 1895 until 1966 a tin smelter operated on what is now Kelly's Bush Reserve, which borders Nelson Parade. The smelter processed tin ore that contained uranium-bearing and thorium-bearing monazite minerals[1]. Low levels of these contaminants remained in the resultant tin slag produced by the smelter.

In 2007, NSW Health commenced a community consultation program with local residents in relation to its development of a remediation strategy. In 2008 a Parliamentary Inquiry was held into the former radium extraction site at Hunters Hill[2]. The report of the Inquiry concluded that the need to remediate part of the area was not in dispute. However, the extent of the area requiring remediation was still unclear, and the report called for an "extensive retesting of the entire area to engender public confidence and to ensure that all areas of contamination are included in any remediation activities." Following the report, the NSW Department of Health engaged the Australian Nuclear Science and Technology Organisation (ANSTO) to carry out a more extensive radiological survey and characterisation of Nelson Parade, Hunters Hill.

After consultation between the NSW Department of Health, the NSW Department of Environment and Climate Change (DECC) and ANSTO, it was agreed that a staged approach would be employed. The first stage was designed to identify areas of elevated contamination and dose rate levels, provide some characterisation of the nature of the radiological contamination and provide an assessment of potential exposure, where possible. The second stage was designed to provide a detailed characterisation of the radiological contamination at identified locations and to assess radon levels inside dwellings.

As the Lots 5, 7, 9 and 11 on Nelson Parade have been assessed in previous studies[3, 4, 5], these lots were not included in this radiological survey.

This report details the areas surveyed in this first and second stages of the radiological assessment and includes the gamma radiation levels measured, analysis of the radiological

[1] Mudd, G M, 'The legacy of early uranium efforts in Australia 1906 to 1945: From Radium Hill to the atomic bomb and today.' *Historical Records of Australian Science*, 2005, 16 (2), pp174

[2] Report on Former uranium smelter site at Hunter's Hill: New South Wales Parliament, Legislative Council General Purpose Standing Committee No.5, Report No.28 of 2008

[3] Australian Radiation Services, 'Radiation Assessment (preliminary findings): 11 Nelson Parade, Hunter's Hill , NSW', May 2008

[4] ANSTO, 'Radiological survey of specific properties between blocks 3 to 11 on Nelson Parade Hunters Hill and the roadway from No's 11 to 19', prepared on behalf of NSW Health, March 2008.

[5] Egis Consulting, 'Environmental management Plan for Site Investigations, Nos 7 and 9 Nelson Parade Hunters Hill', prepared on behalf of NSW Department of Health, July 1999.

characteristics in the areas in comparison to natural background radiation, radon levels measured and potential dose estimates, where possible.

3 Basic Radiological Issues

3.1 Radiation Basics

Most elements consist of a number of different isotopes. Some of these isotopes are stable; however, some isotopes are not and transform into a more stable nuclear state by losing energy in the form of ionising radiation. In some cases, the newly formed nuclides are also unstable and decay into other isotopes. This process continues until the final decay product is stable. Various types of ionising radiation can be emitted in the transformation of the nucleus of an atom. Predominately the emissions are in the form of gamma radiation or beta or alpha particles. This transformation is called radioactivity.

The rate at which a radionuclide decays is different for each isotope and is expressed as its ‘half-life’. In a decay chain, each isotope will have a different half-life.

Alpha radiation is a particle and is identical to the positively charged nucleus of a helium atom, consisting of two protons and two neutrons. This alpha particle is a relatively large particle which only has a short range in air and poses more of an internal radiation hazard than an external radiation hazard.

Beta radiation is a particle in the form of an electron, whose range in air is dependent upon its energy. It is a smaller particle than an alpha particle. It can pose an external skin dose hazard and an internal hazard.

Gamma radiation is in the form of electromagnetic radiation whose range in air, although dependent upon its energy, is longer than alpha or beta radiation. Gamma radiation poses an external radiation hazard.

There are other types of ionising radiation, such as X-rays and neutrons; however, these types of radiation are usually emitted by radiation apparatus or sources used in industrial or medical applications. They are not relevant to this survey.

3.2 Radiation Terms and Units

The unit used to quantify radioactivity is the *Becquerel* (Bq), with one Bq being equivalent to one nuclear transformation per second. It does not indicate what type of radiation has been emitted or what its effects might be. The non-SI unit for radioactivity is the Curie (1Ci = 3.7×10^{10} Bq).

When radiation passes through matter, it deposits some of its energy in material in the body. The amount of energy deposited per unit mass of the material in the body is called the *absorbed dose* and is measured in the unit *Gray* (Gy), where 1 Gy = 1 J/kg of the material.

The different types of radiation will cause differing amounts of biological damage. Therefore the energy deposited in material in the body, the *absorbed dose*, is multiplied by a radiation weighting factor to determine the *equivalent dose*. The equivalent dose is measured in Sieverts (Sv) and is a measure of the biological affect of the absorbed dose from different types of radiation. Sieverts are relatively large units and so fractions of a Sievert are commonly referred to, predominately micro-sieverts (μSv) or milli-sieverts (mSv).

<u>Note:</u> 1 Sv = 1000 mSv = 1000000 μSv.

<u>Note:</u> 1E-3 mSv = 1×10^{-3} mSv = 0.001 mSv = 1 μSv

To account for the different radiosensitivities of different organs and tissues within the body, the equivalent dose to a particular organ or tissue can be multiplied by a tissue weighting factor to give a measure of the overall affect of the radiation exposure. This is known as the *effective dose* and also measured in the units of Sieverts (Sv).

Committed Effective Dose (CED) is the effective dose which an individual will receive from an intake of loose radioactive material into their body.

3.3 Exposure Pathways

Human tissue can be exposed to radiation via four main pathways.

- Exposure from external radiation is from radiation sources external to our bodies which penetrates our skin and deposits energy in our organs and tissues.
- Another exposure pathway is via inhalation of gases such as radon or airborne particulates into the lungs, which may remain in the lungs or be absorbed into the bloodstream, depending upon its particular physical and chemical properties.
- Radioactive material can also be ingested via the mouth, where it will either be absorbed into the bloodstream and distributed around the body, or passed through the gut and be excreted if insoluble.
- The fourth main exposure pathway is the entry of radionuclides into the bloodstream through cuts and abrasions in the skin or in some cases through absorption through the skin.

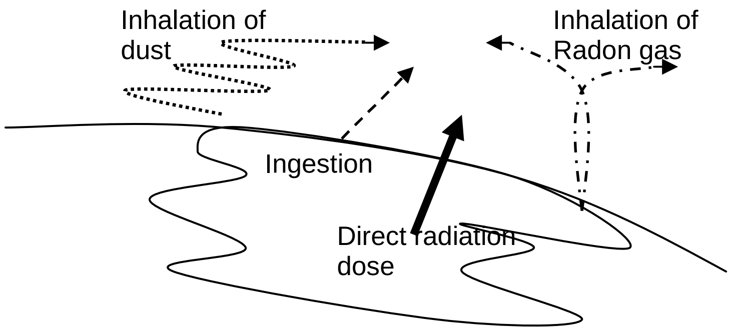

Figure 1 - Simple conceptual model of potential exposure pathways in the immediate vicinity of radioactively contaminated land.

