Australian Government

ansto

Nuclear-based science benefiting all Australians

Radiation Consultancy & Training Services

Health Physics Report on

Radiological Survey of Kelly's Bush, Hunters Hill - Stages 1 and 2

For NSW Dept Health and NSW DECC

15th June 2009

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

15th June 2009

Table of Contents

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, Kelly's Bush and surrounding areas in Hunters Hill, NSW. This report assesses the spatial extent of radiological contamination in Kelly's Bush 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 at the site of the former Tin Smelter in Kelly's Bush, around the Kelly's Bush foreshore and one section of Weil Park. Elevated levels of radioactivity were also detected from the surface of numerous roads in the area, as a result of the historical use of waste slag from the former Tin Smelter 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. 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

From 1895 until 1966, a tin smelter operated on what is now Kelly's Bush Reserve, which borders Nelson Parade, Hunters Hill. The smelter processed tin ore that contained uranium-bearing and thorium-bearing monazite minerals[1]. The ore smelted came from numerous alluvial tin deposits throughout Australia and generally contained between 50% and 70% of tin oxide by weight. Low levels of these thorium and uranium contaminants remained in the resultant tin slag produced by the smelter.

This tin slag was emplaced in the vicinity of the smelter and the foreshore areas of Kelly's Bush. Over many years of operation, the tin slag from the smelter was also used extensively in road building in the surrounding area. In 1966 the smelter discontinued operations and the equipment and buildings were removed from the site. In the late 1970s and early 1980s there was much community discussion about a proposal for the residential development of the land at Kelly's Bush, but after considerable investigation and debate the lands were dedicated as parklands and have been managed as such to date.

In December 2008 the NSW Department of Health and NSW Department of Environment and Climate Change (DECC) engaged the Australian Nuclear Science and Technology Organisation (ANSTO) to carry out an extensive radiological survey and characterisation of the use of tin slag at Kelly's Bush and surrounding areas of Hunters Hill.

This report details the areas surveyed in Kelly's Bush, roadways and surrounding areas in the first and second stages of the radiological assessment and includes the gamma radiation levels measured, analysis of the radiological characteristics in the areas in comparison to natural background radiation, and potential dose estimates, where possible. The results of the survey of a former radium extraction plant in Nelson Parade, Hunters Hill, are covered in a separate report[2].

---

[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] ANSTO, Radiological survey of Nelson Parade, Hunters Hill, Stages 1 and 2. 2009

Basic Radiological Issues

2.1 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.

2.2 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 affects 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.

2.3 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.

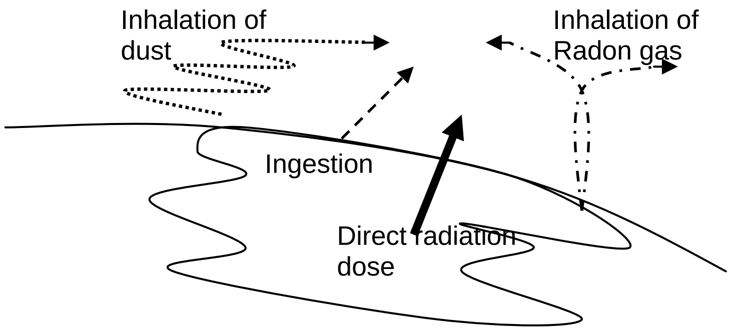


Figure 1 - Simple conceptual model of potential exposure pathways in the immediate vicinity of radioactively contaminated land.

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.

2.4 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[3] 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 Kelly's Bush, Hunters Hill.

3 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

[3] 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[4]. (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.

4 Scope of Radiological Assessment

The main purpose of the radiological surveys was to determine whether the radiation levels in and around Kelly’s Bush, roads and footpaths, 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 public land, properties, footpaths and roadways in and around Kelly’s Bush;
- Characterisation of the relative Uranium, Thorium and Potassium-40 content of soil in the above areas;
- 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 the site of the former radium extraction plant at Nelson Parade, as this is covered in a separate report.

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

5 Survey results

The survey results have been divided up into potential external and internal hazards, and into Background results, Kelly's Bush, the roadways and other areas surveyed.

5.1 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 $\times 10^{-3}$ 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

5.2 External Gamma Radiation Levels, Kelly's Bush

A continuous survey was undertaken of the ambient gamma radiation in accessible areas of Kelly's Bush, Weil Park and adjacent public areas, using sensitive 2 inch NaI detectors. Based on these results, a detailed survey of the ambient gamma dose rates was conducted at regular intervals throughout the survey area, using the methodology described in Appendix 3. These survey locations (Survey Points 56 – 68) are indicated in Appendix 4.

For the majority of areas surveyed in and around Kelly's Bush, only natural background readings were detected. However there were some areas identified where radioactivity levels were elevated. Often these were discrete spots of activity, in a variety of scattered locations. A few larger areas of elevated readings were also identified.

