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ENVIRONMENTAL SURVEY AT LUCAS HEIGHTS RESEARCH LABORATORIES 1991

by

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REPORT E

AUSTRALIAN NUCLEAR SCIENCE
AND TECHNOLOGY ORGANISATION

LUCAS HEIGHTS RESEARCH LABORATORIES

ENVIRONMENTAL SURVEY AT LUCAS HEIGHTS RESEARCH LABORATORIES. 1991

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ABSTRACT

Results are presented of the environmental survey conducted in the neighbourhood of the Lucas Heights Research Laboratories during 1991. No activity which could have originated from these laboratories was found in samples collected from possible human food chains. All low-level liquid and gaseous waste discharges were within authorised limits. The maximum possible annual dose to the general public from airborne waste during this period is estimated to be less than 0.01 mSv, which is one per cent of the limit for long term exposure that is recommended by the National Health and Medical Research Council.

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ANSTO; AIR; AUSTRALIA; BERYLLIUM 7; CESIUM 137; COBALT 60; CONTAMINATION; ENVIRONMENT; EXPERIMENTAL; DATA; FRESH WATER; GASEOUS WASTES; GROUND WATER; HUMAN POPULATIONS; IODINE 131; LIQUID WASTES; MAN; MILK; PLUTONIUM 239; PLANTS; RADIATION DOSES; RADIATION MONITORING; RADIOACTIVITY; RIVERS; SAND; SOILS; STRONTIUM 90; TRITIUM.

EDITORIAL NOTE

The Australian Nuclear Science and Technology Organisation (ANSTO) replaced the Australian Atomic Energy Commission (AAEC) on 27 April 1987. Reports issued after April 1987 have the prefix ANSTO with no change of the symbol (E, M, S OR C) or numbering sequence.

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ENVIRONMENTAL MONITORING AT LUCAS HEIGHTS

1.0 INTRODUCTION

Surveys of the radioactivity levels in environmental samples collected in the vicinity of the Lucas Heights Research Laboratories (LHRL) are routinely undertaken by the Australian Nuclear Science and Technology Organisation (ANSTO) to verify that no unacceptable effects on human health and the environment have occurred or are likely to occur as a result of site operations and research activities.

These monitoring programs are designed to detect and quantify any radioactive contaminants, that may be released from LHRL either routinely as authorised discharges or accidentally, and to verify that such releases do not result in radiation doses to the general public in excess of the limits recommended by the International Commission on Radiological Protection (ICRP) and adopted by the National Health and Medical Research Council of Australia (NH&MRC).

This report summarises the results from the environmental survey during 1991 and assesses the effects of radioactive discharges on both the local population and the environment.
[The results obtained in earlier surveys have been published regularly and are listed in **Appendix A.**]

2. 0 PATHWAYS OF EXPOSURE

Under the NSW Radioactive Substances Regulations (1959), radioactive effluent discharge limits are set by special authorisation approved by the Radiological Advisory Council, or are specified in the Schedule of the Regulations. The discharge limits are based on a consideration of the possible routes through which members of the public could be exposed to activity from LHRL origin, termed *exposure pathways*. The resulting dose rates to the *critical group* (that is, the most exposed individuals) from these exposure pathways cannot exceed the prescribed limits.

Possible pathways by which radioactivity could enter the environment from LHRL are:

- atmospheric discharges from stacks (including tritium, fission products, activation products and noble gases released from isotope production facilities, research laboratories and the HIFAR research reactor);

- discharge of low-level liquid effluent, via the Water Board Sewer system;

- radionuclide transport by ground water and/or contaminated airborne dust dispersion from the Little Forest low-level radioactive waste Burial Ground (LFBG);

- accidental releases or spillages.

2.1 Atmospheric releases

Atmospheric releases from LHRL have been regulated from 1968 onwards when expansion of radioisotope production made it necessary to consider possible releases of iodine-131. Iodine-131, strontium-90 and caesium-137 have the potential to concentrate in milk after deposition onto grazing land. Thus, milk consumption by humans is a potentially significant pathway for the transfer of airborne radioactivity to food .

The critical group for the pathway of milk consumption is assumed to be one year old infants living adjacent to LHRL (Steven's Hall Motel) who obtain all their milk (0.7 L per day) from a hypothetical local dairy. Since there are no registered dairy herds near LHRL, milk samples are obtained from a cow belonging to a family living at Lucas Heights.

A hypothetical critical group for inhalation of airborne activity is assumed to consist of people living close to the site boundary. Accordingly, continuous air samplers are located close to the site perimeter fence nearest to suburban residences.
Other potential pathways for the transfer of airborne radioactivity to members of the public usually include such dietary items as drinking water and vegetable produce. However, these are not considered likely sources of exposure since that there is little or no food production or processing in the neighbourhood of LHRL and small creeks draining the site are not used as sources of drinking water.

2.2 The discharge of low-level liquid effluent

The low-level liquid effluent generated from various operations at the LHRL is treated and analysed before discharge to the sewer. Before 1980, the treated effluent was released into the Woronora Estuary and discharge limits were based on hypothetical, highly conservative exposure scenarios involving a critical group member living alongside the Woronora River. After June 1980, when the effluent was re-directed to the Water Board sewer rather than the Woronora River, the discharge limits were the maximum permissible concentration specified in the NSW Radioactive Substances Regulations (1959).

2.3 The Little Forest Burial Ground (LFBG)

Between 1960 and 1968 the then Australian Atomic Energy Commission (AAEC) used an area locally known as Little Forest (**Figure 1**) for the disposal (by burial) of solid waste with low levels of radioactivity that originated predominantly from LHRL. Shallow land burial is widely accepted internationally as a safe and practical way to dispose of low level solid radioactive waste, provided that the possible return of radionuclides via the human food chain, water, inhaled air or the external radiation environment is within the limits recommended by international bodies as acceptable for members of the general public (ICRP 1977, IAEA 1981). The site was selected and wastes disposed of using international guidelines prevalent at the time.

The possible exposure routes for the movement of radioactivity from buried waste depend upon the characteristics of the disposal site and the nature of the waste. They fall into three general categories. Two occur from the transport of particulate and/or dissolved radionuclides by water and air, respectively. The third is caused by the radiation field of the waste.

Water transport of radionuclides, involving ground and/or surface flow, can lead to contamination of :

- drinking water;
- crops from irrigated fields;
- fresh or seawater edibles.

Areas adjacent to LFBG have been used by various government and private agencies for the disposal of liquid industrial and solid municipal wastes, as well as nightsoil. Ground water and surface water associated with the LFBG and surrounding area is not utilised as a potable water supply. The ephemeral nature of the nearby streams excludes their use for any large scale irrigation of crops. The hydrogeological conditions at LFBG ensure that groundwater movement in the immediate area of the wastes is very slow and all radionuclides, except for tritium, are readily adsorbed onto the clay subsoil of the burial trenches area.

Airborne contamination at LFBG could occur through wind suspension/resuspension of radioactive materials at the ground surface. Surface contamination can arise from erosion of any cover material, or through the movement of contaminated ground water to the surface followed by precipitation or evapo-transpiration. The airborne transport route requires further consideration at LFBG because beryllium oxide was also buried there. Beryllium is not radioactive but it is toxic if inhaled as a fine dust.

Direct exposure to external radiation from buried waste is significant only if the waste becomes exposed through either physical upheaval or erosion of the cover, and ground water transports the dissolved radionuclides to the surface, since the thickness of the soil cover is more than enough to shield the buried waste.

3.0 DISCHARGE AUTHORISATIONS

The policy of ANSTO and AAEC since the 1960's has been to comply with the requirements of both the NSW Radiological Advisory Council (NSW RAC) and the NSW Radioactive Substances Regulation (1959) as amended, regarding the discharge of radioactive effluents from the LHRL. The authorised discharge limits for both liquid and gaseous discharges approved by the Radiological Advisory Council were based on a consideration of a conservative set of exposure scenarios and associated pathways through which a member of the public could be exposed to radiation doses. Compliance with these discharge limits is continuously monitored by ANSTO.

Summaries of radioactive discharge data have been published in annual environmental survey reports (**Appendix A**). More detailed information, including sampling and

measurement techniques, has been provided to the Radiation Health Services Section of the Department of Health.

Regular compliance auditing of ANSTO gaseous emissions and liquid effluent discharges was carried out by the Radiation Health Services Section of the Department of Health. Random auditing of liquid effluent discharges was also undertaken by the Water Board.

3.1 Low Level Liquid Effluent

In early 1961, the Maritime Services Board and the NSW RAC formally authorised liquid effluent discharge limits for discharges of treated effluent from the LHRL, via a pipeline, to the tidal reaches of the Woronora River. The authorisation was based on a report by Wilson (1959). In 1966, a revised formula was approved based on a formula described by Fry (1966).

This authorisation remained in place until discharge were redirected to the Water Board (previously the Metropolitan Water Sewerage and Drainage Board) sewer in mid-1980. Discharge to the sewer means that ANSTO was required to comply with both the Water Board Standards for Acceptance of Liquid Trade Waste to Sewers, and the NSW Radioactive Substances (Regulation (1959), as amended).

Radioactive liquid wastes receive batch chemical treatment prior to discharge to the sewer. Radioactive liquid waste is analysed before and after treatment and all batches of liquid effluent discharged off site pass through on-line proportional sampling system.

3.2 Gaseous Emissions

In 1968, a major review was undertaken of all sources of radioactive gaseous effluents at LHRL with a view to establishing recommended permissible discharge rates. As a result, new working limits were derived and these were approved by the NSW RAC.

These limits have recently been reviewed (ANSTO/CR25, 1989) using a newly developed computer model based on limiting doses to continuously exposed members of the public. This was submitted to the NSW RAC for approval as a site-wide airborne radioactive discharge authorisation.

Appendix B lists the various types of radioactive airborne effluent releases from LHRL and their origin.

3.3 Surface Waters

The NSW Clean Waters Act (1972) as amended limits the gross alpha and gross beta activity in waters to 1.1 and 11.1 Bq/L, respectively. In order to assess ANSTO's compliance with these regulations sampling points were selected by the then State Pollution Control Commission (SPCC) at Strassman, Barden and MDP Creeks surrounding the site and shown in **Figure 1.**

4.0 ENVIRONMENTAL SAMPLE COLLECTION AND PREPARATION

Environmental samples were collected at the sites shown in **Figures 1,2 & 3**, and details of collection and sample preparation are given in **Table 1**. The isotope symbols used in this report are listed in **Appendix C**.

The levels of activity encountered in environmental samples are usually very low. Therefore, the samples are often concentrated so meaningful analyses can be performed. These concentrated samples can be stored for long periods, in case further re-analysis is required. Removing water by drying procedures is the simplest technique. Samples can then be ashed in a muffle furnace to reduce the carbon content and concentrate the sample even further.

Sediments

The stormwater outlets tend to accumulate sediments, and these are sampled with a scoop to take the first 4 cm from the surface. The samples are checked for gross levels of alpha and beta activity as well as gamma emitters. Results are recorded as Bq/g dry weight (DW) of sample.

Soils

Soils are dried, stones and vegetable matter removed manually, and passed through a quarter-inch mesh sieve. The soil is then ashed, and is ready for gross beta counting. The ashed sample is sieved further, and the fraction between 60 and 100 mesh BSS used for alpha counting. Results are in Bq/g Dry Weight (DW).

Vegetation, biota

The vegetation samples are available only in sufficient quantities at sites where the drains are large enough to retain enough water to support plant growth. The plant species sampled, 2-3kg, is Crofton Weed (*Eupatorium adenophorum*). The whole, unwashed vegetation is then dried and ashed. Results are expressed in terms of the fresh weight (FW) of the sample.

Ashed samples of vegetation, milk, oysters, etc., are ground and homogenised in a mortar and pestle, then compacted into 2-inch diameter tablets using a hydraulic press. This ensures that the samples are presented to the alpha, beta or gamma detectors in uniform dimensions.

Surface and Ground Waters

Surface waters from the SPCC sampling points (which comply with the NSW Clean Waters Act Regulations) are evaporated in small aliquots onto aluminium planchettes according to the Australian Standard Method 3550.5-1990.

Ground water samples (10 litres or more) are evaporated and the residue counted for radioactivity. Results are in Bq/Litre for most samples, but in Bq/g sediment for the groundwaters from LFBG.

Water samples for tritium analysis are distilled and counted in a Liquid Scintillation Counter (LSC) following the International Standard Method ISO 9698:1989(E), and results are quoted as Bq/mL.