The exposure via these pathways is highly dependent upon the chemical and physical properties of the radionuclides, and the concentrations of the radionuclides in the environment.

3.4 Natural Background Radiation

Everybody is exposed to ionising radiation every day, from a variety of natural radiation sources. These include cosmic radiation from outer space, potassium-40 inside our bodies, the presence of uranium, thorium and potassium-40 in the earth's crust and subsequent incorporation into food, water and building materials, and radon gas released during the decay of uranium and thorium.

The global average total dose to an individual is approximately 2.4mSv[6] per year. However, this varies considerably depending upon factors such as local geology, altitude, the material that houses are built out of and the food consumed. Typical doses in Australia are somewhat lower; around 1.5 mSv per year.

Uranium, Thorium and isotopes from their associated decay chains are present in low concentrations in rocks and soils. Typically they average about 3 parts per million (ppm) Uranium and 10 ppm Thorium in ordinary soil, and up to 30 ppm or more in some granites. Uranium ores range from 0.03% (300 ppm) up to a few percent (> 10,000 ppm) in the richest international uranium ore deposits. A number of radionuclides in these natural decay chains emit gamma radiation, which can be an external radiation hazard to people. Radioactive potassium-40 also exists naturally alongside stable potassium isotopes and contributes to external radiation exposure. In addition, potassium-40 exists within our bodies and naturally is a source of internal exposure.

Some radionuclides from the Uranium and Thorium decay series may be incorporated into food and drinking water, which results in internal exposures to radiation.

Radon (^{222}Rn) gas and Thoron (^{220}Rn) gas can be a significant source of exposure through inhalation, and may contribute to more than half of the exposure to individuals from natural sources. The exposure from Radon and Thoron will vary significantly, depending upon the ventilation of the dwelling, the local geology and the weather.

Activities such as the mining of resources containing naturally occurring radiological materials (NORM) or indeed mining the minerals themselves, can lead to additional exposure. Enhanced levels of NORM may also be present at a site as a result of processing this material, such as in the processing which occurred at Nelson Parade, Hunters Hill.

4 Dose Limits and their Application

Dose limits to members of the public are intended to control the risk from exposure to ionising radiation from practices (existing human activities which result in exposure to ionising radiation and to which a current system of radiation protection applies). They do not apply directly when exposure pathways are present due to human activities which occurred in the past. However it may be appropriate to take actions to control public exposure resulting from such activities by the process of *intervention*. Intervention includes any actions which are taken to reduce existing exposures, and, like other methods of exposure control, must be justified (likely to do more good than harm), and optimised to obtain the maximum net benefit.

The planning of intervention may include consideration of dose limits but is not ruled by them. Radiation Protection Series No. 1, ARPANSA 2002 (RPS 1) states that the national effective

[6] UNSCEAR 2000, United Nations Scientific Committee on the Effects of Atomic Radiation, Sources and Effects of Ionising Radiation, 2000

dose limit for members of the public from practices is 1mSv per year, excluding background, occupational and medical exposures[7]. (Note that this limitation also specifies that in special circumstances a higher value of effective dose could be allowed in a single year provided that the average over 5 years does not exceed 1mSv per year.) It should be noted that RPS 1 also states "it is not sufficient merely to ensure that individual doses do not exceed the limits: they should be controlled through optimisation to be as low as reasonably achievable. Conversely, it is not a matter of undue concern for a person's health if, on occasion, that person's dose slightly exceeds the dose limit".

The areas surveyed in Hunters Hill are examples of locations where exposure pathways are present due to human activities that occurred in the past, and as such, it is not appropriate to use the 1mSv per year public dose limit. However it should be considered when intervention is planned.

Before intervention is initiated it should be justified; that is it should be shown that it is likely to do more good than harm. Once justified, the form, scale and duration of the intervention should be optimised to obtain the maximum net benefit. The cost of intervention is not simply a monetary cost. Non-radiological and social impacts also need to be considered.

5 Scope of Radiological Assessment

The main purpose of the radiological surveys was to determine whether the radiation levels on properties, roads and footpaths in Nelson Parade and adjacent areas are typical of those in the local area, and to characterise the radiological properties of any areas of elevated radiation levels. This will form the basis for identifying areas that may require consideration to be given to potential future remediation.

The following tasks have been performed in undertaking this radiological assessment:

- Survey of the external radiation dose rates arising from gamma ray emitting radionuclides on properties, footpaths and roadway on Nelson Parade;
- Characterisation of the relative Uranium, Thorium and Potassium-40 content of soil in the above areas;
- Measurement of the levels of radon gas inside selected dwellings;
- Analysis and comparison of the results with local radionuclide concentrations and radiation levels normally expected as a result of natural background radiation; and
- Estimation of the potential annual effective dose to an individual arising from the above.

The physical extent of the radiological survey was determined and adjusted based upon results from Stage 1 of the survey.

The survey area did not include Lots 5, 7, 9 and 11 on Nelson Parade, as these have previously been extensively assessed in other reports[3, 4, 5].

[7] Recommendations limiting exposure to ionising radiation, Radiation Protection Series No.1, ARPANSA, 2002

6 Survey results

6.1 Background Readings

As mentioned previously, background radiation levels vary both locally and globally. To estimate the natural ambient radiation levels in the local area, external gamma radiation levels were taken at a variety of offsite locations. Two background readings were taken at areas adjacent to and representative of the soil of the Nelson Parade site, and four background readings were taken from suburbs near Hunters Hill (Five Dock, Huntley's Cove, Padstow and Ryde).

The methodology adopted was identical to that discussed in Appendix 3 'Survey Methodology', using the same instruments.

The average background dose rate measured was 0.08E-3 ± 0.01E-3 mSv/h.

(Note: 0.08E-3 mSv/h = 0.08 x10^{-3} mSv/h = 0.00008 mSv/h = 0.08 μSv/h)

The average background reading on the E-600 2" NaI detectors was 123 ± 17 cps.

The average background radionuclide concentrations based upon 3 inch sodium iodide (NaI) detector gamma spectrometer system, were:

K-40 (Bq/kg)	U (Bq/kg)	Th (Bq/kg)
118.4	8.1	31.8

6.2 External Gamma Radiation Levels, Nelson Parade

A continuous survey was undertaken of the ambient gamma radiation along all parts of the Nelson Parade roadways and footpaths, using sensitive 2 inch NaI detectors. Based on these results, a detailed survey of the ambient gamma dose rates was conducted at regular intervals along the roadway of Nelson Parade using the methodology described in Appendix 3. These survey locations (Survey Points 1 – 19) are indicated in Appendix 4.

An offer was made by NSW Department of Health to all property owners in Nelson Parade who were contactable, for ANSTO to carry out a survey of the ambient gamma radiation dose rates on each property. These survey point locations are also indicated in Appendix 4 (Survey Points 20 – 55). In addition, 2 inch NaI detectors were also used to provide a continuous survey of the properties and, if requested by the resident/owner, the interior of house was also surveyed. In some cases, based upon the results of the survey of the property exterior to the house, the resident decided that they no longer required the interior of the house to be surveyed.