The highest levels of activity were detected around:

- The foreshore area of Kelly's Bush;
- A localised area on one side of Weil Park;
- Several areas around the site of the former Tin Smelter in Kelly's Bush, near the end of Alfred Street. Some of these areas extended onto private property, which was not able to be surveyed.

These areas of elevated activity were primarily, but not exclusively, associated with the presence of black or white rocks, which is waste slag from the former tin smelter, as shown in

Figures 1 to 4. This is supported by background information provided by Cardew's study[5] of the Tin Smelter operations, which states that "Prior to 1952 the molten final slag was run out into a mould and after it had cooled and solidified, was broken up with hammers and then carted away and dumped".

Figure 1 - Scattered black slag from the former Tin Smelter process, as found in Kelly's Bush

Figure 2 - Black slag from the former Tin Smelter process, as found in Kelly's Bush

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

Figure 3 - Black slag from the former Tin Smelter process, on rocks at low tide, as found at Kelly's Bush foreshore area.

Figure 4 - Black slag from the former Tin Smelter process, on rocks at low tide, as found at the western end of the Kelly's Bush foreshore area.

Detailed analysis of these rocks show relatively elevated levels of thorium decay products, indicating their origin as being from the tin smelter in Kelly's Bush as opposed to the radium extraction plant on Nelson Parade. The black slag contains the higher concentrations of thorium in a vitreous/glassy matrix.

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 2 inch NaI detector results. The dose rates measured in Kelly's Bush and surrounding areas ranged from 0.000 mSv/h to 0.002 mSv/h (at contact) above natural background levels.

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 indicated in the table in Appendix 6. During the survey, it was observed that some of the public park land locations were occupied by individuals for up to an hour at a time. Assuming that an individual may occupy an area for an average of one hour every day of the year, the contribution to the total annual exposure by external gamma radiation would be:

- 0.00 mSv for the majority of areas surveyed,
- 0.15 mSv at the western end of the foreshore area (Survey point 67),
- 0.38 mSv adjacent to the seating area near Alfred Street (Survey point 61),
- 0.43 mSv at the site of the previous tin smelter (Survey points 59 and 58).

Elevated levels of activity were also detected from some concrete pathways in and around Kelly's Bush. It was observed that the concrete contained small black pebbles which were similar in appearance to the black slag, as shown in Figures 5 and 6. The two predominant areas where this concrete was measured was the public walk way in Kelly's Bush leading to the lookout above the foreshore area, and at the western end of the foreshore area.

Figure 5 – Concrete impregnated with black slag from the former Tin Smelter, as found in Kelly's Bush

Figure 6 – Concrete walls impregnated with black slag from the former Tin Smelter, as found in Kelly's Bush

6 Internal Radiation Exposure, Kelly's Bush

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.

6.1 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.

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[6]. Using the results from Appendix 8, this would equate to an average ingestion of 16.1 Bq per annum (uranium) and 27.0 Bq per annum (thorium). These intakes would result in a maximum committed effective dose of <0.010mSv for adults and 0.130mSv for children less than one year old[7].

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.

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. However, as Kelly's Bush is public land it is unlikely that edible plants are grown and consumed on a regular basis.

The average Uranium and Thorium concentrations above natural background levels, from the 3 inch sodium iodide (NaI) detector gamma spectrometer system, measured in Kelly's Bush were 439.9 Bq/kg and 739.4 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 of the near surface contamination across the survey area and a more realistic assessment of potential internal radiation exposure.

---

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

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

6.2 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[8]. If this dust contained Uranium-238 and Thorium-232 at the average concentrations detected in Kelly's Bush, the potential inhalation of suspended particles can be estimated. Based on the two scenarios of somebody gardening in Kelly's Bush 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 of 439.9 Bq/kg and 739.4 Bq/kg respectively, this would equate to a committed effective dose of approximately 0.005 mSv and 0.134 mSv[9, 10]. It should be noted that these calculations assume that both scenarios generate high volumes of respirable dust in the immediate vicinity of people for the full occupancy time.

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.

[8] Safe Work Australia, Guidance note on the interpretation of Exposure Standards for Atmospheric Contaminants in the Occupational Environment NOHSC 3008 (1995)
[9] Table II-VII Basic Safety Standards, Safety Series 115, IAEA, 1996
[10] Assumptions based upon Moderate absorption type for >17 year old members of the public

6.3 Exposure Summary, Kelly's Bush

The total exposure from external gamma radiation and internal radiation for the Kelly's Bush survey area is summarised in Table 1 below. It should be noted that although exposure from different pathways is cumulative, some 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 0.43	Highest dose rate, occupied for one hour every day of the year
Ingestion via transfer	<0.01	100mg/day soil ingestion, adult >17 years old
Inhalation of dust	0.134	10mg/m^3 dust breathed for 24 hours a day for 2 weeks a year

Table 1 – Summary of total exposure for pathways monitored, for Kelly's Bush survey area

7 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 and rock samples.