5.0 MEASUREMENT OF RADIOACTIVITY

5.1 Units of measurement

Radioactivity
The SI (International System) unit of radioactivity is the Becquerel (Bq). One becquerel is equal to one nuclear disintegration per second. This is a direct measure of the amount of radioactivity in a sample.
Radiation dose
The absorbed dose is the energy imparted to matter by ionising radiation per unit mass of irradiated material at the place of interest. The dose equivalent, often referred to as the effective dose, is the product of absorbed dose at the point of interest in tissue and the quality factor (QF). This measurement enables the dose received by exposed persons to be expressed on a scale common to all ionising radiation. The unit for dose equivalent is the sievert (Sv). This dose is most commonly expressed as millisieverts (mSv). The dose limit to the general public recommended by the ICRP and adopted by the NH&MRC is 1 mSv/year. Section 8 discusses the potential effective doses to humans from activities at LHRL based on the results of environmental monitoring in 1991, and the actual airborne effluent stack release data.

5.2 Types of radioactivity measured

Following is a brief explanation of the types of radioactivity measured in these environmental surveys. The precise definitions of terms can be found in the Glossary.

Gross alpha activity: refers to the measurement of unspecified alpha-emitting nuclides in a sample. Screening for gross alpha emitters is a rapid, simple qualitative technique used to determine whether more complete analyses for specific radionuclides is warranted.

Gross Beta activity: similar to gross alpha, but concerned with to the measurement of unspecified beta-emitting nuclides in a sample.

Gamma activity: Radionuclides emitting gamma activities, gamma photons are detected by semiconductor detectors, high purity germanium crystals. A spectrum of counts for each sample is accumulated for gamma photopeaks in the energy range 0 to 2000 keV. The photopeaks in the spectrum are then analysed for significant nuclides and the specific activity calculated. Nuclides detected by this method include cobalt-60 (half-life 5.26 years), caesium-137 (half-life 30.2 years) and iodine-131 (half-life 8.08 days).

Iodine-131: This radionuclide has a half-life of only 8 days, but is biologically important because it can deposit onto pasture and be incorporated into milk. Human consumption of this milk can then lead to iodine-131 up-take by thyroid tissue.

Further, inhalation of gaseous iodine-131 can also result in doses to the lung and thyroid.

Tritium: Tritium (H-3) is an isotope of hydrogen , with a half-life of 12.26 years. It decays by the emission of a weak beta particle, with a maximum energy of 18.6 keV and an average energy of 5.69 keV. The penetration of the tritium beta is consequently low, the stopping distance in air is about 7 mm, and by 0.01 mm thickness of paper, or the outer dead layer of human skin. Thus, only exposure through internal uptake needs to be considered in assessing radiation dose. The allowable limit of intake for tritium is relatively high in comparison with other radionuclides. The guideline value for safe levels of tritium in drinking water is derived as follows, in line with the approach used in the draft revision of the World Health Organisation (WHO) Drinking Water Guidelines:

$$\textit{Guideline value (Bq/L)} = \frac{\textit{committed effective dose (mSv/year)}}{\textit{annual consumption of water x dose conversion factor}}.$$

This equation involves the following assumptions:

Committed effective dose - The committed effective dose limit for an individual nuclide in drinking water is set at 0.1 mSv/year, which is approximately a twentieth of the average background radiation dose from all sources (UNSCEAR, 1988);

Volume of water consumed - The volume of water consumed by an adult each day is assumed to be 2 litres. This figure is used by the World Health Organisation and is believed to be appropriate for Australian conditions. Annual consumption is then 730 litres;

Dose conversion factor - Once a radionuclide is inside the body, its metabolic behaviour and internal dosimetry (*i.e.* the effect of a given dose on specific organs) must be considered. This yields the dose conversion factor, which is the effective dose (in mSv) received as a result of ingesting one becquerel of the radionuclide (NRPB, 1991). The dose conversion factor for tritium is 1.8×10^{-8} mSv/Bq. For tritium, the drinking water guideline value is then calculated as follows:

$$\text{Guideline value (Bq/L)} = \frac{0.1\text{mSv}}{730\text{ L} \times 1.8 \times 10^{-8}\text{ mSv/Bq}}.$$

$$= 7610\text{ Bq/L or } \mathbf{7.6\ Bq/mL}$$

Similar calculations for caesium-137 yield a guideline value of 365 Bq/L or 0.37 Bq/mL.

5.3 Natural radioactivity in environmental samples

Uranium and thorium series

The uranium-238 and thorium-232 chains are two of the primordial radioactive decay series found in nature. The extremely long half-lives (approx. 4.5×10^9 and 1.4×10^{10} years respectively) of the parent nuclides mean that the various daughter radionuclides produced by their decay are ubiquitous in nature, occurring to varying degrees in soils, water, vegetation and air. When present in environmental samples, the daughter products of the uranium and thorium series can contribute significantly to the levels of gross alpha, gross beta and gamma radioactivity of such samples. The activity of members of the uranium and thorium series seen in LHRL environmental survey samples, has not been quantified because detailed extensive procedures are required to take into account the natural origin of such activity. Whenever they are detected by gamma spectroscopy, this is noted in the relevant tables under the heading "gamma-emitters" simply as "U & Th series". Typical activities of uranium and thorium and each of their 24 radioactive daughters range from 0.005- 0.048 Bq/g in different rock types.

Potassium-40

Potassium-40 is a primordial radioisotope of potassium which is biologically important since it found in all living and formerly living things. Potassium is an essential element for humans, and is absorbed mainly from ingested food. Potassium-40 does not accumulate in the body but is maintained at a constant level. The average concentration of potassium in an adult male is about 2g per kg of body weight, or about 60 Bq of potassium-40 per kg of body weight.

Potassium-40 occurs naturally in a fixed ratio to stable potassium, and decays by beta emission with a specific activity is 27.6 Bq/g of stable potassium (NH&MRC 1987). For crustal rock, the mean potassium-40 activity is 0.63 Bq/g, while some granites may have concentrations exceeding 1.85 Bq/g (Kathren 1984). Soils are lower, with a mean of around 0.44 Bq/g. Concentrations in seawater are approximately 10 Bq/litre.

Most gross beta measurements of LHRL survey samples have the contribution from potassium-40 deducted. The potassium-40 activity has been calculated in two ways in the past; either by direct calculation from its 1460 keV peak in the gamma spectrum of the sample, or by chemical analysis of the potassium content and a subsequent calculation of the potassium-40 activity from the specific activity figure. In many cases, the beta activity of samples is almost entirely due to the potassium-40.

Beryllium-7

Beryllium-7 is a cosmic-produced spallation product mainly seen in vegetation and occasionally in soils.

5.4 Analytical methods

Analytical procedures used for the measurement of radioactivity in the survey samples are described in **Appendix D.**

5.5 Meteorological measurements

In common with many other nuclear facilities, ANSTO undertakes an extensive program of meteorological measurements. The prime reason for such a program is to allow estimates to be made of the downwind concentration of any airborne pollutants, particularly radionuclides, released from the site through routine operations or under accident conditions. The data collected from this program provide the necessary input to the atmospheric dispersion model called ADDCOR (ANSTO 1989) which can be used to compute the effective dose to an individual due to the routine airborne or accidental release of radionuclides from the LHRL.
The monitoring stations used to gather local meteorological data are shown on **Figure 1.**
The meteorological tower and associated laboratory are shown on **Figure 4.**

6.0 RESULTS

Environmental survey measurements during 1991 are presented in **Tables 2 to 13.**

Authorised airborne release data are given in **Tables 14 & 15.**

Authorised liquid effluent discharges to the Water Board sewer are summarised in **Table 16.**

7.0 DISCUSSION OF RESULTS

7.1 Airborne releases

Some radioactive material is inevitably released through gaseous emissions from the stacks at LHRL. The location of these discharge stacks around the site is shown on **Figure 4.**

Appendix B summarises the types of stack discharges which occur at LHRL and comments on their causes.

Estimates of possible doses to members of the public due to airborne releases from LHRL can be made by utilisation of the ADDCOR air dispersion and dosimetry computer model and the airborne stack release data (**Section 8**). In addition, continuous air sampling stations are positioned inside the site perimeter fence to monitor for iodine-131. The critical group for the pathway of inhalation of iodine-131 is an hypothetical infant living at Stevens Hall Motel.

Measurable quantities of iodine-131 were occasionally recorded in air samplers during 1991 (**Table 2**). The highest reading , registered for the week ending 16 April 1991, was 3.6 x 10^{-2} Bq /m^3 or 0.36 % of the derived working limit of 10 Bq /m^3 . The derived air concentration (DAC) for iodine-131 in air for the most sensitive individuals, i.e. child members of the public, is 10 Bq /m^3 (CRP 1977, 1990a, 1990b).

The average iodine-131 concentration in air for the year was 4.0 x 10^{-3} Bq/m^3, which at 0.04 % of the DAC is well below the recommended ICRP limit for members of the public.
The average concentration of iodine-131 in air would have resulted in an effective dose of <0.3 x 10^{-2} mSv/y or <0.6 x 10^{-3} of the limit for total body dose as recommended by the NSW Radioactive Substances Regulations, 1959.

The milk monitoring data for caesium -137 and iodine-131 are given in **Table 3**. No caesium-137 or iodine-131 was detected in milk throughout the year.

Table 14 presents the quarterly airborne emissions for the individual stack release points, and **Table 15** lists the same figures expressed as percentages of the quarterly authorised discharge limits. In previous environmental survey reports, the figures in **Table 15** were expressed as fractions. Where values in **Tables 14 & 15** are quoted as less-than figures, the figure is the maximum possible discharge, based on the limits of detection. It does not imply that the radioactivity has been detected in the effluent.

Figures for the gross alpha and the gross beta activity are quoted 3 months in arrears to permit more accurate figures for the long-lived alpha and beta activities. In past reports, the gross beta activity was reported as strontium-90 because this is the most restrictive radionuclide. The levels measured are usually below the limit of detection, indicating that no significant strontium-90 activity, if any, has been discharged from the site.

Past discharge records show that for the period 1977 to 1991, the majority of airborne emissions from LHRL have been consistently well below the limits authorised by the relevant authorities. In most instances, the discharges can be regarded as negligible. However, discharges of noble gases from HIFAR and the Bld.54 hotcells, as well as iodine-131 from Bld.23A and Bld.54 hotcells, occasionally approached the quarterly guideline values. **Table 15** shows that the airborne discharge for noble gases from Bld 15 (HIFAR) during the third quarter exceeded the quarterly working limits by 5%. This occurred during the start-up and commissioning of HIFAR after an extended shut-down for major refurbishments. However, since the NSW RAC authorisation is for yearly discharge limits, the concentrations must be as average over a period of one year. Since the averages for most periods are below the annual discharge limits for each stack, the authorisation has never been exceeded.

If it is assumed that airborne emissions were at the maximum authorised levels throughout the year, and there is continuous exposure, the most exposed individual would receive less than 0.01 mSv per year, *i.e.* less than 1% of the public dose limit of 1 mSv per year using the calculation method of Petersen (1982).

7.2 Woronora estuary samples

Discharges of radioactive effluents to the Woronora River from LHRL ceased on 1 July 1980. Residual levels of radioactivity in samples from the estuary were monitored until December 1983 when no further extraneous radioactivity could be measured. Routine water samples are collected on a weekly basis from the boat ramp in Jannali Reserve throughout the year. These water samples are analysed for tritium as a precaution against unknown accidental releases. No tritium was detected in these samples during 1991 (**Table 4**).

7.3 Stormwater outlets and creeks draining LHRL

Results for samples of soil and vegetation collected in stormwater drains are shown in **Table 5**. Results for water samples collected at the same sites are shown in **Table 6**. Samples are collected every three months, after rain, if possible. However fewer water samples were available this year due to dry conditions at the time of sampling.

Stormwater
Caesium-137 was occasionally identified in water samples from stormwater outlet No.1, which drains the SE corner of the site into MDP creek (**Figure 2**). Measurable amounts of radioactivity were also detected in samples of soil and vegetation collected at this point.

If the extremely improbable scenario is assumed that a person took all of his or her drinking water supplies from this stormwater, the average caesium-137 concentration in water measured during 1991 (**Table 6**) represents much less than 1% of the guideline value recommended by WHO (**Section 5.2**).

The detection of small but measurable quantities of tritium in stormwater and creeks draining the site is not unexpected at LHRL, since tritiated water vapour, released into air from HIFAR operation will readily exchange with rain water and other free water surfaces. Tritium was occasionally detected in stormwater drains, at levels well below the drinking water guideline value of 7.61 Bq/mL (**Section 5.2**). None of the stormwater from LHRL drains into any drinking water supply, therefore the tritium found has no health significance.