Generally, the highest dose rates were detected upon the roadway of Nelson Parade. Readings were also elevated on the properties immediately adjacent to the site of the old radium extraction plant (although still below the levels on the roadway).

Both the highest dose rates and the 'average' dose rates measured at each survey site are shown in Appendix 6. These levels have had natural background radiation levels subtracted. The 'average' dose rate at each site in Appendix 6 is based upon both the measured dose rates and relative readings of the continuous survey using sensitive 2 inch NaI detectors.

When estimating the potential contribution to people's annual exposure from external gamma radiation, consideration should be given to the occupancy of areas. The assumed occupancy factor for each survey site is also indicated in the table in Appendix 6. When considering the occupancy of residents inside and outside of their house, standard practice is to assume a 0.8 indoor and 0.2 outdoor ratio[8] (approximately 19 hours indoors and 5 hours outdoors each day). A conservative estimate that people may spend up to 2 hours every day on the roadway has also been adopted.

From the results shown in Appendix 6, the potential contribution from external gamma radiation to a person's total exposure ranged from 0.000mSv up to 0.631mSv per annum. The upper estimations are based upon conservative assumptions about people occupying the areas of the highest dose rates for extended periods of time over the entire year.

A natural variation in ambient gamma dose rates was observed when comparing houses. Part of this was due to the variation in building materials used to construct the houses, variations in floor tiles and in kitchen benches. Measurable natural radioactive materials are commonly incorporated in higher levels in some bricks, tiles and kitchen granite bench tops. These are not related to radiological contamination from the former radium extraction plant. Dose rates of 0.1E-3 mSv/h above background were measured directly from these materials in some houses.

Generally the highest dose rates from the survey area were from the roadway of Nelson Parade. Further investigation from core samples indicated that the radioactive contamination was contained in the road base below the road surface. Analyses of these cores indicate relatively elevated levels of thorium decay products. This is consistent with background information provided in Cardew's study of the Tin Smelter operations[9], which operated in Kelly's Bush. Slag from the former Tim Smelter was used in road construction in the area.

Figure 1 - Partially ground Road base containing slag from the Tin Smelter

Figure 2 - Partially ground Road surface

[8] UNSCEAR 2000, United Nations Scientific Committee on the Effects of Atomic Radiation, Sources and Effects of Ionising Radiation, 2000

[9] A P St E Cardew, Th-232 Contamination from Tin Smelting Operations, Radiation Protection in Australia, 2 (1982)

The contamination is sealed underneath the roadway in the road base and the slag itself is thereby relatively immobilised. Therefore the main contribution to a person's dose from the roadway is from external gamma radiation, with any contribution from internal exposure being minimal. Subsequent monitoring indicates that similar low levels of radioactivity are present in a number of roadways in Hunters Hill and surrounding suburbs[10].

[10] ANSTO, Radiological Survey of Kelly's Bush, Hunters Hill, (2009)

7 Internal Radiation Exposure, Nelson Parade

As discussed, internal radiation exposure can result from a variety of possible pathways. Each internal pathway has been assessed where possible, to determine their contribution to total exposure.

7.1 Ingestion

Internal exposure is possible through ingestion of radioactive material through either transfer of contamination to the gastrointestinal tract via the mouth, or an uptake of radioactive isotopes by plant matter and subsequent ingestion, such as may occur with vegetables grown in contaminated soil.

The survey methodology used provides a suitable indication of the levels of Uranium and Thorium concentrations which are present in the immediate area, shown in Appendix 8. It should be noted that surveys were not carried out at Numbers 5, 7, 9 and 11 Nelson Parade, as discussed in the scope. The results of the survey undertaken can be utilised to estimate the potential uptake of radiological contamination into plant material that may be consumed by people.

The average Uranium and Thorium concentrations above natural background levels, from the 3 inch sodium iodide (NaI) detector gamma spectrometer system, measured in front or backyards (only) on properties on Nelson Parade were 53.4 Bq/kg and 7.8 Bq/kg respectively. The results from the core sampling analysis were not directly used for this assessment as the core sampling was specifically targeting areas of the highest localised activity. The core samples also showed that the contamination was horizontally stratified below the near surface layer of soil. The results from the 3 inch NaI detector gamma spectrometer provided a clearer assessment than the core samples of the near surface contamination across the survey area and a more realistic assessment of potential internal radiation exposure.

Based on the modelling that the soil to plant transfer factor for Uranium and Thorium is 8.3E-3 and 1.8E-3 for leafy green vegetables[11], these average concentrations would equate to an uptake of approximately 0.44 Bq/kg (Uranium) and 0.01 Bq/kg (Thorium) in leafy green vegetables. Although there are a number of factors that affect both the accuracy of the concentrations and the actual uptake of contamination in vegetable matter, this provides an indication of potential concentrations that may be ingested. For example, if a person consumed 50kg of green leafy vegetables a year grown entirely in these areas, this would equate to an uptake of 22 Bq (Uranium) and 0.7 Bq (Thorium), or a Committed Effective Dose of <0.005mSv (Uranium) and <0.005mSv (Thorium).

The maximum Uranium and Thorium concentrations above background levels, measured at the soil surface in front and backyards of properties, were 603.8 Bq/kg and 30.8 Bq/kg respectively. Based on the same assumptions as above, this would equate to an uptake of approximately 5.01 Bq/kg (Uranium) and 0.06 Bq/kg (Thorium) in leafy green vegetables grown in the areas of highest concentrations. Again as an example, if 50kg of green leafy vegetables is consumed a year, grown entirely in these highest activity areas, this would equate to a maximum Committed

[11] Handbook of Parameter Values for the prediction of radionuclide transfer in temperate Environments, IAEA, Vienna, 1994, Table VI.

Effective Dose of 0.011mSv (Uranium) and < 0.005mSv (Thorium)[12]. It should be noted that although higher, if the highest localised concentrations of contamination from the core samples was used in the above calculations, the committed effective dose would only be a magnitude higher than calculated above.

The examples of the consumption of 50kg of green leafy vegetables per year, grown entirely in contaminated soil, is provided as an indicator of the total committed effective dose that a person may receive from this pathway. It was observed at the time of the survey, that although vegetables were being grown in some residences, none were being grown in the highest contaminated areas used in the examples above.

[12] Table II-VI Basic Safety Standards, Safety Series 115, IAEA, 1996

Figure 3 – Area of elevated activity, Nelson Parade

Figure 4 – Discrete spot of elevated activity, Nelson Parade

Figure 5 – Example of vegetables grown in the backyard of a property, Nelson Parade

The potential exposure from transfer of contamination in the soil to the mouth will vary significantly depending upon a number of factors, including depth of contamination and activities undertaken that disturb the soil.