7.1 Soil Samples

Soil samples were taken at five specific locations where elevated activities were detected in and around Kelly's Bush. Samples were taken at several depths, 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 some vertical stratification of contamination. The depth of the maximum levels of contamination and the approximate lower extent of the contamination are shown in Table 2 below.

Sample ID	HH-008 to HH-010	HH-011 to HH-014	HH-015 to HH-019	HH-020 to HH-024	HH-025 to HH-026
Depth of maximum contamination	80 cm	50 cm	Surface slag	Not defined	50 cm
Approximate depth of extent of contamination	100 cm	100 cm	100 cm	100 cm	100 cm

Table 2: Soil core sample results indicating the depth of maximum contamination levels and the approximate vertical extent of contamination, where defined

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 tin smelter and not from natural occurrence. This is consistent with historical information and other previous studies completed.

7.2 Rock Samples

During the survey of Kelly's Bush, a few rocks showing elevated activity levels were analysed using gamma spectroscopy. Additional rocks were also recovered and analysed during core drilling of soil samples. Most rocks were dark brown or black in colour. A large plate of similar material was discovered in Kelly's Bush at survey points 58 and 59, buried a few centimetres below the surface. From the results in Appendix 10, which show disproportional elevated levels of thorium decay chain products, it is assumed that the rocks are probably slag from the former tin smelter.

8 Roadways in Hunters Hill

A continuous survey was undertaken of the roadways in Hunters Hill and the results recorded in Appendix 11. Based on the results of this survey, core samples were taken of the roadway at Alfred Street, Nelson Parade and Avenue Road, Hunters Hill in areas of higher activity. The aims of these core samples were to determine if the elevated activity was contained in the road surface material, the road base or substrate material below the road, and if they were all of similar origin. 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 at each location 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[11], 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.

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

Figure 7 – Partially crushed Road surface

Figure 8 – Partially crushed Road base containing slag from the Tin Smelter

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. However, if road works are undertaken that significantly break up the road base and generate large quantities of dust from this road base, there can be potential inhalation of suspended radiological particles. It is assessed that the protection measures that are employed to protect people from non-radiological dust hazards in such a situation would provide suitable protection from radiological hazards.

Subsequent monitoring indicates that similar low levels of radioactivity are present in a number of roadways in Hunters Hill and surrounding suburbs. No clear boundary to the extent of activity contained within the roadways was able to be defined.

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. A conservative estimate that people may spend up to 2 hours every day of the year on the roadways has been adopted. The maximum dose rate measured on the roadways was 1.02E-3 mSv/h. Based on the occupancy factor above, this would equate to an annual exposure of 0.774 mSv.

Figure 9 – Typical road surface in Hunters Hill

8.1 Exposure Summary from Roadways

The total exposure from external gamma radiation and internal radiation from roadways in the survey area is summarised in Table 3 below.

Monitored Exposure Pathway	Potential exposure (mSv per annum)	Assumptions
External gamma radiation	0.00 to 0.77	Highest dose rate, occupied for two hours every day of the year
Inhalation of dust	Negligible	Immobile in current state. Protection worn for non-radiological hazards if significant dust generated is suitable for radiological hazards

Table 3 – Summary of total exposure for pathways monitored, from roadways in the Hunters Hill survey area

9 Other areas surveyed in Hunters Hill

Based upon results of the continuous survey of Kelly's Bush, additional adjacent areas were surveyed.

9.1 Weil Park

A survey was conducted on Weil Park, located at the top of Kelly's Bush. Elevated levels of radioactivity were detected on the northern side of the park, as indicated by survey point 57. The activity extended from the edge of the park and under the garden beds towards the footpath.

Based on the dose rates measured, if an occupancy factor of one hour per day every day of the week is assumed, this would equate to an external exposure of 0.044 mSv per annum.

A core sample was taken at this location but only low levels of activity were detected in the sample. The core sample was unable to penetrate the ground more than 50cm in depth. The results could not determine whether the activity is loose contamination in the soil or buried slag from the former tin smelter.

9.2 Surrounding areas

Upon request, a school adjacent to Weil Park, Marist Sisters' College, was also surveyed. All readings within the school grounds were consistent with natural background levels.

Upon request of the owner, the front yard of a private property on Alfred Street was surveyed. No activity above natural background levels was detected during the survey, with the exception of the private pathway leading from the street to the front door of the residence. The private pathway was made of concrete which was similar in appearance and in activity levels to the concrete pathways present in Kelly's Bush, containing small black pieces of slag from the former tin smelter. Any hazards from this private pathway would be similar to those discussed above for Kelly's Bush. 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[12] (approximately 19 hours indoors and 5 hours outdoors each day). From the results shown in Appendix 6, the potential contribution from external gamma radiation to a person's total exposure at this residence is 0.753 mSv per annum. This estimation is based upon conservative assumptions about people occupying the areas of the highest dose rates for extended periods of time over the entire year.