Gross alpha and beta radiation results for stormwater outlet No.1 were at background levels.

Vegetation & soils
There is extensive growth of Crofton Weed in stormwater outlet No.1. Samples collected here since 1990 have shown residual levels of the fission products caesium-137, caesium-134, cobalt-60, americium-241, cerium-144 and zirconium-95. Natural activity detected includes beryllium-7, potassium-40, uranium and thorium series. Since this plant concentrates and retains elements and radionuclides from its environment, these isotopes will be seen in vegetation from this area while ever contaminated water and sediment exists in this area.

Traces of caesium-137 and cobalt-60 were found in sediment from the drains in the area opposite Bld 23, where isotope production is carried out.

The low levels of activities found in these soil and vegetation samples do not have any consequences for humans because no pathway to the human food chain exists.

Creek water - SPCC sampling points

The stormwater which drains from the LHRL flows into three small local streams which are classified as class 'C' waters under the NSW Clean Waters Regulation (1972) as amended. The then SPCC, required that the stormwater be sampled periodically at selected locations, in order to demonstrate compliance with the activity limits specified in the Regulations. Sampling points on Strassman Creek, Bardens Creek and MDP Creek (**Figure 2**) were sampled and analysed for gross alpha and beta activity. This data is presented in **Table 7**. Here the gross beta activity results include the contribution of natural potassium-40. All results were well below the NSW Clean Waters limits of 1.1 Bq/L for gross alpha activity, and 11.1 Bq/L for gross beta activity, and in most cases were close to the limits of detection.

Samples of water were collected from the SPCC sampling weir on Bardens Creek at weekly intervals during 1991, for tritium analysis. The results are shown in **Table 8**. The highest value recorded during the year was 0.92 Bq/mL, which is 12.1% of the guideline value for tritium in drinking water (**Section 5.2**). The average weekly concentration at this location was 0.40 Bq/mL, which is 5.3% of the guideline value. It should be noted that water from Bardens Creek is not a part of our known drinking water supply.

7.4 Effluent discharge pipeline

Surveys of the dose rates along the ANSTO effluent liquid disposal pipeline (**Figure 2**), which runs above ground for much of its length, were carried out in 1991, and the results are summarised in **Table 9**. These surveys were performed as part of the regular care and maintenance of the pipeline program.

The dose rates recorded along the pipeline from 1978 to 1991 ranged from 0.0003 to 0.001 mSv/hour. The maximum annual effective dose for continuously exposed members of the public is 1 mSv (ICRP 1979). Because of the isolated position of the exposed sections of the pipeline, the likelihood of continued exposure of any member of the public is extremely low, so the limits would not be exceeded.

7.5 Little Forest Burial Ground (LFBG)

Results of sampling at the LFBG are given in **Tables 10, 11, 12** and **13**. The locations of the sampling points and the burial trenches are shown on **Figure 3**.

Groundwater Monitoring

Annual surveys of the burial trench area are carried out by the environmental monitoring team with field dose rate monitors to check for surface contamination.

Groundwater from bores located inside the LFBG and outside the fenced area was analysed for tritium, gross alpha, gross beta and gamma emitters.

Tritium, as tritiated water, does not undergo geochemical processes such as ion exchange, adsorption or precipitation when it flows through geologic media. Accordingly it travels at the same velocity as groundwater. Tritium levels in monitoring bores outside the fenced area were less than the limit of detection. Tritium is readily detectable inside the burial ground with higher values adjacent to the burial trenches. Levels of tritium found in bores BHF, BH10, OS2, OS3, MB12, MB13, MB15, MB16 and MB17 are similar to those measured in the past. The detected concentrations are of no health significance since the groundwater at LFBG is not used for any purpose. The general quality of groundwater in the Little Forest area is affected by the presence of nearby sites used for the disposal of night soil, industrial liquid wastes and municipal wastes.

The levels of gross alpha and beta activity in groundwater are similar to those found in the past, and are mainly due to the contribution from natural uranium and thorium series, and potassium-40.

Due to the high levels of suspended solids (silt) in many of the bore waters, radionuclides of the uranium and thorium series are routinely detected at environmental levels. The only bore which contained fission-product gamma activity was MB16, which is not unexpected since this bore is in the centre of the burial trench area.

Soil and vegetation

Samples of soil and vegetation were collected from the area near MB16, to monitor for any expression of buried activity at the surface. The levels of activity measured are consistent with naturally occurring background concentrations for potassium-40, gross alpha and beta, beryllium-7 and the uranium & thorium series. The cobalt-60 and caesium-137 levels found at a very localised site, point #6, were consistent with those measured in the past indicating some expression of these radionuclides which has not changed significantly in the recent past.

Creeks draining LFBG

No tritium or other activity above background levels was found in samples of surface water and sand collected from station T2 (junction of Mill Creek and Bardens Creek).

Air sampling

No beryllium (Be) or plutonium-239 was detected on aerosol filters from the air sampling station near the burial trenches. The minimum detectable level for Be is 0.2×10^{-3} mg/m^3 and for plutonium-239 is 2.0×10^{-5} Bq/m^3. The threshold level value (TLV) for Be is 2×10^{-3} mg/m^3, and the derived working concentration (DWC) for plutonium-239 is 5×10^{-3} Bq/m^3. These limits were conservatively calculated assuming chronic exposure for 24 hours each day.

8.0 POTENTIAL RADIATION EXPOSURE OF MEMBERS OF THE PUBLIC RESULTING FROM OPERATIONS AT LUCAS HEIGHTS

The principle sources of potential radiation exposure to members of the public from routine operations at LHRL are from airborne and low level liquid effluents. These effluents are controlled in compliance with formal discharge authorisations of the NSW Radiological Advisory Council or limits specified in the NSW Radioactive Substances Regulation (1959) as amended. The authorised discharge limits were based on limiting the doses to hypothetical members of the public at nominated receptor locations (eg. 100% occupancy at the site fence) to levels below the public dose limits. At no time in the operation of the LHRL facilities have these dose limits been exceeded.

Airborne Emissions

In order to evaluate doses at various receptor location from airborne discharges, a recently developed (ANSTO,1989) atmosphere transport, dispersion and dosimetry computer code (ADDCOR) was used. **Table 17** summaries the calculated public doses at LHRL at the various receptor locations. These can be compared with typical levels of radiation doses to the public from natural radioactivity in the environment as well as from medical sources shown in **Tables 18 and 19**. It can be readily seen that the estimates resulting from continuous discharge of airborne effluent from LHRL even at the 1968 authorised limit, are at least two orders of magnitude less than the background radiation level of 2 mSv per year.

Low level liquid effluent

Radioactive liquid waste is chemically treated before controlled discharge to the Water Board sewer. Prior to 1980, discharges were routinely made to the Woronora River. Dose estimates based on actual radioactive concentrations measured in environmental samples from 1969 to 1979 were given in the relevant environmental survey reports (**Appendix A**). These dose estimates confirmed the negligible impact on public health of low level liquid effluent discharges to the Woronora Estuary. Current discharge into the sewer will have an even lower impact because of the greater dilution factors inherent in ocean discharge (the discharge outlet from Cronulla Sewage Treatment Plant is at Potter Point).

9.0 CONCLUSIONS

None of the samples taken from possible human food chains in the vicinity of the Lucas Heights Research Laboratories contained radioactivity which could be attributed to the operation of the site.

Discharges of airborne radioactive gases were within authorised limits when averaged over the year (**Tables 14 and 15**). The dose to the most sensitive members of the public from iodine-131 releases, calculated from the results in **Table 2**, was $<0.4 \times 10^{-3}$ mSv/year and the calculated dose from released noble gases to the most exposed individuals was less than 0.01 mSv/year. These figures represent less than one per cent of the most restrictive limits recommended by the NH&MRC.

The annual average liquid effluent discharge to the Water Board Sewer during 1991 **(Table 16)** was less than 29 per cent of the permitted level. For tritium, the concentration was less than 2 per cent of the specified limit.

The data presented in this report clearly shows that the environmental impact of operations at LHRL has been very low. The effective dose to residents living in the immediate neighbourhood of the reactor are very difficult to measure directly but calculated dose estimates are far lower than those due to natural background radiation and medical exposures.

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Alpha spectrometry (for plutonium-239) on the composite air filter sample from the LFBG was performed by the Environmental Radiochemistry Laboratory.

Airborne effluent release data (**Table 14**) were supplied by ANSTO's Health and Safety Program.

Liquid effluent release data (**Table 16**) were supplied by Waste Management (Nuclear Technology Program).

The information in **Section 8** was contributed by D.Woods of ANSTO's Health and Safety Program.

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TABLE 1

SAMPLE COLLECTION SCHEDULE AND PREPARATION DETAILS

Sample	Station	Frequency	Collection Details	Special Preparations
Stormwater	MDP Creek 60m from LHRL Outlet No.1	Weekly	3L, sampled with polyethylene bottle	Weekly samples evaporated to dryness, the residue combined to form a monthly composite sample for α,β,γ counting. 250mL collected and distilled for tritium
	Others	Quarterly (after rain)	250 mL, sampled by bottle at the drain outlet	Distilled for tritium
Estuary water (Woronora River)	E5.9	Weekly	250 mL, sampled by bottle ar surface	Distilled for tritium
Radioactive iodine in air	Along the eastern boundary of the site (stations 1,2,3,4)	Weekly	Collected on Maypacks (charcoal filters)	Gamma spectrometry of Maypacks
Milk	T4	Monthly	Sampled from milk produced by locally grazed cow	Gamma spectrometry of whole milk
Vegetation (Crofton Weed)	LHRL stormwater outlets	Quarterly (where available)	Stems & leaves clipped	Gross $\alpha\beta$ Gamma spectrometry of whole unwashed vegetation (ashed)
Groundwater	Little Forest Burial Ground (LFBG)	Six monthly	MB series bore holes; pumped dry, allowed to refill and sampled from the bottom of the bore	10L sample evaporated to dryness.The residue counted for α,β,γ.250mL distilled for tritium
Sand / Soil	LFBG	Six monthly	Scooped from surface	Gamma spectrometry of sieved & ashed sample. Gross α β counting also
	LHRL stormwater outlets	Quarterly	At drain outlet	
	T2: Barden & Mill Creeks	Yearly	From creek bed	as above

Table 1 continued ...

Sample	Station	Frequency	Collection Details	Special Preparations
Be, ^{239}Pu in dust on air filters	Little Forest Burial Ground	Quarterly	Duplicate samples collected on 0.8 μm aerosol filters	Subsampled for Be analysis. Composite of quarterly samples for ^{239}Pu analysis by alpha spectrometry
Creek water	Bardens Creek Weir	Weekly	250 mL, sampled from weir overflow	Distilled for tritium
	Weirs on Bardens Ck & MDP Ck; Strassman Ck	Monthly	1Litre, sampled after rain	Gross α β according to Clean Waters Act Regulations: AS 3550.0 (1990)
	T2: Barden & Mill Creeks (above junction)	Yearly	5 L, surface water	Evaporated to dryness, and residue counted for α,β,γ. 250ml distilled for tritium
Effluent Pipeline (dose)	Joints and ground below	Six monthly	Soil samples collected if dose rate is high	Gamma spectrometry and gross α β counting of sieved & ashed soil

TABLE 2

RADIOACTIVE IODINE IN AIR, 1991

Sampled during the week ending :	Iodine-131 in air (Bq/m^3)	Sampled during the week ending :	Iodine-131 in air (Bq/m^3)
8.1.91	0.0027	2.7.91	LLD
15.1.91	LLD	9.7.91	LLD
22.1.91	0.0027	16.7.91	LLD
29.1.91	0.0031	23.7.91	LLD
5.2.91	LLD	30.7.91	LLD
12.2.91	0.005	6.8.91	LLD
19.2.91	LLD	13.8.91	LLD
26.2.91	LLD	20.8.91	LLD
5.3.91	0.024	27.8.91	LLD
12.3.91	0.0068	3.9.91	LLD
19.3.91	0.0034	10.9.91	LLD
26.3.91	LLD	17.9.91	LLD
2.4.91	LLD	24.9.91	LLD
9.4.91	LLD	1.10.91	-
16.4.91	0.036	8.10.91	0.007
23.4.91	0.0073	16.10.91	LLD
30.4.91	LLD	24.10.91	LLD
7.5.91	0.0028	29.10.91	LLD
14.5.91	LLD	5.11.91	0.0029
21.5.91	LLD	12.11.91	LLD
28.5.91	LLD	19.11.91	0.0049
4.6.91	LLD	26.11.91	0.0045
11.6.91	LLD	3.12.91	LLD
18.6.91	LLD	10.12.91	0.0034
25.6.91	LLD	17.12.91	0.0026
		24.12.91	LLD

Notes:
Four air samplers are located along the eastern boundary of the site, where suburban residences are closest (Figure 2). Results are calculated making the conservative assumptions that:
(i) all iodine-131 activity was released during the first day of the sampling period; and
(ii) all the activity was concentrated at one sampling point.