It is estimated that a person will ingest approximately 30% of soil that is on their hands, based on a total hand surface area of 990 cm^2 and soil adherence factor of 0.3487 mg/cm^2. It is therefore assumed that a soil ingestion rate for both children and adults is approximately 100mg/day[13]. Using the results from Appendix 8, this would equate to an average ingestion of 1.6 Bq per annum (uranium) and 0.3 Bq per annum (thorium) and a maximum ingestion of 22.3 Bq per annum (uranium) and 2.3 Bq per annum (thorium). These intakes would result in a maximum committed effective dose of <0.010mSv.

Skin is fairly impervious to the contamination found at Hunters Hill, and as such internal exposure via absorption through skin is assessed to be negligible.

7.2 Inhalation

Exposure to dust from a disturbed site can result in inhalation of suspended particles. The degree of exposure will be dependent upon the physical and chemical properties of the radiological contamination, the nature of activities that involve the disturbance of soil, and environmental conditions such as moisture content and meteorological conditions. To determine this exposure, a detailed dust sample would be required at the time of the activity being undertaken. However it was noted that the majority of locations within the survey area were well vegetated, which would significantly reduce the re-suspension of dust.

To provide a general estimation of the potential inhalation of suspended particles, some assumptions about the nature of the soil and the activity leading to the suspension of particles need to be made. Based upon these assumptions and various non-radiological Standards on airborne contaminants in occupational environments, the maximum respirable dust concentrations at a work site could be limited to 10 mg/m^3 due to non-radiological hazards, prior to using respiratory protection[14]. If this dust contained Uranium-238 and Thorium-232 at the average concentrations detected in front and back yards of Nelson Parade, the potential inhalation of suspended particles can be estimated. Based on the two scenarios of either somebody gardening in their backyard for 6 hours a week each week of the year, or a major excavation job occurring where a person may be inhaling the dust for 24 hours a day for two weeks, this would equate to an inhalation period of 312 hours and 336 hours respectively.

Using the average uranium and thorium concentrations above background levels in front and back yards of 53.4 Bq/kg and 7.8 Bq/kg respectively, this would equate to a committed effective dose of approximately 0.6E-3 mSv and 1.4E-3 mSv[15, 16]. It should be noted that if the same calculations are made for the most vulnerable group of people (children less than one year old), the committed effective dose would only be 2.6E-3 mSv and 2.6E-3 mSv respectively.

It should also be noted that these calculations assume that both scenarios generate high volumes of respirable dust in the immediate vicinity of a member of the public.

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[13] Technical update, Calculation of an Enhanced Soil Ingestion rate, Massachusetts Department of Environmental Protection (MADEP). 2002. Office of Research and Standards, MADEP, Boston, MA

[14] Safe Work Australia, Guidance note on the interpretation of Exposure Standards for Atmospheric Contaminants in the Occupational Environment NOHSC 3008 (1995)

[15] Table II-VII Basic Safety Standards, Safety Series 115, IAEA, 1996

[16] Assumptions based upon Moderate absorption type for >17 year old members of the public

As certain assumptions have been made in the examples above, if potential earthworks were implemented at the site, dust monitoring should be included in the risk assessment for the work.

7.3 Radon

The inhalation of radon gas can be one of the main contributors to internal exposure. The release of radon is dependent upon a number of factors including radium content, the depth and permeability of the soil, meteorological influences, and ventilation. Generally exposure from radon in outdoor environments is negligible due to the natural ventilation which inhibits the build up of airborne concentrations.

The average concentration of radon in Australian homes[17] is about 12 Bq/m^3. Although the average radon concentrations in Australian homes are quite low in comparison to with some other countries, some homes may contain concentrations of radon much higher than the average.

Radon concentrations inside the properties on Nelson Parade were measured inside five houses adjacent to the location of the former radium extraction plant. All measurements were taken in commonly occupied rooms under minimal ventilation conditions, to provide the most realistic representation of potential exposure. All readings were less than 43 Bq/m^3 (see Appendix 11) with the exception of one house, where the highest level measured was 174 Bq/m^3. The Radiation Protection Series No. 1, ARPANSA 2002, states that the recommended action level for Radon-222 concentration in air inside dwellings is 200 Bq/m^3. If measured values are found to consistently exceed this action level, consideration should be given to possible remediation action[18]. This action level is based upon total radon concentration and does not subtract natural background concentrations.

This action level of 200 Bq/m^3 for existing dwellings is further explained in Radiation Protection Series No.1, ARPANSA 2002 (RPS 1) and the NRPB Board Statement on Radon in Homes, 1990[19].

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[17] ARPANSA Fact sheet – Radon in Homes, ARPANSA, 2007
[18] Recommendations limiting exposure to ionising radiation, Radiation Protection Series No.1, ARPANSA, 2002
[19] National Radiological Protection Board, UK, Volume 1 No 1, 1990

7.4 Exposure Summary

The total exposure from external gamma radiation and internal radiation for the Nelson Parade survey area is summarised in Table 1 below. It should be noted that although exposure from different pathways is cumulative, many of the conservative assumptions made in this assessment are based upon occupancy factors of 100% and are therefore mutually exclusive.

Monitored Exposure Pathway	Potential exposure (mSv per annum)	Assumptions
External gamma radiation	0.00 to 0.63	Highest dose rate, at 0.2 to 0.8 outdoor to indoor occupancy ratio
Average uptake via vegetables	<0.05	Uptake factors of 8.3E-3 (U) and 1.8E-3 (Th) for leafy green vegetables
Ingestion via transfer	<0.01	100mg/day soil ingestion
Inhalation of dust	<0.01	10mg/m^3 dust breathed for 24 hours a day for 2 weeks a year
Radon	Levels below National recommended action levels for Existing Dwellings of 200 Bq/m^3.	

Table 1 – Summary of total exposure for pathways monitored, for Nelson Parade survey area

8 Depth Profiles

Based upon the results of the continuous ambient gamma dose rate surveys using sensitive 2 inch NaI detectors and tripod mounted dose rate monitors, soil and core samples were taken at a number of sites where elevated levels of activity were detected. The aim of collecting these samples was to:

- Determine the maximum activity concentrations in the survey area;
- Provide a detailed analysis of the radioisotopes present in the survey area; and
- Provide information on the vertical profile of the contamination, including guidance on the maximum depth of contamination, for potential future remediation evaluations.

These samples consisted of core soil samples, rock samples and roadway samples.

8.1 Soil Samples

Soil samples were taken at four specific locations where elevated activities were detected in residential properties in Nelson Parade. Sub samples were taken at several depths at each location, as shown in Appendix 9, with the total depth sampled dependent upon the physical depth of the soil.

Each soil sample was screened for relative radioactivity levels using sensitive 2 inch NaI detectors. Of these, several individual samples were chosen for further detailed radionuclide analysis, the results of which are shown in Appendix 10.

From the relative activity levels of each sample, most areas sampled appeared to have a clear vertical stratification of contamination. The depth of the maximum levels of contamination and the approximate lower extent of the contamination is shown in Table 2 below.