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

10 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 Kelly's Bush, Weil Park and adjacent areas and roadways.

The survey results within the survey area varied significantly, depending upon their location. Most areas indicated nil presence of radiological contamination above natural background levels.

The areas of the highest radiological activity measured were from roadways in Hunters Hill, concrete pathways embedded with slag from the tin smelter, the foreshore area of Kelly's Bush, several areas around the location of the former tin smelter and an area of Weil Park.

This report details the areas surveyed, the potential exposure arising from external gamma radiation and the potential internal exposure from potential inhalation of radioactive dusts 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 a variety of possible external and internal exposure pathways have been analysed, with all exposures assessed to be less than 1 mSv per year.

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.
- The results of the survey are based upon current land use in Kelly's Bush. If the land use of this area were to change significantly, it is recommended that additional monitoring be undertaken, as appropriate.

<u>Report prepared by:</u>

Robert Blackley

Health Physicist
Leader, Radiation Consultancy and Training Services
ANSTO

Appendix 1 – References

Australian Nuclear Science and Technology Organisation, '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.

Australian Nuclear Science and Technology Organisation, 'Radiological Survey of Nelson Parade, Hunters Hill, Stages 1 and 2', June 2009.

ARPANSA 2002. Australian Radiation Protection and Nuclear Safety Agency, Recommendations and National Standard - Recommendations for Limiting Exposure to Ionising Radiation (1995) and National Standard for Limiting Occupational Exposure to Ionising Radiation [NOHSC:1013 (1995)], Radiation Protection Series No. 1, Commonwealth of Australia, 2002.

ARPANSA, Fact Sheet – Radon in Homes, 2007.

http://www.arpansa.gov.au/radiationprotection/factsheets/is_radon.cfm

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

Cardew, A. P. St. E, Th-232 contamination from Tin Smelting Operations, Radiation Protection in Australia, 2. 1982.

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.

Gandy, G.F. 1982. Radium contamination of residential areas. *Radiation Protection in Australia* Issue 2/82 p. 117-129.

International Atomic Energy Agency, 1994. Handbook of Parameter Values for the Prediction of Radionuclide Transfer in temperate Environments, IAEA, Vienna, (1994).

International Atomic Energy Agency, 1996. International Basic Safety Standards for Protection Against Ionising Radiation and the Safety of Radiation Sources, Safety Series No. 115, IAEA, Vienna, (1996).

Mudd, G M. 2005. 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.

Massachusetts Department of Environmental Protection (MADEP). 2002. Technical update, Calculation of an Enhanced Soil Ingestion rate,. Office of Research and Standards, MADEP, Boston, MA. (http://www.mass.gov/dep/cleanup/laws/soiling.doc).

National Radiological Protection Board, Board Statement on Radon in Homes, Volume 1 No.1, 1990.

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

Safe Work Australia, Guidance note on the interpretation of Exposure Standards for Atmospheric Contaminants in the Occupational Environment NOHSC 3008 (1995) 3rd Edition, Section 14.

UNSCEAR 2000. United Nations Scientific Committee on the Effects of Atomic Radiation, Sources and Effects of Ionising Radiation, UNSCEAR 2000 Report to the General Assembly, United Nations, New York, 2000.

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

Survey Methodology

As per NSW Government request, the aim of the survey was to provide a current and extensive radiological survey of Kelly's Bush 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.