LLD = Less than the limit of detection, which is 0.0025 Bq/m^3 for iodine-131 in air.

TABLE 3

RADIOACTIVITY IN LOCAL MILK, 1991

Station	Date	Radioactivity (Bq/g fresh milk)	
		Caesium-137	Iodine-131
T4 (Menai)	31.1.91	LLD	LLD
	28.2.91	LLD	LLD
	28.3.91	LLD	LLD
	30.4.91	LLD	LLD
	28.5.91	LLD	LLD
	28.6.91	LLD	LLD
	29.7.91	LLD	LLD
	28.8.91	LLD	LLD
	1.10.91	LLD	LLD
	31.10.91	LLD	LLD
	28.11.91	LLD	LLD
	20.12.91	LLD	LLD

LLD = Less than the limit of detection. For iodine-131 in milk this is 0.001 Bq/g fresh milk. For caesium-137 the minimum detectable level is 0.0003 Bq/g fresh milk.

TABLE 4

TRITIUM IN WORONORA RIVER WATER SAMPLES
FROM STATION E5.9, 1991

Date	Tritium (Bq/mL)	Date	Tritium (Bq/mL)
2.1.91	LLD	2.7.91	LLD
8.1.91	LLD	9.7.91	LLD
15.1.91	LLD	16.7.91	LLD
22.1.91	LLD	23.7.91	LLD
29.1.91	LLD	30.7.91	LLD
5.2.91	LLD	6.8.91	LLD
12.2.91	LLD	13.8.91	LLD
19.2.91	LLD	21.8.91	LLD
26.2.91	LLD	27.8.91	LLD
5.3.91	LLD	3.9.91	LLD
12.3.91	LLD	10.9.91	LLD
19.3.91	LLD	17.9.91	LLD
26.3.91	LLD	24.9.91	LLD
2.4.91	LLD	1.10.91	LLD
9.4.91	LLD	8.10.91	LLD
16.4.91	LLD	16.10.91	LLD
23.4.91	LLD	24.10.91	LLD
30.4.91	LLD	29.10.91	LLD
7.5.91	LLD	5.11.91	LLD
14.5.91	LLD	12.11.91	LLD
21.5.91	LLD	19.11.91	LLD
28.5.91	LLD	26.11.91	LLD
4.6.91	LLD	3.12.91	LLD
11.6.91	LLD	10.12.91	LLD
18.6.91	LLD	17.12.91	LLD
25.6.91	LLD	24.12.91	LLD

Notes:
LLD = Less than the limit of detection for tritium,which is 0.25 Bq/mL.

The guideline value for tritium in drinking water is 7.61 Bq/mL (WHO, NH&MRC Drinking Water Guidelines).

TABLE 5

RADIOACTIVITY IN SAMPLES OF SOIL AND VEGETATION
FROM STORMWATER OUTLETS, 1991

Sample Location	Date	Sample type	RADIOACTIVITY (Bq/g DW or FW#)			
			Gross α	Gross β *	γ-emitters	^{40}K
Drain on road at west fence	22.2.91	soil	0.24	0.13	U & Th series	ND
	30.4.91	soil	0.31	0.15	U & Th series	ND
	6.9.91	soil	0.22	0.12	U & Th series	0.01
	30.10.91	soil	0.30	0.89	U & Th series	0.08
Drain opposite Fermi Street	22.2.91	soil	0.40	0.27	U & Th series	ND
	30.4.91	soil	0.69	0.31	U & Th series	0.09
	6.9.91	soil	0.58	0.49	U & Th series trace ^{60}Co trace ^{137}Cs	ND
	30.10.91	soil	0.76	1.38	U & Th series ^{60}Co=0.009 ^{137}Cs=0.006	0.21
Drain opposite Bld 23	22.2.91	soil	0.50	0.25	U & Th series ^{60}Co=0.022	ND
	30.4.91	soil	0.70	0.40	U & Th series ^{60}Co=0.10 ^{137}Cs=0.017	0.14
	6.9.91	soil	0.67	ND	U & Th series ^{60}Co=0.006 ^{137}Cs=0.005	0.20
	30.10.91	soil	0.66	1.33	U & Th series ^{60}Co=0.011	0.07
Drain No.1 opp. Strassman Crescent	22.2.91	soil	0.36	0.27	U & Th series ^{60}Co=0.020 ^{7}Be=0.098	0.13
	22.2.91	vegetation	0.01	0.18	U & Th series ^{7}Be=0.048	0.22
	30.4.91	soil	0.59	0.31	U & Th series	0.14
	30.4.91	vegetation	<0.01	0.02	U & Th series ^{7}Be=0.020	0.09
	6.9.91	soil	0.22	0.10	U & Th series	0.07
	28.8.91	vegetation	0.04	0.04	U & Th series ^{7}Be=0.010	0.12
	30.10.91	soil	0.24	0.90	U & Th series	0.15
	30.10.91	vegetation	0.07	0.15	U & Th series ^{7}Be=0.011	0.14
Drain opposite meteorological tower	22.2.91	soil	0.31	0.22	U & Th series ^{137}Cs=0.020	0.10
	30.4.91	soil	0.37	0.23	U & Th series	0.09
	6.9.91	soil	0.50	0.17	U & Th series	0.11
	30.10.91	soil	0.48	1.20	U & Th series	0.12

TABLE 5 continued ...

Sample Location	Date	Sample type	RADIOACTIVITY (Bq/g DW or FW#)			
			Gross α	Gross β *	γ-emitters	^{40}K
20 m from Stormwater Outlet No.1	22.2.91	soil	0.95	0.82	U & Th series ^{137}Cs=0.12 ^{134}Cs=0.007 ^{144}Ce=0.079 ^{241}Am=0.013 ^{95}Zr=0.005	0.10
	22.2.91	vegetation	0.01	0.23	U & Th series ^{137}Cs=0.14 ^{134}Cs=0.011 ^{7}Be=0.053	0.16
	30.4.91	soil	1.51	1.79	U & Th series trace ^{60}Co ^{137}Cs=0.61 ^{134}Cs=0.034	0.21
	30.4.91	vegetation	0.0044	0.17	^{137}Cs=0.062 ^{134}Cs=0.004 ^{7}Be=0.017	0.08
	6.9.91	soil	1.5	2.55	U & Th series ^{60}Co=0.008 ^{137}Cs=1.1 ^{134}Cs=0.08 ^{144}Ce=0.27 ^{241}Am=0.12	0.02
	28.8.91	vegetation	0.06	0.03	U & Th series ^{137}Cs=0.028 ^{144}Ce=0.008 ^{7}Be=0.020	0.16
	30.10.91	soil	1.14	2.07	U & Th series ^{60}Co=0.070 ^{137}Cs=0.15 ^{134}Cs=0.010 ^{144}Ce=0.12 ^{241}Am=0.025	0.17
	30.10.91	vegetation	0.03	ND	U & Th series ^{60}Co=0.007 ^{137}Cs=0.055 ^{134}Cs=0.002 ^{144}Ce=0.018 ^{241}Am=0.001 ^{7}Be=0.016	0.15
Control sample (hillside above Stormwater Outlet No.1)	22.2.91	vegetation	0.01	nd	U & Th series ^{137}Cs=0.001 ^{7}Be=0.033	0.19

Notes:
Radioactivity is in units of Becquerels per gram fresh weight (FW) for vegetation, and in Becquerels per gram dry weight (DW) for soils.
* The gross beta results DO NOT include the contribution from natural potassium-40, this has been deducted.
"ND" indicates that no net beta activity remained after subtraction of the potassium-40 activity.
In the gamma-emitters column, "U & Th series" refers to the presence of daughter products from the decay of the uranium-238 and thorium-232 series, which occur naturally in the environment.

TABLE 6

RADIOACTIVITY IN WATER SAMPLES FROM STORMWATER OUTLETS
1991

Sample Location	Date	RADIOACTIVITY (Bq/L)			Tritium Bq/mL
		Gross α	Gross β (incl. ^{40}K)	γ-emitters	
Drain behind Bld.1	22.2.91	-	-	-	LLD
	30.4.91	-	-	-	LLD
	30.8.91	-	-	-	LLD
	30.10.91	-	-	-	LLD
Drain opposite Fermi Street	30.4.91	-	-	-	LLD
	30.8.91	-	-	-	LLD
	30.10.91	-	-	-	LLD
Drain opposite Bld. 23	30.4.91	-	-	-	LLD
	30.8.91	-	-	-	0.28
	30.10.91	-	-	-	LLD
Drain No.1 opp. Strassman Crescent	22.2.91	-	-	-	LLD
	30.8.91	-	-	-	0.39
	30.10.91	-	-	-	LLD
Drain opposite meteorological tower	30.8.91	-	-	-	LLD
	30.10.91	-	-	-	LLD
20m from LHRL Stormwater Outlet No.1	22.2.91	-	-	-	LLD
	30.4.91	-	-	-	LLD
	30.8.91	-	-	-	LLD
60m from LHRL Stormwater Outlet No.1 *	January	0.19	0.27	ND	LLD
	February	0.16	0.31	ND	LLD
	March	0.19	0.27	U & Th series	0.26
	April	0.18	0.29	ND	LLD
	May	0.32	0.37	ND	LLD
	June	0.35	0.44	^{137}Cs=0.050	LLD
	July	0.28	0.29	^{137}Cs=0.012	LLD
	August	0.23	0.34	ND	0.28
	September	0.54	0.83	^{137}Cs=0.038	0.25
	October	0.24	0.60	^{137}Cs- trace	1.45
	November	0.31	0.57	^{137}Cs=0.020	0.76
	December	0.44	0.60	ND	0.69

Notes: Refer to Figure 2 for the location of these sampling points.
Radioactivity (Bq/L) refers to the radioactivity per litre of water sample (suspended & dissolved).
The gross beta results include the contribution from natural potassium-40.
The limit of detection for tritium is 0.25 Bq/mL.
* This location is sampled weekly, however all the weekly samples for a calendar month are combined to make a single composite sample. Tritium analyses are performed on these composites.
"ND" indicates that no activity was detected above background levels.
In the gamma-emitters column, "U & Th series" refers to the presence of daughter products from the decay of the uranium-238 and thorium-232 series, which occur naturally in the environment.

TABLE 7

RADIOACTIVITY IN WATER SAMPLES FROM SPCC SAMPLING POINTS, 1991

Date	Radioactivity (Bq/L)					
	Strassman Creek		Bardens Creek weir		MDP creek weir	
	Gross α	Gross β*	Gross α	Gross β*	Gross α	Gross β*
22.1.91	LLD	LLD	LLD	0.14	LLD	0.29
4.3.91	LLD	0.11	LLD	0.10	LLD	0.23
26.3.91	LLD	LLD	0.05	0.20	LLD	0.26
30.4.91	0.04	LLD	0.04	LLD	LLD	0.15
30.5.91	0.04	0.25	LLD	0.13	LLD	0.19
28.6.91	LLD	0.12	LLD	0.14	LLD	0.12
29.7.91	LLD	LLD	LLD	0.15	LLD	0.28
28.8.91	LLD	0.11	LLD	LLD	LLD	0.16
30.9.91	0.03	0.30	0.03	0.11	LLD	LLD
29.10.91	LLD	LLD	LLD	LLD	LLD	0.86
27.11.91	0.04	LLD	LLD	LLD	0.03	0.61
20.12.91	LLD	LLD	LLD	0.10	LLD	0.51

Notes:

* All gross beta results include the contribution from natural potassium-40.

LLD = Less than the limit of detection. The limits of detection are 0.03 Bq/L for gross α and 0.10 Bq/L for gross β.

The NSW Clean Waters Regulations (1972) specify limits for radioactivity in class C waters as follows: gross α = 1.1 Bq/L

gross β = 11.1 Bq/L.