Sample ID	HH-001 to HH-007a	HH-027 to 031	HH-032 to 036	HH-037 to 040
Depth of maximum contamination	5 to 30cm	125cm	150cm	50cm
Approximate depth of extent of contamination	40cm	180cm	250cm	100cm

Table 2: Soil core sample results indicating the depth of maximum contamination levels and the approximate vertical extent of contamination. Sample locations are shown in Appendix 5.

Under secular equilibrium conditions, the individual radionuclides in the Uranium and Thorium decay chains exist in specific ratios. Detailed analysis of the individual radionuclide concentrations contained in the soil samples in Appendix 10 show disequilibrium between radionuclides in each of the decay chains. This alteration in the equilibrium indicates that the source of the activity is likely to be from tailings from the former radium extraction plant and not from natural occurrence. This is consistent with historical information and other previous studies completed on Lots 5, 7, 9 and 11 Nelson Parade.

8.2 Rock Samples

Whilst investigating an elevated activity level in the backyard of a residential property in Nelson Parade, a small smooth rock was retrieved approximately 10cm below the soil surface. This rock was the source of the elevated activity in the immediate area and so was analysed using gamma spectroscopy. The results are shown as KM-002 in Appendix 10. From the results showing disproportional elevated levels of uranium decay chain products, it is assumed that the rock is probably slag from the radium extraction plant.

8.3 Roadway samples

As discussed previously, a continuous survey was undertaken of the roadway in Nelson Parade. Based on the results of this survey, a core sample was taken of the roadway at an area of higher activity. The aim of this core sample was to determine if the elevated activity was contained in the road surface material, the road base or substrate material below the road. Screening of the roadway core samples indicated that the contamination was contained in the road base below the road surface. Detailed analysis of the roadway core samples taken in Nelson Parade confirm that the elevated levels of activity are contained within the road base. The isotopes present indicate relatively elevated levels of thorium decay products as shown in

Appendix 10. This is consistent with background information provided in Cardew's study of the Tin Smelter operations[20], which operated in Kelly's Bush. Slag from the former Tim Smelter was used in road construction in the area. Pieces of black slag material were sighted in the road base sample.

[20] A P St E Cardew, Th-232 Contamination from Tin Smelting Operations, Radiation Protection in Australia, 2 (1982)

9 Recommendations and Conclusions

The Australian Nuclear Science & Technology Organisation (ANSTO) carried out two stages of an extensive radiological radiation survey of areas of Nelson Parade, Kelly's Bush, Weil Park and surrounding areas, beginning on 24 November 2008, as requested by NSW Government agencies. This report covers the findings of the surveys undertaken in Nelson Parade and adjacent areas.

Surveys were not undertaken on the Lots No's 5, 7, 9 and 11 Nelson Parade, as these have been surveyed on previous occasions.

An offer was made by NSW Department of Health to all property owners in Nelson Parade who were contactable, for ANSTO to carry out a survey of the ambient gamma radiation dose rates on each property. Surveys were not completed in the yards and houses of residents in Nelson Parade who were not contactable or were not available to provide access during the two weeks of the Stage 1 surveys.

The survey results within the survey area varied significantly, depending upon their location. Most areas indicated nil or negligible presence of radiological contamination above natural background levels. The areas of the highest radiological activity measured were from roadways in Hunters Hill and in properties immediately adjacent to the former radium extraction plant site in Nelson Parade.

This report details the areas surveyed and the potential exposure levels arising from external gamma radiation and the internal exposure from potential inhalation of radioactive dusts and radon, and the ingestion of particles and foodstuffs. It also provides guidance on the spatial and vertical distribution of contamination and the level of uranium and thorium in the soil.

The exposure from ingestion, dust inhalation and external exposure pathways have been analysed, with the exposure assessed to be less than 1 mSv per year.

Indicative radon concentrations have been measured, with all results being below the recommended action level for possible remediation action. However, in one dwelling elevated radon levels were measured which were just below this action level. Due to natural daily and seasonal fluctuations in the concentration of radon from environmental and climatic factors, an extended monitoring time would be required to obtain a more accurate radon concentration representation.

Core samples were taken in the areas of elevated radioactivity and the cores analysed. From the activity screening and analysis, the maximum activities were calculated, the radionuclide ratios identified and the vertical extent of the contamination estimated at each site.

Based upon the survey results, the following recommendations are made, for consideration:

- The results of the completed dose assessments do not in themselves justify remediation of the sites covered by the survey on radiological safety grounds. However, this conclusion does not consider non-radiological and social impacts.

- All measured radon levels were below the recommended action level. However to obtain a more representative assessment of the fluctuation in radon concentrations in the residence with the highest radon reading, it is recommended that a longer monitoring procedure be implemented upon completion of any potential remediation work.
- If potential intrusive remediation actions were implemented at the site, dust monitoring should be included in the risk assessment for the work.

<u>Report prepared by:</u>

Robert Blackley

Health Physicist
Leader, Radiation Consultancy and Training Services
ANSTO

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Appendix 2 – Instrumentation

Instrument / equipment	MTE / Serial No.	Detector	Use
Mini Instrument Environmental Gamma monitor 6/80	2306 Calibration Due 29/08/09	MC-71A 1" GM detector	For measuring environmental low level radiation dose (µSv/h)
Exploranium GR-320 + Garmin GPS	2127	Scintillation type 3" diameter X 3" wide NaI(Tl) calibrated for U, Th, K activity measurement	GPS based contour mapping by activity level
Berthold TOL-F/ LB1321	3635 Calibration Due 08/01/2010	Ion Chamber in micro sieverts per hour	Measures X-ray and gamma radiation from 10keV to 70 Mev over the range of 0.1µSv/h to 100Sv/h
Eberline E-600 / SPA-3	2903 Calibration Due 21/01/09	Scintillation type 2" diameter X 2" wide NaI(Tl) calibrated in counts per second	High sensitivity gamma measurements, for identifying localised elevated areas in the γ energy range from 60 keV to 2 MeV
Eberline E-600 / SPA-3	2904 Calibration Due 21/01/09	Scintillation type 2" diameter X 2" wide NaI(Tl) calibrated in counts per second	High sensitivity gamma measurements, for identifying localised elevated areas in the γ energy range from 60 keV to 2 MeV
Eberline E-600 / SPA-3	2568 Calibration Due 21/11/09	Scintillation type 2" diameter X 2" wide NaI(Tl) calibrated in counts per second	High sensitivity gamma measurements, for identifying localised elevated areas in the γ energy range from 60 keV to 2 MeV

Appendix 3 – Survey Methodology

<u>Survey Methodology</u>

As per NSW Government request, the aim of the survey was to provide a current and extensive radiological survey of Nelson Parade and the surrounding area. The survey was completed in a grid pattern, where practical. Initially sensitive 2 inch sodium iodide (NaI) detectors were used to locate localised elevated levels of contamination and other areas of interest by comparing relative levels of activity, in order to rapidly determine the boundaries of the main grid survey area.

The external gamma measurements were then carried out using a tripod-mounted GM detector used for measuring radiation exposure rate (mSv/h), and a GPS-based 3 inch sodium iodide (NaI) detector gamma spectrometer system for mapping the radiological content. Supplementing this instrumentation, another 2 inch NaI detector was used to verify relative levels at survey points in terms of counts per second only.