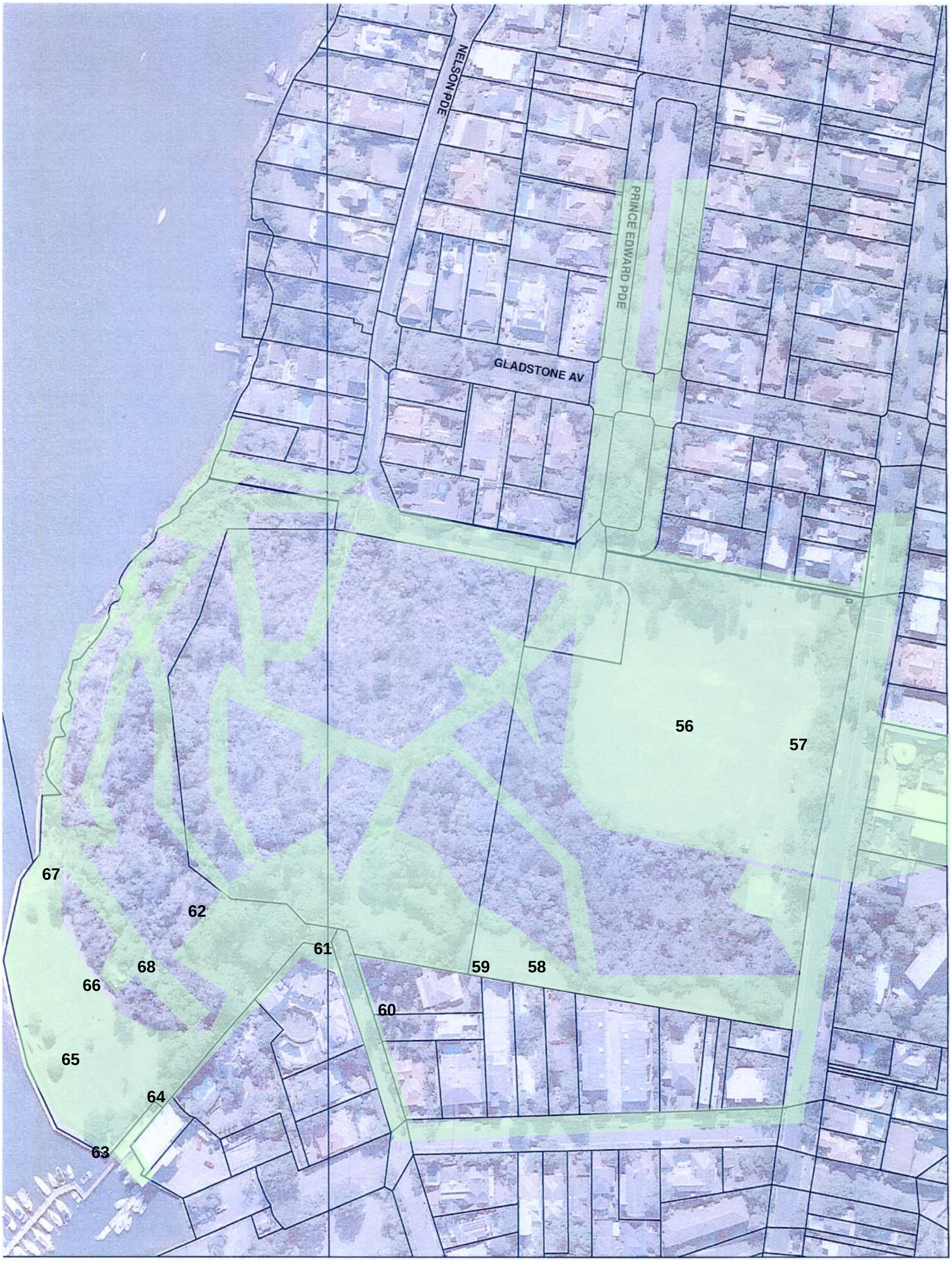
The survey was carried out along roadways, footpaths, public spaces, tracks through Kelly's Bush and other publicly accessible areas.

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

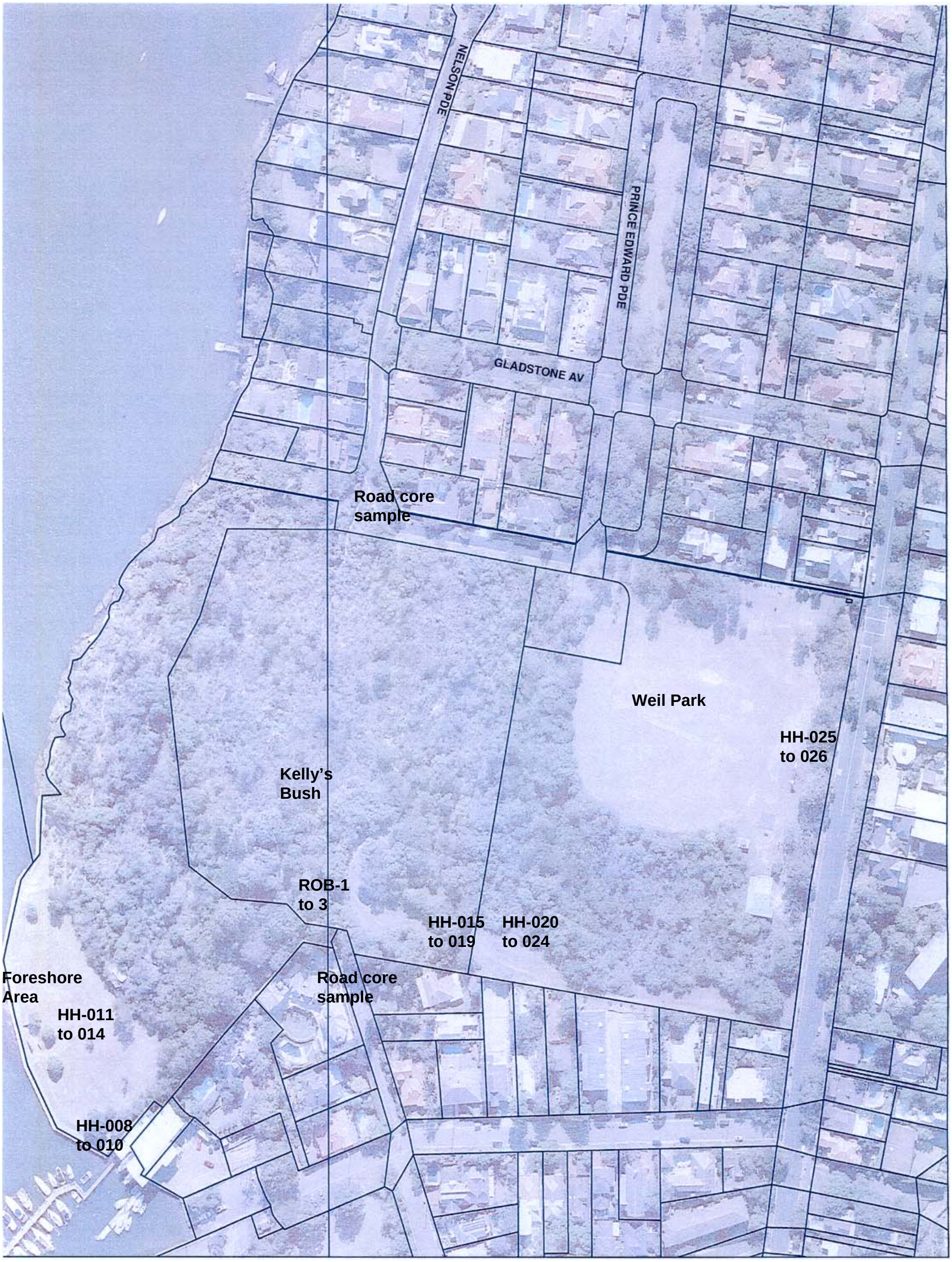
Appendix 4 – Survey Points, Kelly's Bush