TABLE 8

TRITIUM IN WATER FROM BARDENS CREEK WEIR
(at SPCC sampling point)
1991

Date	Tritium Bq/mL	Date	Tritium Bq/mL
2.1.91	LLD	2.7.91	0.66
8.1.91	LLD	9.7.91	0.77
15.1.91	LLD	16.7.91	0.41
22.1.91	LLD	23.7.91	0.92
29.1.91	LLD	30.7.91	0.58
5.2.91	LLD	6.8.91	0.73
12.2.91	LLD	13.8.91	0.49
19.2.91	LLD	21.8.91	0.49
26.2.91	LLD	27.8.91	0.58
5.3.91	LLD	3.9.91	0.51
12.3.91	LLD	10.9.91	0.47
19.3.91	LLD	17.9.91	0.47
26.3.91	LLD	24.9.91	0.44
2.4.91	LLD	1.10.91	0.49
9.4.91	LLD	8.10.91	0.47
16.4.91	LLD	16.10.91	0.42
23.4.91	LLD	24.10.91	0.38
30.4.91	LLD	29.10.91	0.39
7.5.91	LLD	5.11.91	0.46
14.5.91	LLD	12.11.91	0.34
21.5.91	LLD	19.11.91	0.51
28.5.91	LLD	26.11.91	0.39
4.6.91	LLD	3.12.91	0.48
11.6.91	0.47	10.12.91	0.46
18.6.91	0.82	17.12.91	LLD
25.6.91	0.81	24.12.91	LLD

Notes:
LLD = Less than the limit of detection for tritium, which is 0.25 Bq/mL.
The guideline value for tritium in drinking water is 7.61 Bq/mL (WHO, NH&MRC Drinking Water Guidelines)

TABLE 9

GAMMA SURVEY - EFFLUENT DISCHARGE PIPELINE, 1991

Survey of exposed portions of pipeline between LHRL and the MWS&DB sewer connection, using an Eberline PRM-7 field rate meter.

Date	Location*	Dose Rate (uSv/hour)		Background range (uSv/hour)
		ground below joint	pipe joint	
19.6.91	Joints #1-17	<0.10	<0.10	0.05 to 0.11
	Joints # 20-22	<0.08	<0.08	0.06 to 0.07
18.11.91	Joints #1-17	<0.09	<0.11	0.06 to 0.11
	Joints # 20-22	<0.07	<0.07	0.06 to 0.07

* Joints # 18 & 19 are inaccessible.

TABLE 10

RADIOACTIVITY IN SAMPLES OF SOIL & VEGETATION FROM LITTLE FOREST BURIAL GROUND, 1991

Sample Location	Date	Sample Type	RADIOACTIVITY (Bq/g DW)			
			Gross α	Gross β (less ^{40}K)	γ-emitters	^{40}K
Point # 5	8.7.91	Soil	0.65	0.58	U & Th series	0.17
Point # 6	8.7.91	Soil	0.58	2.21	U & Th series ^{60}Co = 0.31 ^{137}Cs = 0.036	0.19
Point # 5	23.12.91	Soil	0.59	0.39	U & Th series	0.28
Point # 6	23.12.91	Soil	0.54	2.04	U & Th series ^{60}Co = 0.27 ^{137}Cs = 0.032	0.25
Near Point #6	23.12.91	Vegetation (grass)	0.69 *	1.88 *	U & Th series ^{60}Co = 0.009 * ^{137}Cs = 0.005 * ^{7}Be = 0.127 *	0.18

Notes:
Refer to Figure 3 for the location of these sampling points.

* Radioactivity is in units of Becquerels per gram fresh weight (FW) for vegetation.

The gross beta results DO NOT include the contribution from natural potassium-40, this has been deducted from all samples.

In the gamma-emitters column, "U & Th series" refers to the presence of daughter products from the decay of uranium-238 and thorium-232, which occur naturally in the environment.

TABLE 11

RADIOACTIVITY IN SAMPLES OF GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1991

Borehole No.	Date	RADIOACTIVITY (Bq/g sediment)			Tritium
		Gross α	Gross β *	γ-emitters	Bq/mL
BHF	24.6.91	1.4	4.2	ND	0.89
BH10	"	1.1	1.1	ND	0.92
OS2	"	4.5	1.0	U & Th series	3.2
OS3	"	4.1	3.0	ND	2.1
MB11	"	2.5	0.46	ND	LLD
MB12	"	1.5	0.40	U & Th series	LLD
MB13	"	3.7	1.0	U & Th series	3.6
MB14	"	1.5	0.44	U & Th series	LLD
MB15	"	2.7	0.67	U & Th series	1.6
MB16	"	7.8	5.3	U & Th series ^{137}Cs=0.17 ^{60}Co=0.46	15
MB17	"	4.8	1.2	U & Th series	LLD
MB18	"	3.5	0.63	ND	LLD
MB19	"	1.6	0.53	U & Th series	LLD
MB20	"	2.2	0.95	ND	LLD
MB21	"	1.6	0.48	ND	LLD
BHF	9.12.91	1.1	1.1	U & Th series	1.5
BH10	"	0.85	0.96	U & Th series	7.5
OS2	"	3.8	0.93	U & Th series	3.9
OS3	"	5.3	2.2	U & Th series	7.1
MB11	"	0.22	0.09	ND	LLD
MB12	"	1.2	0.38	U & Th series	2.2
MB13	"	1.7	1.2	U & Th series	16
MB14	"	1.5	0.42	U & Th series	LLD
MB15	"	1.6	0.50	U & Th series	LLD
MB16	"	6.2	3.0	U & Th series ^{137}Cs=0.013 ^{60}Co=0.51	23
MB17	"	2.2	0.66	U & Th series	3.7
MB18	"	2.3	0.75	U & Th series	LLD
MB19	"	0.74	0.32	U & Th series	LLD
MB20	"	1.8	0.71	U & Th series	LLD
MB21	"	1.3	0.34	U & Th series	LLD

Notes: * The gross beta results include the contribution from natural potassium-40.
"ND" indicates that no activity was detected above background levels.
"LLD" = Less than the limit of detection for tritium, which is 0.25 Bq/mL
"U & Th series" refers to the presence of daughter products from the decay of uranium-238 and thorium-232, which occur naturally in the environment.

TABLE 12

RADIOACTIVITY IN SAMPLES TAKEN FROM CREEKS NORTH OF LITTLE FOREST BURIAL GROUND, 1991

SAND

Sample Location	Date	RADIOACTIVITY (Bq/g DW)			
		Gross α	Gross β * (less ^{40}K)	γ-emitters	^{40}K
Mill Creek (before it joins Bardens Creek)	25.11.91	0.22	0.02	U & Th series	0.08
Bardens Creek (before it joins Mill Creek)	25.11.91	0.10	0.06	U & Th series	ND

WATER

Sample Location	Date	RADIOACTIVITY (Bq/L)			Tritium
		Gross α	Gross β	γ-emitters	(Bq/mL)
Mill Creek (before it joins Bardens Creek)	25.11.91	<0.03	0.08	ND	LLD
Bardens Creek (before it joins Mill Creek)	25.11.91	0.23	0.10	ND	LLD

Notes: Refer to Figure 1 for the location of these sampling points.
* The gross beta results for SAND *do not include* the contribution from natural potassium-40, this has been deducted.
"ND" indicates that no activity was detected above background levels.
In the gamma-emitters column, "U & Th series" refers to the presence of daughter products from the decay of uranium-238 and thorium-232, which occur naturally in the environment.
"LLD" = less than the limit of detection for tritium, which is 0.25 Bq/mL.

TABLE 13

RESULTS OF AIR SAMPLING AT LITTLE FOREST BURIAL GROUND, 1991

Sampling period	Air volume sampled (m^3)	Beryllium (ug/m^3)	^{239}Pu (Bq/m^3)
18.12.90 to 4.4.91	292.8	LLD	-
4.4.91 to 31.6.91	76.32	LLD	-
31.6.91 to 18.9.91	113.0	LLD	-
18.9.91 to 23.12.91	279.5	LLD	-
1991 Composite of B filters *	761.62	-	LLD

Notes:
* Composite sample of duplicate set of air filters for 1991. Result determined by alpha spectrometry.
"LLD" = less than the limit of detection. The limit of detection for beryllium is 0.2 ug/m^3 and for ^{239}Pu is 0.00002 Bq/m^3.

TABLE 14

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, 1991

Period & Bld. No.	Gross α (kBq)	^{131}I (MBq)	Gross β (MBq)	^{3}H (GBq)	Noble gases (TBq)	Other activity (MBq)
Quarter 1						
Bld 54 (hotcells)	<7	8 394	<0.2	-	145	41 054
3	<4	1.8	<0.1	-	-	-
15(Hifar)	<2	2.2	<0.17	579	21.5	94
19	<12	4.7	<0.3	-	-	-
20	<5	5.6	<0.12	1.25	-	-
21A	2	0.7	0.05	-	-	-
21B	0.5	0.18	0.01	-	-	-
23A	<10	2 234	<0.25	-	-	-
23B	<1.2	2.02	<0.03	-	-	-
41	<4	4.4	<0.06	-	-	-
56	<14	8.5	<0.3	-	-	-
57	<1.1	0.7	<0.02	48.2	-	-
Quarter 2						
Bld 54 (hotcells)	<7	4 770	<0.2	-	72.2	18 200
3	<6	0.3	<0.1	-	-	-
15(Hifar)	<2	5.0	<0.2	10 080	13	57
19	<12	4	<0.3	-	-	-
20	<6	10	<0.1	14	-	-
21A	2	0.2	0.05	-	-	-
21B	0.5	0.2	0.01	-	-	-
23A	<11	3 410	<0.3	-	-	705
23B	<1	6.8	<0.03	-	-	-
41	<4	0.6	<0.10	-	-	-
56	<15	2.5	<0.4	-	-	-
57	<1	0.8	<0.03	2.5	-	-

TABLE 14 continued ...

Period & Bld. No.	Gross α (kBq)	^{131}I (MBq)	Gross β (MBq)	^{3}H (GBq)	Noble gases (TBq)	Other activity (MBq)
Quarter 3						
Bld 54 (hotcells)	<7	4 000	<0.2	-	121.2	18 700
3	<7	0.8	<0.1	-	-	-
15(Hifar)	<2	1.3	<0.2	1 180	28.6	53
19	<11	4	<0.3	-	-	-
20	<6	1	<0.1	21	-	-
21A	<2	0.3	<0.05	-	-	-
21B	<0.4	nd	<0.01	-	-	-
23A	<10	1 930	<0.3	-	-	356
23B	<1	1.0	<0.03	-	-	4
41	<4	0.8	<0.10	-	-	-
56	<13	2.3	<0.3	-	-	-
57	<1	0.1	<0.03	18.9	-	-
Quarter 4						
Bld 54 (hotcells)	<7	15 000	<0.2	-	104.2	77 300
3	<4	0.3	<0.1	-	-	-
15(Hifar)	<2	1.5	<0.3	460	25.6	69
19	<11	3	<0.3	-	-	-
20	<6	2	<0.1	7	-	-
21A	<2	0.5	<0.05	-	-	-
21B	<0.5	0.1	<0.01	-	-	-
23A	<10	2 040	<0.3	-	-	96
23B	<1	0.9	<0.03	-	-	-
41	<4	1.1	<0.11	-	-	-
56	<14	2.1	<0.4	-	-	-
57	<1	1.1	<0.03	46.2	-	-

Notes:
The Bld 54 hotcells stack was referred to in previous years as Bld 2. A duct from the hotcells leads into the Bld 2 stack.
Where values are quoted as less-than figures, the figure is the maximum possible discharge, based on the limits of detection. It does not necessarily imply that the radioactivity has been detected in the effluent.
Figures for the gross alpha and the gross beta activity are quoted 3 months in arrears to permit more accurate figures to be determined of the long-lived alpha and beta activities. In past reports, the gross beta activity was reported as strontium-90 assuming, in the worst case, that all measured beta activity was due to this radionuclide. The levels measured are usually at the limit of detection, indicating that no significant strontium-90 activity has been discharged from the site.