At each tripod mounted survey point, a 100-second timed gamma count was made. The raw counting data was later converted, using specific calibration files for each of the instruments, into dose rate per hour and activity level (Bq/kg) for suitable radioisotopes. The survey results were compared to analysed soil calibration samples.

A survey was carried out along roadways, footpaths, and other publicly accessible areas.

In addition, the survey was completed in the yards and houses of residents in Nelson Parade who had provided approval to NSW Department of Health and were available to provide access over the weeks of the survey.

Based upon these results, core samples were taken at areas of elevated activity levels and analysed for radioisotope identification and concentrations.

Based upon the results of Stage 1, indicative radon gas measurements were taken in houses in closest proximity to No. 7 and 9 Nelson Parade, and the results compared to the National recommended action levels for existing dwellings.

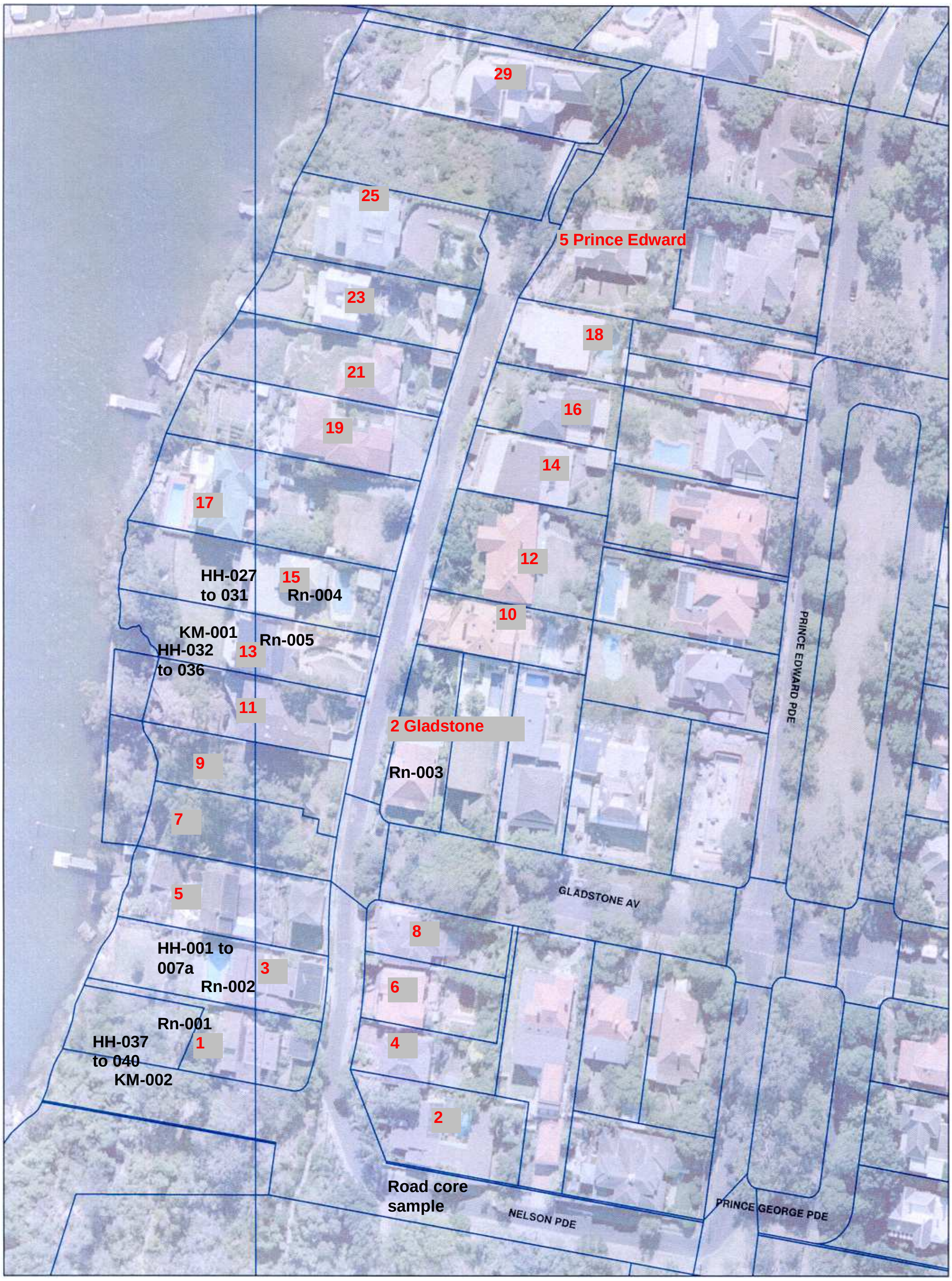
Appendix 4 – Survey Points, Nelson Parade

Key   1-29 = House Numbers

1 – 54 = Fixed Survey Points

= Area covered by continuous survey

Appendix 5 – Radon and Soil Coring Locations



Appendix 6 – Dose rates survey results

The average and maximum dose rates measured at each property, with background subtracted. These results are based upon fixed dose rate results and relative continuous surveying results using 2 inch NaI probes.

The maximum dose rates at each site are indicated in *italics*.

For survey locations, refer to Appendix 4.

Location	Survey points	Average Dose rate & *maximum Dose rate* (mSv per hour)	Assumed Occupancy factor (hours per annum)	Potential contribution to annual exposure (mSv per annum)
Nelson Parade Roadway	1 to 19, 52 to 55	0.23E-3 *0.56E-3*	730 hrs p.a. (2 hours per day)	0.168 *0.409*
No. 1Nelson Parade (outdoors)	37, 38	0.01E-3 *0.02E-3*	1752 hours p.a.	0.018 *0.035*
No. 2 Nelson Parade (indoors & outdoors)	36	0.00E-3 *0.00E-3*	8760 hours p.a.	0.000 *0.000*
No. 3 Nelson Parade (indoors)	28	0.09E-3* *0.09E-3*	7008 hours p.a.	0.631 *0.631*
No. 3 Nelson Parade (outdoors)	27	0.02E-3 *0.02E-3*	1752 hours p.a.	0.035 *0.035*
No. 6 Nelson Parade (outdoors)	20, 21	0.02E-3 *0.02E-3*	1752 hours p.a.	0.035 *0.035*
No. 8 Nelson Parade & pathway	51	0.01E-3 *0.02E-3*	1752 hours p.a.	0.018 *0.035*
No. 2 Gladstone Avenue (outdoors)	23, 25	0.01E-3 *0.03E-3*	1752 hours p.a.	0.018 *0.053*
No. 2 Gladstone Avenue (indoors)	22, 24	0.03E-3 *0.07E-3*	7008 hours p.a.	0.211 *0.491*
No.10 Nelson Parade (outdoors)	6	0.01E-3 *0.01E-3*	1752 hours p.a.	0.018 *0.018*
No. 12 Nelson Parade (outdoors)	29, 39	0.00E-3 *0.03E-3*	1752 hours p.a.	0.000 *0.053*
No. 13 Nelson Parade (indoors)	49	0.01E-3 *0.02E-3*	7008 hours p.a.	0.070 *0.140*
No. 13 Nelson Parade (outdoors)	49	0.01E-3 *0.22E-3*	1752 hours p.a.	0.018 *0.386*
No. 14 Nelson Parade (indoors & outdoors)	30	0.01E-3 *0.02E-3*	8760 hours p.a.	0.088 *0.175*
No. 15 Nelson Parade (indoors)	47, 48	0.03E-3 *0.03E-3*	8760 hours p.a.	0.263 *0.263*
No.15 Nelson Parade (outdoors)	47, 48	0.03E-3 *0.04E-3*	1752 hours p.a.	0.053 *0.070*
No. 16 Nelson Parade (outdoors)	31, 32	0.00E-3 *0.00E-3*	1752 hours p.a.	0.000 *0.000*
No. 17 Nelson Parade	44, 46	0.01E-3	8760 hours p.a.	0.088