<u>Key</u> 56 – 68 = Fixed Survey Points

= Approximate area covered by continuous survey



Appendix 5 – Soil Coring Locations



Appendix 6 – Dose rates survey results

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

For survey locations, refer to Appendix 4.

Location	Survey point	Dose rate (mSv per hour)	Assumed Occupancy factor (hours per annum)	Potential contribution to annual exposure (mSv per annum)
Weil Park Cricket pitch	56	0.00E-3	365	0.000
Nth Edge of Weil Park	57	0.12E-3	365	0.044
Behind former tin smelter site #1	58	0.89E-3	365	0.325
Behind former tin smelter site #2	59	1.18E-3	365	0.431
Pathway on No2 Alfred St house	60	0.43E-3	1752	0.753
Kelly's Bush at end of Alfred St	61	1.04E-3	365	0.380
Seating area, Kelly's Bush	62	0.02E-3	365	0.008
Eastern foreshore near Marina	63	0.02E-3	365	0.008
Eastern foreshore area	64	0.15E-3	365	0.055
Middle of foreshore area	65	0.07E-3	365	0.026
Foreshore area below look out	66	0.56E-3	365	0.205
Rocks at western end of foreshore	67	0.40E-3	365	0.146
Concrete pathway to look out	68	0.07E-3	365	0.026

Notes: - Background dose rates of 0.08E-3 mSv/h have been subtracted from all results.

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

Note: These results are inclusive of background

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

Survey Point No.	K (Bq/kg)	U (Bq/kg)	Th (Bq/kg)
56	250.2	8.9	30.8
57	206.7	104.2	190.3
58	361.6	1073.4	2011.1
59	667.1	1175.8	2270.8
60	447.5	683.5	1513.4
61	585.0	1085.2	1509.4
62	261.2	7.0	36.7
63	209.1	70.8	143.0
64	447.7	265.2	254.4
65	235.4	104.6	183.2
66	373.3	455.1	719.6
67	411.6	635.6	890.7
68	231.1	155.2	272.1
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)	**242.2**	**439.9**	**739.4**

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-008	80	100	Light brown sand	Surface counts = 450, refusal at 50cm after 5 attempts
HH-009	100	20	Dark brown sand	
HH-010	25	25		Rock sample from hole
HH-011	50	50	Dark sandy, loose soil	Refusal at 50cm after 1 attempt
HH-012	100	Background	Dark sandy, loose soil	
HH-013	10	20		Rock sample from hole
HH-014	130	10	Finer dark sandy loam	
HH-015	50	10	Dark sandy loam	
HH-016	100	10	Light loose clayey sand	
HH-017	150	10	Light grey loose silt	
HH-018	180	10	Light grey loose silt	
HH-019	0	100	Surface slag sample	Surface slag sample
HH-020	50	Background	Dark loamy sand	
HH-021	100	Background	Yellow loamy clay	
HH-022	150	Background	White sandy clay	
HH-023	170	Background	White sandy clay, pink rock fragments	
HH-024	1	10	Rock sample	Rock sample collected from large slab section of tarmac adjacent ~1cm depth
HH-025	50	10	Yellow brown sandy loam	Refusal at 20-50cm after 5 attempts
HH-026	100	Background	Sand with rock fragments	
ROB-1	0	-	Rock and soil sample – dark brown colour	Mixed soil and small rocks from Kelly's Bush
ROB-2	0	-	Rock sample – light ash colour	Rock from Kelly's Bush surface
ROB-3	0	-	Rock sample – light ash colour	Rocks from Kelly's Bush surface