TABLE 15

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, EXPRESSED AS PERCENTAGES OF QUARTERLY WORKING LIMITS, 1991

Period & Bld. No.	Gross α % of limit	^{131}I % of limit	Gross β % of limit	^{3}H % of limit	Noble gases % of limit	Other activity % of limit
Quarter 1						
Bld. 54 (hotcells)	<0.001	12.7	<0.00003	-	85.3	2.56
3	<0.25	0.011	<0.0076	-	-	-
15 (HIFAR)	<0.006	0.014	<0.00065	0.45	79.6	0.14
19	<0.004	0.014	<0.0001	-	-	-
20	<0.18	0.035	<0.029	0.015	-	-
21A	0.20	0.012	0.036	-	-	-
21B	0.22	0.014	0.030	-	-	-
23A	<0.063	14	<0.002	-	-	-
23B	<0.018	0.013	<0.0005	-	-	-
41	<0.0012	0.028	<0.00002	-	-	-
56	<0.18	0.019	<0.027	-	-	-
57	<0.18	0.019	<0.011	2.67	-	-
Quarter 2						
Bld. 54 (hotcells)	<0.001	7.2	<0.00003	-	42.5	1.14
3	<0.38	0.0018	<0.0076	-	-	-
15 (HIFAR)	<0.006	0.031	<0.0008	7.75	48.15	0.086
19	<0.0036	0.012	<0.0001	-	-	-
20	<0.21	0.062	<0.024	0.17	-	-
21A	0.20	0.0034	0.036	-	-	-
21B	0.22	0.015	0.030	-	-	-
23A	<0.069	21.3	<0.0023	-	-	2.14
23B	<0.015	0.042	<0.0005	-	-	-
41	<0.0012	0.0038	<0.00004	-	-	-
56	<0.19	0.006	<0.0004	-	-	-
57	<0.16	0.022	<0.033	0.14	-	-

TABLE 15 continued ...

Period & Bld. No.	Gross α % of limit	^{131}I % of limit	Gross β % of limit	^{3}H % of limit	Noble gases % of limit	Other activity % of limit
Quarter 3						
Bld. 54 (hotcells)	<0.001	6.06	<0.00003	-	71.3	1.17
3	<0.48	0.005	<0.0077	-	-	-
15 (HIFAR)	<0.006	0.008	<0.00077	0.91	105.9	0.080
19	<0.033	0.012	<0.001	-	-	-
20	<0.21	0.006	<0.024	0.26	-	-
21A	0.20	0.0052	0.036	-	-	-
21B	0.17	-	0.030	-	-	-
23A	<0.062	12.1	<0.0023	-	-	1.08
23B	<0.015	0.0063	<0.00047	-	-	0.025
41	<0.0012	0.005	<0.00004	-	-	-
56	<0.17	0.0052	<0.027	-	-	-
57	<0.16	0.0027	<0.033	1.05	-	-
Quarter 4						
Bld. 54 (hotcells)	<0.001	22.7	<0.00003	-	61.3	4.83
3	<0.25	0.0018	<0.0076	-	-	-
15 (HIFAR)	<0.0061	0.0094	<0.0011	0.35	94.8	0.10
19	<0.0033	0.0090	<0.0001	-	-	-
20	<0.21	0.012	<0.024	0.086	-	-
21A	0.20	0.0086	0.036	-	-	-
21B	0.22	0.0077	0.030	-	-	-
23A	<0.063	12.7	<0.0023	-	-	0.29
23B	<0.015	0.0056	<0.00047	-	-	-
41	<0.0012	0.0068	<0.00004	-	-	-
56	<0.018	0.0047	<0.036	-	-	-
57	<0.16	0.030	<0.033	2.57	-	-

TABLE 16

LIQUID RADIOACTIVE EFFLUENT DISCHARGED TO THE WATER BOARD SEWER DURING 1991

MONTH	VOLUME m^3	TRITIUM MBq/m^3	ALPHA KBq/m^3	BETA KBq/m^3	FRACTION OF LIMIT
January	6915.2	40.2	0.51	22.5	0.29
February	6351.7	326	0.48	24.1	0.37
March	6317.1	11.7	0.17	20.4	0.22
April	7886.2	10.3	0.11	9.9	0.11
May	7375.5	13.1	0.14	21.4	0.23
June	9566.0	64.0	0.19	20.7	0.24
July	9072.2	47.3	0.07	5.4	0.07
August	7179.8	35.9	0.07	5.8	0.08
September	7996.4	40.7	0.54	26.2	0.10
October	7587.8	205	8.72	11.9	1.04
November	8186.6	30.2	0.37	41.7	0.47
December	9306.6	15.7	0.26	12.5	0.16

Table 17

ESTIMATED WHOLE BODY DOSES (mSv/yr) AT LHRL

Receptor Location	Airborne whole body dose 1991# mSv
Library	0.0093
Outside HIFAR	0.0019
Building 9	0.0122
Main gate	0.0089
Stevens Hall	0.0085
MWDA Depot	0.0072
BMX track	0.0044
Woronora Valley	0.0011

Note: # using 1991 actual stack discharge figures and 1991 meteorological data. The current permissible level for continuous exposure for the general public is 1 mSv/yr, or 20 mSv/yr for occupational exposure (ICRP 1990b).

Table 18

AVERAGE RADIATION DOSES FROM NATURAL SOURCES

Natural source	Average annual effective dose (mSv)
cosmic rays	0.30
foodstuffs	0.35
terrestrial (soil)	0.32
radon	1.00
Total	**~2.00**

Table 19

TYPICAL RADIATION DOSES FROM DIAGNOSTIC MEDICAL PROCEDURES

Medical source	Typical effective dose (mSv)
x-rays:	
- chest	0.03
- dental	0.14
- spinal	2.50
- CT scan	5.00
Nuclear medicine scans:	
- bone	5.00
- thyroid	2.00
- lung	0.80

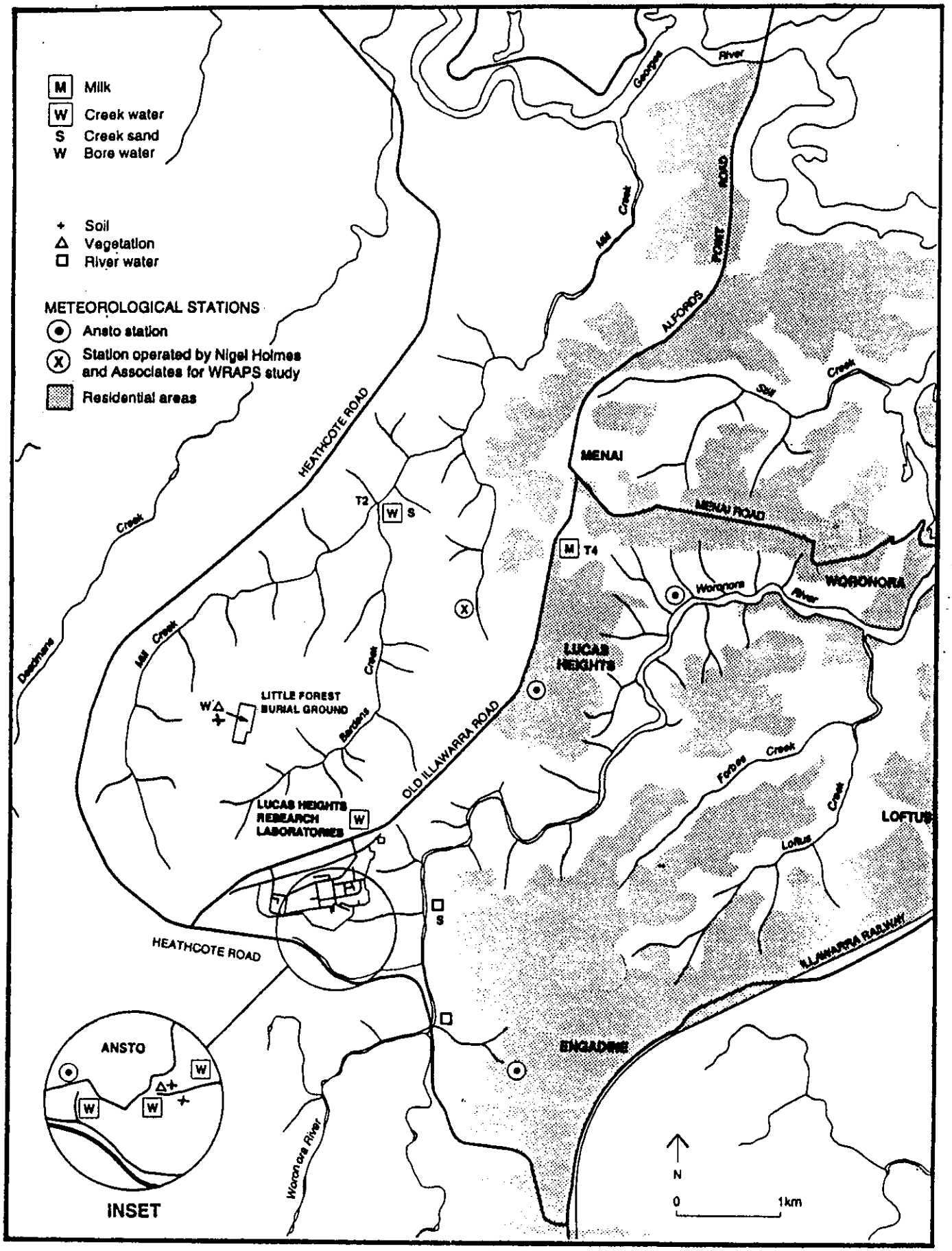
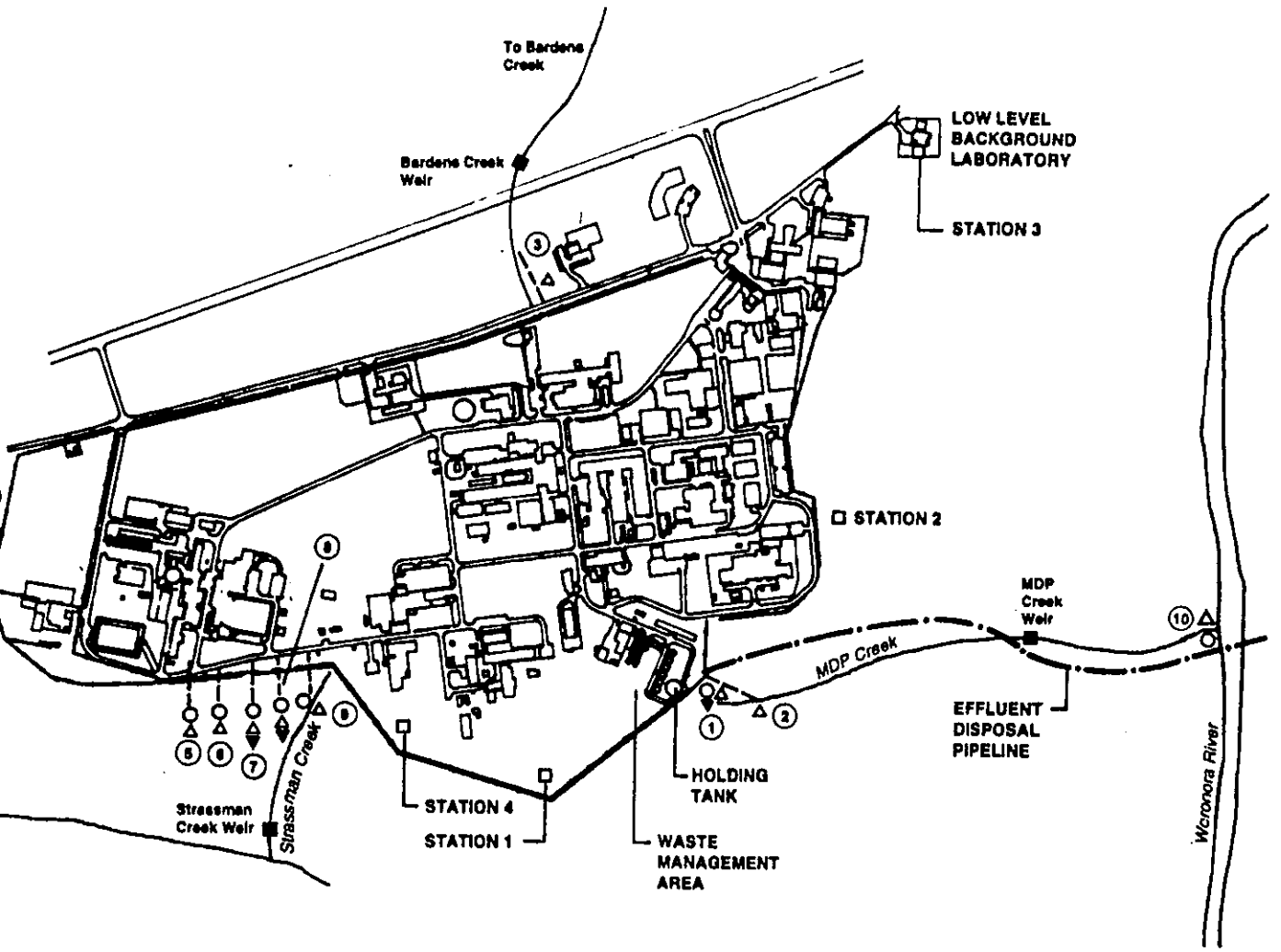