(indoors & outdoors)		*0.02E-3*		*0.175*
No. 18 Nelson Parade (outdoors)	41	0.00E-3 *0.00E-3*	1752 hours p.a.	0.000 *0.000*
No. 19 Nelson Parade (outdoors)	35	0.01E-3 *0.01E-3*	1752 hours p.a.	0.018 *0.018*
No. 21 Nelson Parade (indoors & outdoors)	33, 34	0.00E-3 *0.00E-3*	8760 hours p.a.	0.000 *0.000*
No. 23 Nelson Parade (outdoors)	43	0.01E-3 *0.01E-3*	1752 hours p.a.	0.018 *0.018*
No. 25 Nelson Parade (outdoors)	42	0.00E-3 *0.00E-3*	1752 hours p.a.	0.000 *0.000*
No. 29 Nelson Parade (outdoors)	26	0.00E-3 *0.00E-3*	1752 hours p.a.	0.000 *0.000*
No. 5 Prince Edward Parade (outdoors)	40	0.01E-3 *0.01E-3*	1752 hours p.a.	0.018 *0.018*

Notes: - Background dose rates of 0.08E-3 mSv/h have been subtracted from all results.
- Permission to undertake the survey was not provided by No.4 Nelson Parade.
- The vacant property at No.27 Nelson Parade was inaccessible.
- Access was not available at the relevant time to undertake a survey of the backyard of No.8 Nelson Parade.

* Dose rates measured inside this property were slightly higher than outside the property due to naturally occurring radioactive material contained within building materials.

Appendix 7 – Background Dose rate results

The dose rates and radionuclide concentrations measured at background sample sites.

For survey locations, refer to the description in the table.

Survey Point No.	Description	K Bq/kg	U Bq/kg	Th Bq/kg	2 inch NaI Detectors (cps)	Background Dose Rate (msv/h)
69	Background 1 (end of Nelson Parade)	131.8	3.4	30.2	120	0.07E-3
70	Background 2 (near Nelson Parade)	85.7	20.1	31.8	140	0.09E-3
71	Background 3 (Padstow Park)	97.6	8.8	31.7	120	0.08E-3
72	Background 4 (Park - Lyons Rd Five Dock)	177.6	8.7	34.3	130	0.08E-3
73	Background 5 (Park near Huntley's Cove - corner Mary St and Richmond Cresent)	126.6	0.0	31.5	109	0.08E-3
74	Background 6 (Pidding Park - Ryde)	90.9	7.6	31.2	120	0.07E-3

Appendix 8 – Uranium, Thorium and K-40 Concentrations

Results from 3 inch NaI Gamma Spectrometry System

<u>Note:</u> These results are inclusive of background

Concentrations marked in yellow are front or backyards of residences

Concentrations marked in blue are background sites, as described in Appendix 7.

Survey Point No.	K (Bq/kg)	U (Bq/kg)	Th (Bq/kg)
1	377.8	27.5	33.3
2	428.7	17.8	19.4
3	339.1	11.5	26.2
4	477.7	18.7	36.6
5	307	7.2	24.7
6	333.3	28.3	49.1
7	387.8	181.5	283.7
8	480.6	351.8	719.9
9	294.3	383	665.6
10	244.1	255.5	420.3
11	423.1	255.6	410.5
12	486.3	260	395.9
13	406.1	230.6	366.4
14	525.8	476	895.9
15	571.1	279.6	534.4
16	468.2	237.4	531.4
17	476.1	57.6	83.7
18	565.4	101.7	220.1
19	412	393	1011.6
52	325.8	98.7	201.8
53	653.2	584.9	1014.6
54	505.5	589.8	1154.3
55	587.5	370.6	988.2
20	286.8	36.7	43.3
22	442.2	34.2	67
24	280.1	385	37.9
21	387.1	24.9	45.8
23	172.8	23.7	37.8
25	171.8	138.6	46.7
26	205.6	16.9	38.3
27	235.8	39	43.3
28	435.7	242.8	61.7
29	199.9	4.5	28.8
30	205.7	19.6	41.7
31	177.7	4.3	34.3
32	313.7	16.1	35.8
33	357.8	21.9	41
34	253.6	16.6	44.1

35	123.1	11.4	39.4
36	198	16.1	29.2
37	100.2	30.4	36.7
38	108.7	116.1	45.4
39	170.7	21.1	36.4
40	268	26.2	31.3
41	203.1	8.4	32
42	256.3	3.9	28.2
43	299	8	32.9
44	207	48.2	42.7
46	353.4	22.6	30.6
47	272.8	24.6	40
48	185.5	80.9	43.2
49	317.9	611.9	62.6
50	304.2	21.3	41
51	320.2	30.8	46.9
69 Background 1	131.8	3.4	30.2
70 Background 2	85.7	20.1	31.8
71 Background 3	97.6	8.8	31.7
72 Background 4	177.6	8.7	34.3
73 Background 5	126.6	0	31.5
74 Background 6	90.9	7.6	31.2
Average Background	**118.4**	**8.1**	**31.8**
Average for all survey points (net)	**218.0**	**190.7**	**291.6**
Average for House Yards only (net)	**119.4**	**53.4**	**7.8**

Appendix 9 – Core Soil Samples

Results of gross activity levels from soil core samples, to determine a vertical activity profile.

Soil core samples were taken at targeted sites based on elevated levels of activity detected during the continuous radiological survey.

Samples collected into colour groups are from the same core sample site. For core locations, see Appendix 5.