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 and rock 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-008 Foreshore corner @ 80cm	HH-011 Foreshore @ 50cm	HH-014 Foreshore @ 130cm	HH-015 Kelly's Bush @ 50cm	HH-017 Kelly's Bush @ 100cm	HH-021 Kelly's Bush @ 100cm	HH-025 Weil Park @ 50cm
Isotopes	**Radionuclide Activity** (Bq per kg dry weight)						
Uranium (U-238) series							
Th-234	40± 5	70± 7	50± 7	70± 7	40± 5	50± 5	40± 4
Pa-234m	<150	<140	<150	<130	<110	<70	<110
Th-230	<130	<190	<110	<150	<150	<70	<150
Pb-214	40± 4	70± 7	40± 4	60± 6	30± 3	50± 5	40± 4
Bi-214	40± 4	60± 6	40± 4	60± 6	30± 3	50± 5	40± 4
Pb-210	40± 4	50± 6	50± 5	50± 7	30± 3	50± 5	20± 3
Thorium (Th-232) series							
Ac-228	9± 1	110± 11	90± 3	140± 14	90± 9	130± 13	100± 10
Th-228	<210	<290	<200	<240	<200	<90	<30
Ra-224	90± 9	130± 13	100± 10	140± 14	90± 9	120± 12	100± 10
Pb-212	80± 8	140± 14	90± 9	140± 14	90± 9	120± 12	100± 10
Bi-212	90± 9	160± 16	80± 8	170± 17	90± 11	130± 13	<20
Tl-208	30± 3	50± 5	30± 3	50± 5	30± 3	50± 5	40± 4
U-235 series and K-40							
U-235	<10	<10	<10	<10	<10	<10	<10
Th-227	<10	<10	<10	10± 2	<10	10± 2	<10
K-40	380± 4	530± 53	540± 54	160± 16	500± 50	140± 14	100± 10

Due to the sample quantity, some rock samples were only able to be analysed qualitatively. The presence of specific isotopes in these samples is recorded below.

Sample Location and Depth	HH-019 Rocks from Kelly's Bush	ROB-1 Rocks from Kelly's Bush	ROB-2 Rocks from Kelly's Bush	ROB-3 Rocks from Kelly's Bush	HH-013 Foreshore rocks	HH-024 Kelly's Bush rocks
Isotopes	**Radionuclide Activity** (Bq per kg dry weight)					
Uranium (U-238) series						
Th-234	890± 89	400± 40	3300± 330	2000± 200	Yes	Yes
Pa-234m	1300± 130	500± 75	2500± 250	1500± 150	Yes	-
Th-230	2200± 220	700± 112	17000± 1700	11000± 1100	Yes	-
Pb-214	1100± 110	400± 40	2100± 210	1700± 6170	Yes	Yes
Bi-214	1100± 110	400± 40	2100± 210	1700± 170	Yes	Yes
Pb-210	540± 54	300± 30	1900± 190	1500± 150	Yes	Yes
Thorium (Th-232) series						
Ac-228	2300± 230	700± 70	4300± 430	3200± 1320	Yes	Yes
Th-228	2300± 299	<500	4700± 470	3600± 360	Yes	-
Ra-224	2100± 210	600± 60	4200± 420	3100± 310	Yes	Yes
Pb-212	2200± 220	700± 70	4500± 450	3300± 330	Yes	Yes
Bi-212	2200± 220	700± 70	4300± 430	3200± 320	Yes	Yes
Tl-208	820± 82	200± 20	1600± 160	1200± 120	Yes	Yes
U-235 series and K-40						
U-235	<80	<30	100± 12	100± 10	Yes	-
Th-227	90± 9	30± 4	200± 20	100± 10	Yes	Yes
K-40	240± 24	100± 2	300± 30	100± 110	Yes	-