Figure 1: LUCAS HEIGHTS - Location of sampling points



□ Continuous air sampling station

■ SPCC sampling point

– – Stormwater drain outlet

Stormwater drain sampling:

○ Soil

△ Water

▼ Vegetation

Location of drain sampling points

① 20m downstream of outlet no.1

② 60m downstream of outlet no.1

③ Behind building 1

④ On west Fence Road

⑤ Opposite Fermi Street

⑥ Opposite building 23

⑦ No.1 opposite Strassman Crescent

⑧ No.2 opposite Strassman Crescent

⑨ Opposite meteorological tower

⑩ MDP Creek where it joins the Woronora River

N

0 100m

Figure 2: **LOCATION OF STORMWATER SAMPLING POINTS AND AIR SAMPLING STATIONS**

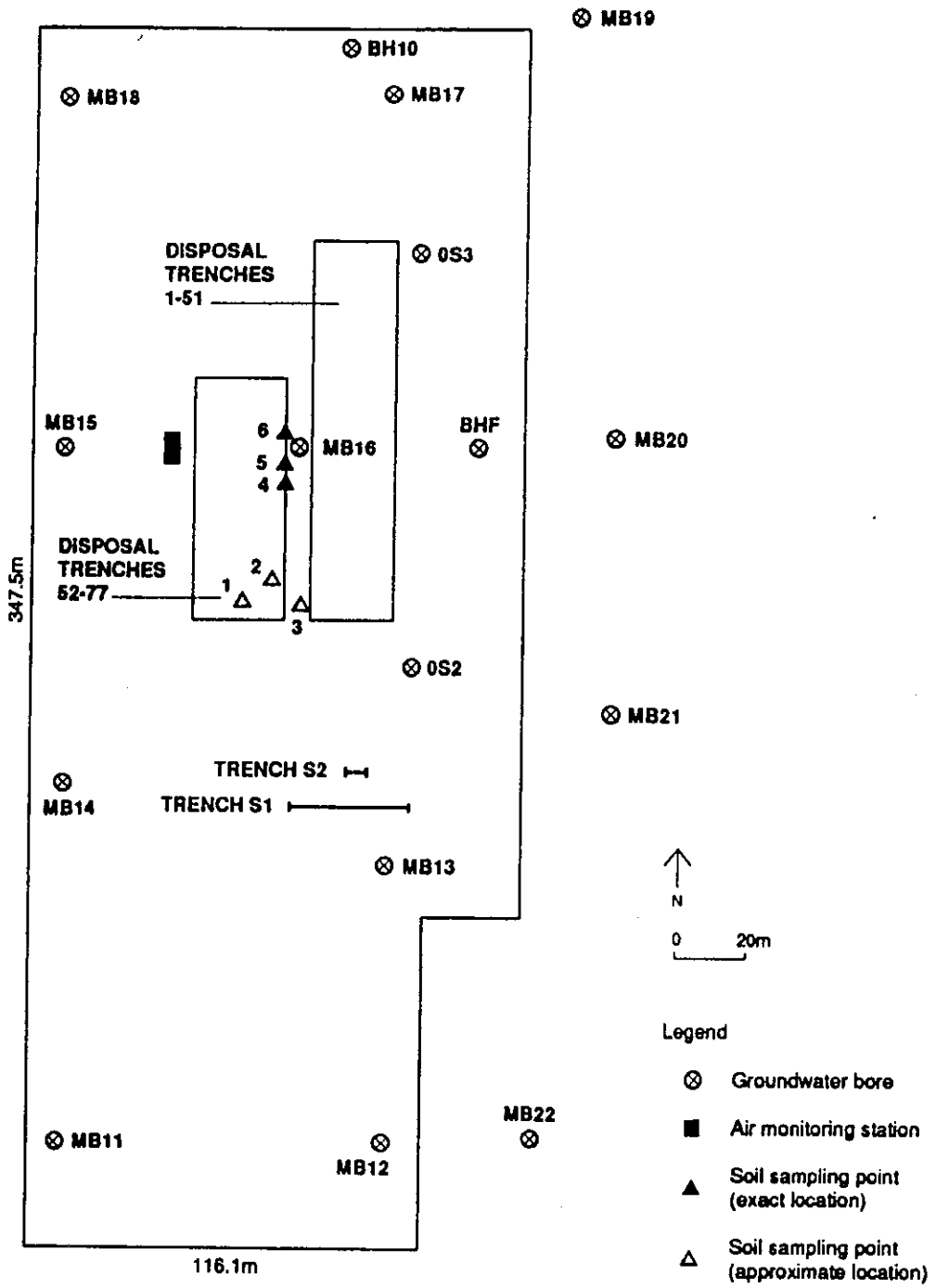


Figure 3: **LITTLE FOREST BURIAL GROUND: LOCATIONS OF TRENCHES, GROUNDWATER BORES AND SOIL SAMPLING POINTS**

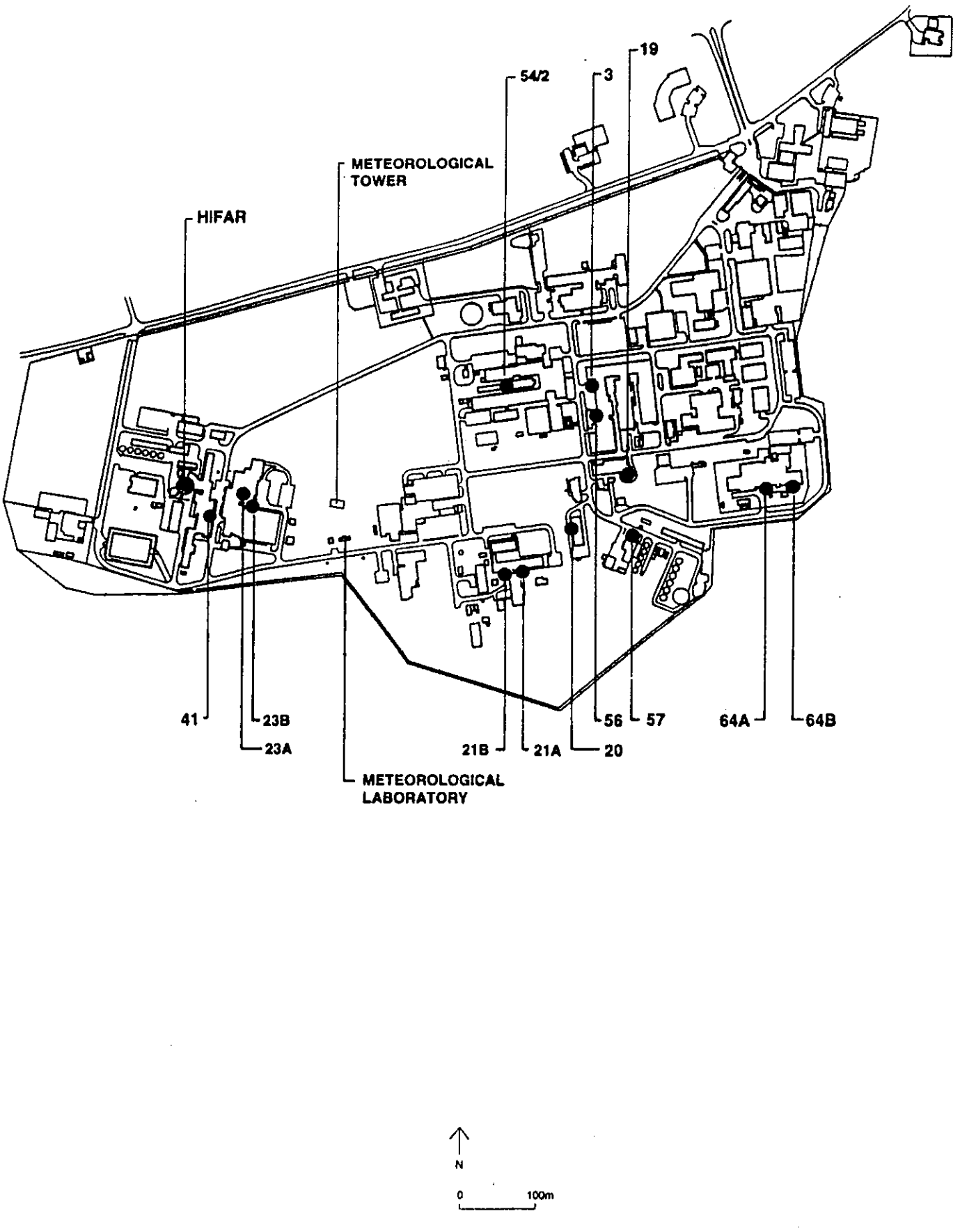


Figure 4: **LOCATION OF AIRBORNE EFFLUENT RELEASE STACKS AND METEOROLOGICAL FACILITIES**

GLOSSARY OF TERMS

activity (of a substance): The number of disintegrations per unit of time taking place in a radioactive material. The unit of activity is the becquerel (Bq), one disintegration per second.

alpha particle: A positively charged particle emitted from the nucleus of an atom during radioactive decay. Consists of two protons and two neutrons (a helium-4 nucleus). Although alpha particles are normally highly energetic, they travel only a few centimetres in air and are stopped by a sheet of paper or outer layer of dead skin.

alpha radiation: The emission of alpha particles when the nucleus of an atom is unstable and radioactive.

background radiation: The ionising radiation in the environment to which we are all exposed. It comes from many sources - outer space, the sun, the rocks and soil under our feet, the buildings we live in, the air we breathe, the food we eat, and from our own bodies.

becquerel (Bq): Unit of activity, equal to one radioactive disintegration per second. This SI unit may be used instead of the curie (Ci): 1 curie = 3.7×10^{10}becquerels.

beta particle (ray): A particle emitted from an atom during radioactive decay. Beta particles (rays) are either electrons with a negative charge or positrons with a positive electric charge. High energy beta particles can travel metres in air and several millimetres into the human body; low energy beta are unable to penetrate the skin. Most beta particles can be stopped by a small thickness of light material, eg. aluminium or plastic sheeting.

beta radioactivity: Radioactive transformation of a nuclide in which high energy electrons are emitted and the mass number remains unchanged but the atomic number changes by 1 with the emission of a beta particle.

daughter product: A nuclide formed in the radioactive decay of another (called the parent).

decay, radioactive: The disintegration of an atomic nucleus resulting in the release of alpha or beta particles, or gamma radiation.

dose limits: The maximum radiation dose that a person may receive over a stated period of time. Internationally recommended limits adopted by Australia are that radiation workers should not accumulate 50 mSv per year (a limit that is in the process of being reduced to 20 mSv per year). Members of the public should nor receive more than 5 mSv (also to be reduced). Where doses are likely to approach this limit over many years, it is

recommended that the lifetime dose equivalent be restricted to a value corresponding to an average annual dose of 1 mSv.

effective dose: Physical quantity used in the measurement of ionising radiation dose to humans, taking into account the harmfulness of different types of radiation and the susceptibility to harm of different organs of the body. The special unit of effective dose is the sievert, or more commonly the millisievert (one-thousandth of one sievert).

electromagnetic radiation: Waves of energy that are caused by the acceleration of charged particles. Includes radio waves, infrared, visible light and ultraviolet radiation (all non-ionising radiation), and x-rays and gamma rays (ionising radiation).

fission: Usually, the division of a heavy nucleus into two similar but generally unequal masses, with the emission of neutrons, gamma radiation and a great deal of energy.

fission product decay: The process by which radioactive atoms from fission become stable through the emission of radioactive particles.

fission products: The atoms formed as a result of fission. Most fission products are very unstable, have short half-lives and are highly radioactive, emitting copious quantities of beta rays and gamma rays over a range of energies. A small number emit delayed neutrons.

gamma radiation: Gamma radiation is short wavelength electromagnetic radiation of the same physical nature as light, x-rays, radio waves, etc. However, gamma radiation is highly penetrating (more so than x-rays) and, depending on its energy, can require a considerable thickness of lead or concrete to absorb it. Because gamma radiation causes ionisation, it constitutes a biological hazard.

gamma radioactivity: Electromagnetic radiation of high quantum energy emitted after nuclear reactions or by radioactive atoms when the nucleus is left in an excited state after emission of alpha or beta particles.

half-life, radioactive: For a single radioactive decay process, the time required for the activity to decrease to half its value by that process. Half-lives vary, according to the radioisotope, from less than one-millionth of a second to more than one billion years.