Sample ID	Depth (cm)	Gross Activity counts above background	Description	Comments
HH-001	5	BG	dark sandy, loose soil	Core #1
HH-002	30	BG	dark loam with white sand	Core #1
HH-003	5	10	dark sandy, loose soil	Core #2, adjacent to core #1
HH-004	30	20	orange sandy clay	Core #2
HH-005	60	BG	dark sandy, loose soil	Core #2
HH-006	90	BG	dark sandy, loose with slag pieces	Core #2
HH-007	120	BG	dark sandy, loose soil	Core #2
HH-007a	150	BG	dark sandy, loose soil	Core #2
HH-027	50	20	dark sandy loam	
HH-028	100	10	dark clayey loam	Rock fragments & building waste at 1m (nails, wire, plastic sheet)
HH-029	125	40	dark loose sandy soil with gravel pieces	
HH-030	150	10	light brown fine sandy soil	
HH-031	170	30	light brown fine sandy soil	
HH-032	50	45	sandy loam	
HH-033	100	75	sandy loam	
HH-034	150	135	sandy loam	
HH-035	200	50	sandy loam with clay layer	
HH-036	240	15	metal fragments	
HH-037	50	BG	sandy clay, brick dust, wet	Core #1
HH-038	100	BG	brick rubble, rock concrete	Core #1
HH-039	50	BG	sandy clay, brick dust, wet	Core #2, adjacent to core #1
HH-040	100	BG	brick rubble, rock concrete	Core #2, Refusal at 1m after 8 attempts (building waste)

Appendix 10 – Radionuclide Concentrations of Core Samples

Radionuclide concentrations from background sites core soil samples.

For locations of background sample sites, refer to description in Appendix 7.

A core soil sample could not be collected from Background Site 1 as a core sample could not be obtained through the paved area.

Activities are in Bq per kg for dried and ground samples.

Less than (<) indicates the limit of detection for each radionuclide for the measurement system.

Colour coded samples are from the same site at differing depths.

Reported uncertainty is calculated for 1σ.

Sample Location and Depth	Background 2	Background 3	Background 4	Background 5	Background 6
Isotopes	**Radionuclide Activity** (Bq per kg dry weight)				
	Uranium (U-238) series				
Th-234	30± 7	<20	30± 6	<10	30± 3
Pa-234m	<100	<200	<100	<100	<70
Th-230	<100	<200	<100	<90	<70
Pb-214	20± 2	20± 2	10± 1	10± 1	20± 2
Bi-214	20± 2	20± 2	10± 1	10± 1	20± 2
Pb-210	50± 5	40± 4	40± 4	50± 5	20± 2
	Thorium (Th-232) series				
Ac-228	40± 4	30± 3	30± 3	30± 3	40± 4
Th-228	<300	<300	<200	<300	<100
Ra-224	30± 7	<30	<20	30± 6	30± 3
Pb-212	30± 3	20± 2	30± 3	20± 2	40± 4
Bi-212	30± 7	<20	<20	30± 6	30± 3
Tl-208	10± 3	10± 1	10± 1	10± 1	10± 1
	U-235 series and K-40				
U-235	<10	<20	<10	<10	<10
Th-227	<10	<10	<10	<10	<3
K-40	100± 11	100± 12	200± 20	50± 7	200± 20

Radionuclide concentrations from targeted sample sites.

Soil core samples were taken at targeted sites based on elevated levels of activity detected during the continuous radiological survey. All cores were monitored for gross activity to determine a vertical activity profile. Selected slices (shown below) of each core of higher activity levels or which formed vertical stratification boundaries were analysed to determine specific radionuclide concentrations.

Sample Location and Depth	HH-003 @ 5cm	HH-004 @ 10cm	HH-027 @ 50cm	HH-031 @ 170cm	HH-034 @ 150cm	HH-036 @ 240cm	HH-039 @ 50cm	HH-040 @ 100cm
Isotopes	**Radionuclide Activity** (Bq per kg dry weight)							
Uranium (U-238) series								
Th-234	1300± 130	1100± 110	300± 30	70± 9	4200± 420	740± 74	150± 15	150± 15
Pa-234m	1200± 120	920± 92	<450	<170	4400± 440	660±79	<120	170±31
Th-230	2000± 200	510± 61	2100± 210	450± 85	12000± 1200	1200± 120	<130	240±43
Pb-214	3100± 310	1100± 110	3100± 310	1000± 100	14000± 1400	1100± 110	460± 46	410± 41
Bi-214	3100± 310	1200± 120	3100± 310	1000± 100	14000± 1400	1100± 110	460± 46	410± 41
Pb-210	2600± 260	720± 72	3100± 310	830± 83	11000± 1100	1100± 110	360± 36	310± 31
Thorium (Th-232) series								
Ac-228	120± 12	90± 9	150± 15	110± 11	290± 29	280± 28	90± 9	110± 11
Th-228	<320	<300	<510	<390	<1000	<500	<170	<200
Ra-224	<80	<40	210± 36	<60	620± 74	190± 19	70±9	70± 9
Pb-212	120± 12	90± 9	150± 15	110± 11	280± 28	290± 29	70± 7	100± 10
Bi-212	110± 11	90± 9	150± 15	110± 13	320± 32	300± 30	90± 9	110± 11
Tl-208	40± 4	30± 3	60± 6	40± 4	100± 10	110± 10	30± 3	40± 4
U-235 series and K-40								
U-235	60±10	50±5	<20	<20	170± 19	<30	<10	<10
Th-227	50±5	10±2	110± 11	20± 3	460± 46	50± 5	<10	<10
K-40	380±38	520±52	370± 37	420± 42	540± 54	680± 68	190± 19	210± 21

Additional samples analysed for Radionuclide Concentrations

Sample Location and Depth	KM-001 Near Surface Dirt sample and rocks	KM-002 White Rock	Road core sample 1 - Road surface bitumen 0-60mm	Road core sample 2 - Road Base 60-110mm	Road core sample 3 - Sandy soil 110-220mm
Isotopes	**Radionuclide Activity** (Bq per kg dry weight)				
Uranium (U-238) series					
Th-234	3600± 360	7400± 740	850± 85	1900± 190	390± 39
Pa-234m	3300± 330	6200± 620	970± 97	<280± 28	440± 75
Th-230	7100± 710	8100± 810	1310± 157	12000± 1200	1000± 100
Pb-214	1400± 140	17000± 1700	600± 60	1300± 130	350± 35
Bi-214	1300± 130	17000± 1700	580± 58	1200± 120	350± 35
Pb-210	1300± 130	16000± 1600	550± 55	1100± 110	280± 28
Thorium (Th-232) series					
Ac-228	200± 20	200± 20	2100± 210	3200± 320	580± 58
Th-228	<500	<1100	1900± 190	3100± 310	760± 76
Ra-224	<100	300± 30	2000± 200	3100± 310	700± 70
Pb-212	150± 15	200± 20	2000± 200	3300± 330	740± 74
Bi-212	140± 14	200± 20	2000± 200	3200± 320	740± 74
Tl-208	50± 5	100± 10	720± 72	1200± 120	270± 27
U-235 series and K-40					
U-235	170± 17	300± 30	100± 13	50± 9	<20
Th-227	330± 33	200± 20	50± 5	130± 13	30± 3
K-40	190± 19	400± 40	460± 46	280± 28	190± 19

Appendix 11 – Indoor Radon Concentrations

Average radon concentrations inside selected dwellings.

For sample locations, see Appendix 5.

Sample ID	**Rn-001**	**Rn-002**	**Rn-003**	**Rn-004**	**Rn-005**
Average Concentration	35 Bq/m^3	42 Bq/m^3	22 Bq/m^3	11 Bq/m^3	174 Bq/m^3