<u>Roadway samples analysed for Radionuclide Concentrations</u>

Sample Location and Depth	Alfred Street – Road core sample - Road surface bitumen 0-50mm	Alfred Street – Road core sample - Road Base 50-100mm	Alfred Street – Road core sample - Sandy soil 100-180mm
Isotopes	**Radionuclide Activity** (Bq per kg dry weight)		
Uranium (U-238) series			
Th-234	46± 6	1300± 130	260± 26
Pa-234m	<120	1000± 100	330± 69
Th-230	<130	5500± 550	410± 41
Pb-214	35± 4	1200± 120	250± 25
Bi-214	36± 4	1100± 110	240± 24
Pb-210	<14	1100± 110	230± 23
Thorium (Th-232) series			
Ac-228	46± 5	1100± 110	280± 28
Th-228	<200	1200± 120	<260± 26
Ra-224	42± 6	970± 97	260± 26
Pb-212	46± 5	1100± 110	280± 28
Bi-212	41± 5	1100± 110	290± 29
Tl-208	18± 2	400± 40	100± 10
U-235 series and K-40			
U-235	<10	49± 5	<10± 1
Th-227	<5	76± 8	16± 2
K-40	360± 36	220± 22	170± 17

Sample Location and Depth	Avenue Road – Road core sample - Road surface bitumen 0-40mm	Avenue Road – Road core sample - Road Base 40-130mm	Avenue Road – Road core sample - Sandy soil 130-190mm
Isotopes	**Radionuclide Activity** (Bq per kg dry weight)		
Uranium (U-238) series			
Th-234	860± 86	2500± 250	150± 15
Pa-234m	990± 99	2300± 230	<65
Th-230	3000± 300	17000± 1700	<130
Pb-214	830± 83	2100± 210	130± 13
Bi-214	810± 81	2100± 210	130± 13
Pb-210	730± 73	1900± 190	120± 12
Thorium (Th-232) series			
Ac-228	1600± 160	4100± 410	280± 28
Th-228	1900± 285	3700± 370	260± 49
Ra-224	1500± 150	3900± 390	260± 26
Pb-212	1600± 160	4100± 410	270± 27
Bi-212	1600± 160	4000± 400	280± 28
Tl-208	580± 58	1500± 150	10± 1
U-235 series and K-40			
U-235	53± 13	88± 11	<7
Th-227	66± 6	160± 16	9± 1
K-40	560± 56	330± 33	150± 15

Sample Location and Depth	Nelson Parade – Road core sample - Road surface bitumen 0-60mm	Nelson Parade – Road core sample - Road Base 60-110mm	Nelson Parade – Road core sample - Sandy soil 110-220mm
Isotopes	**Radionuclide Activity** (Bq per kg dry weight)		
Uranium (U-238) series			
Th-234	850± 85	1900± 190	390± 39
Pa-234m	970± 97	<280± 28	440± 75
Th-230	1310± 157	12000± 1200	1000± 100
Pb-214	600± 60	1300± 130	350± 35
Bi-214	580± 58	1200± 120	350± 35
Pb-210	550± 55	1100± 110	280± 28
Thorium (Th-232) series			
Ac-228	2100± 210	3200± 320	580± 58
Th-228	1900± 190	3100± 310	760± 76
Ra-224	2000± 200	3100± 310	700± 70
Pb-212	2000± 200	3300± 330	740± 74
Bi-212	2000± 200	3200± 320	740± 74
Tl-208	720± 72	1200± 120	270± 27
U-235 series and K-40			
U-235	100± 13	50± 9	<20
Th-227	50± 5	130± 13	30± 3
K-40	460± 46	280± 28	190± 19

Appendix 11 – Dose rate results from roadways in Hunters Hill and surrounding suburbs

Radiation dose rate results from numerous roadways surveyed in Hunters Hill and surrounding suburbs. For sample locations, see description below.

Road Name	Relative counts per second	Dose rate (μSv/h)
Woolwich Rd	1300	0.64
Werambie St	2400	
View St	350	0.87
Hunter St	2000	
Edgecliff Rd	1400	
Elgin St	900	0.22
Woolwich Rd near oval	1000	
Woolwich Rd, corner Vernon St	600	
Woolwich Rd & Wybalena Rd	500	
Corner Croissy Av & Ferry St	600	
Corner Passy Av & Rooke Ln	1900	
Rooke St	1800	0.61
Muirbank Av & Ferry St	600	
Tiree St	900	
Ady St to Madeline St	2000	
Toocooya Rd	900	
Ellesmere Av	670	
Stanley Rd	500	
Mount St (south)	850	
Mount St (north)	1000	
Moorefield Av	1060	
Herberton Av	1400	
Durham St	400	
Madeline St	1950	
Ernest St	1200	
Ferdinand St	1500	
Serpentine Rd	1200	0.46
Vernon St	860	
Glenview Cres	1560	
Futuna St	1100	
Kareela Rd	1500	0.44
Campbell St	800	
Viret St	750	
Corner George St & Centenary Av & De Milhau Rd	1300	
Martin St	1300	
Figtree Rd &Abigail St	1300	
Martin St	400	
Bonnefin Rd	545	
Avenue Rd	2200	1.02
Corner Augustine St & Milling St	1200	
Wallace Av	700	
Mary St	600	
Gladesville Rd	740	