HIFAR (high flux Australian reactor): Nuclear reactor of the DIDO class owned by ANSTO and located at Lucas Heights.

hot cell: A heavily shielded enclosure for highly radioactive materials. It can be used for their handling or processing by remote means, or for their storage.

ionisation: Any process by which an atom, molecule or ion gains or loses electrons.

ionising radiation: Radiation capable of causing ionisation of the matter through which it passes. Ionising radiation may damage living tissue.

isotope: Atoms of an element having the same number of protons but different numbers of neutrons in the nuclei. Different isotopes of the same element have the same chemical properties, but somewhat different physical properties.

low level waste: Any waste material that contains measurable quantities of radioactivity, requiring minimum standards of protection for personnel when the waste is handled, transported or stored.

noble gases: Also known as inert gases, the noble gases (helium, argon, krypton, xenon and radon) have filled electron shells and normally do not react chemically with other elements. There are some radioactive isotopes of noble gases.

nuclear reactor: A structure in which a fission chain reaction can be maintained and controlled. It usually contains fuel, coolant, moderator, control absorbers and safety devices and is most often surrounded by a concrete biological shield to absorb neutron and gamma ray emission.

potassium-40: A naturally occurring radioisotope with a half-life of 1.30×10^9 years. A major contributor to the internal part of radiation dose arising from natural background radiation.

radiation exposure pathways: The routes by which radioactive materials can reach and irradiate people. These include the carrying of radioactive materials by air and water followed by inhalation or ingestion, the carrying of radioactive materials through food or animals that absorb the materials, or direct radiation from sources external to the body.

radioactivity: The property of certain nuclides of spontaneously emitting particles or gamma radiation, or of emitting x-radiation following orbital electron capture, or of undergoing spontaneous fission.

radionuclide: Any nuclide (isotope of an element) that is unstable and undergoes a natural radioactive decay.

sievert: The unit of measurement of dose, effective dose or equivalent dose. It is equal to the absorbed dose (in grays) multiplied by a factor related to a particular part of the body. It is the unit used to assess the effects of ionising radiation on living cells. Usually measured in millisieverts, the whole-body dose that every person receives from natural background radiation in one year is 2 millisieverts. Replaces the rem: 1 Sv = 100 rem.

tritium: The isotope of hydrogen of mass 3. It is rare and is naturally radioactive, but can be made in a number of ways, including neutron absorption in lithium, deuterium or heavy water. It has a half-life of 12.5 years.

APPENDIX A

PREVIOUS ENVIRONMENTAL SURVEY REPORTS

Giles,M.S., Stockdale, J.A., (1966). *The Lucas Heights Environmental Sampling Program.* AAEC/TM336

Giles, M.S., Stockdale, J.A., (1966). *Results of the Lucas Heights Biological Survey, December 1959 to December 1964.* AAEC/E151 Supplement No.1.

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APPENDIX B

STACK DISCHARGES OF RADIOACTIVITY AT LUCAS HEIGHTS

Radioactive Nuclide	Half-life	Stack	Form of Release	Comment
Iodine-131	8 days	All	Vapour	All stacks are continuously sampled for iodine-131, even though only a few are routinely releasing it. This is partly because of the importance of iodine in any accidental release of mixed fission products and partly because it has sometimes been used in tracer experiments, so that small amounts might occasionally appear in any stack effluent.
Strontium-90	29 years	All	Particulate	The same sampler that measures the iodine release discharges, also measures the particulate activity, both alpha and beta. The filter paper which traps the airborne particles is counted the day after its removal from the stack and again after a delay of 3 months to allow the short-lived alpha and beta activity to decay. Any long-lived beta activity on the filters is assumed to be strontium-90, even though this nuclide is not a likely candidate. Note that all the exhaust gases have passed through high efficiency particulate air filters which are better than 99.97% efficient for all sizes of particle.
Argon -41	1.8 hours	HIFAR	Gas	Air is used to cool some of the irradiation rigs in HIFAR. The naturally occurring argon-40 in air becomes activated in passing through the reactor by the absorption of a neutron to form radioactive argon-41 which decays to stable potassium-41. The argon-41 does not deposit on any surface or react with any known substance, since it is a noble gas. It is a beta-gamma emitter which is easy to detect electronically and by film badges.
Tritium	12 years	HIFAR	Water Vapour	The primary coolant and neutron moderator in HIFAR is "heavy water" or deuterium oxide. Deuterium is a naturally occurring isotope of hydrogen with an additional neutron over the common isotope of hydrogen. In the reactor, a few of the deuterium atoms capture another neutron, to form tritium, which is slightly radioactive. If anyone is exposed to tritiated water vapour, some of the tritium will enter the body fluids by diffusion through the skin and lungs. However, the rate of turnover of water in the body is so high that the effective or biological half-life is only about 12 days. The tritiated water vapour is released by evaporation from equipment, which is wet by the coolant, when it is removed from the reactor.

Radioactive Nuclide	Half-life	Stack	Form of Release	Comment
Tritium	12 years	Bld 20	Water Vapour	Bld 20 is the decontamination centre and occasionally handles coolant pumps removed from the reactor for maintenance.
Tritium	12 years	Bld 57	Water Vapour	Bld 57 is where the spent resin beds, used to purify the coolant water, is regenerated or replaced. Most of the tritiated water on the resin beds is trapped before the drying gas is discharged to the stack.
Mercury-197 Mercury-203	64 hours 47 days	HIFAR	Vapour	Slight traces of mercury vapour in the air within the HIFAR containment are activated in passing through the HIFAR reactor. The mercury probably comes from a thermometer dropped at some time in the containment building.
Arsenic-76	26 hours	HIFAR	Arsene Vapour	Very slight traces of arsenic vapour in the air within the HIFAR containment are activated in passing through the HIFAR reactor. The arsenic vapour is being slowly emitted from wood, treated with preservative, which was used a few years ago, when renewing the thermal cladding of the containment building.
Iodine-131	8 days	HIFAR	Vapour	Even though there are only traces of iodine-131, if any, in the exhaust from HIFAR under normal operation, the effluent is continuously sampled for iodine, since it is the most important activity released in a serious accident to the reactor.
Xenon-133 Xenon-135 Xenon-135m Krypton-87 Krypton-85m Krypton-88	5.3 days 9.2 hours 15 mins 76 mins 4.5 hours 2.8 hours	Bld 54	Gas	These are all "fission product noble gases". The radio-nuclide most often used as a diagnostic tracer in nuclear medicine is technetium-99m, extracted from fresh fission products. Small uranium targets are irradiated in HIFAR for a few days before they are dissolved in nitric acid in a fully enclosed apparatus in one of the heavily shielded "Hot Cells" in Bld 54. The noble gases which are released during dissolution are trapped on a large charcoal bed in the next cell. When the targets are completely dissolved the charcoal bed is isolated and the noble gases allowed to decay while trapped on the bed. However, additional noble gases are formed in the nitric acid solution, from radioactive gases released from the apparatus as the liquid is manipulated into different parts of the equipment by means of vacuum lines. The exhaust gases from the vacuum lines pass through small charcoal beds to trap most of the iodine-131 but they are ineffective for noble gas. About 90% of the noble gases are trapped during dissolution leaving only 10% to be released during processing.

Radioactive Nuclide	Half-life	Stack	Form of Release	Comment
Iodine-131	8 days	Bld 54	Organic Iodine Vapour	Iodine-131 is also released during technetium-99m extraction from fresh fission products. Iodine is very volatile even at room temperature and about 3% escapes from the enclosed apparatus, despite efforts to contain it. To prevent this quantity of iodine being released to the atmosphere, the exhaust from the hot cells passes through sixteen beds filled with a specially impregnated charcoal, which was developed in England to trap all forms of airborne iodine, even at high humidity. The beds are tested regularly and are replaced whenever the efficiency falls below 99.9%. The most penetrating form of airborne radio-iodine has been found to be the vapour of an organic compound, methyl iodide, formed when the extremely dilute radioactive iodine reacts with traces of organic vapours.
Iodine-131	8 days	Bld 23		Iodine-131 is an important medical isotope in its own right, being used in the treatment of thyroid cancer. It is produced by the irradiation of a tellurium target in HIFAR, before being processed in a small shielded hot cell in Bld 23. The exhaust from the group of cells passes through three charcoal beds similar to the ones in Bld 54.

APPENDIX C

LIST OF ISOTOPE SYMBOLS USED
IN TABLES OF SURVEY RESULTS

Symbol	Name
^{241}Am	americium-241
^{7}Be	beryllium-7
^{60}Co	cobalt-60
^{137}Cs	caesium-137
^{134}Cs	caesium-134
^{3}H	tritium
^{131}I	iodine-131
K	potassium(stable)
^{40}K	potassium-40
^{95}Nb	niobium-95
^{239}Pu	plutonium-239
^{226}Ra	radium-226
^{90}Sr	strontium-90
^{232}Th	thorium-232
^{238}U	uranium-238
^{95}Zr	zirconium-95

PREFIXES USED IN REPORT

K (Kilo) = 10^3 =1 000
M (Mega) = 10^6 = 1 000 000
G (Giga) = 10^9 = 1 000 000 000
T (Tera) = 10^{12} = 1 000 000 000 000

m (milli) = 10^{-3} = 0.001
u (micro) = 10^{-6} = 0.000001
n (nano) = 10^{-9} = 0.000000001
p (pico) = 10^{-12} = 0.000000000001

APPENDIX D - ANALYTICAL PROCEDURES

Tritium in waters

Water samples to be analysed for tritium are prepared by distillation. 3ml of distilled sample is combined with 15 ml of scintillant, refrigerated and stored in the dark for several hours prior to repeated counting on a Canberra/Packard model 300c liquid scintillation counter. The limit of detection is presently 0.25 Bq/mL.

Alpha and Beta activity in soils, vegetation and waters

The beta activity in sand and soil is counted under a Geiger-Mueller tube with a 2-inch diameter end-window. Alpha counting of these samples is done on a fraction with a grain size of 60 to 120 mesh BSS, in an AERE type alpha-drawer assembly (a zinc sulphide scintillating screen monitored by a photomultiplier tube) kept in a desiccated atmosphere. Beta and alpha activities are assumed to have energies similar to potassium-40 and natural uranium respectively. Analytical grade KCl is used to standardise the detector for beta activity because of its natural potassium-40 content. A sand specially coated with uranyl nitrate, and of the same particle size as the sample, is used to standardise the alpha detector. In calculating the net beta activity in soils and vegetation, the activity due to natural potassium-40 is subtracted. The potassium-40 content is determined by gamma spectrometry of the sample.

Ashed samples of vegetation, milk, oysters, etc., are ground and homogenised in a mortar and pestle, then compacted into 2-inch diameter tablets using a hydraulic press. This ensures that the samples are presented to the alpha, beta or gamma detectors in uniform dimensions.

Water samples from the SPCC sampling points are analysed according to Australian Standard AS 3550.5 - 1990 for drinking waters. The samples are evaporated in small aliquot's onto aluminium planchettes, and counted in a Canberra 2400 thin-window gas-flow proportional alpha/beta counter.

All other water samples (LFBG bore waters, and monthly composites from Stormwater Outlet No.1) are evaporated in large volumes, the residue homogenised and tabletted, and counted for both alpha and beta activity in the Canberra 2400 alpha/beta counter. A tablet of KCl and an alloy disc of aluminium and uranium are used to standardise the counter for beta and alpha activity, respectively.

Gamma spectrometry - water residues, soils, vegetation

Gamma spectra are obtained by placing tabletted samples or soils in petri dishes, on the Ortec high-purity germanium (HPGe) crystal, and gamma counts are acquired for times varying from 3 to 24 hours. A multi-channel analyser sorts the spectra according to the energy of the gamma photons. Peaks in the spectra identify the isotope and the amount present in the sample. The energy spectrum is calibrated using a range of standard sources of known activity, in the same matrix and geometry as the samples.

Gamma spectrometry of whole fresh milk is performed initially on a 2.4 litre fresh sample using a large (8 x 4 inch) sodium-iodide crystal. The sample is then ashed and tabletted for gamma analysis on the HPGe detector.

Iodine-131 in air samples - Maypack filters

In 1980, three continuous air sampling stations were deployed along the eastern fence boundary of the site where suburban residences are closest, in order to monitor concentrations of iodine-131 in air. In August 1988, a fourth station was added. The locations of these samplers are shown on **Figure 2**. Air is sampled at a rate of approximately 35 m^3 per day, flow rates are checked and filters are replaced weekly.

The air is sampled by a pair of Maypacks (activated charcoal filter cartridges) operating on the same vacuum pump, so that duplicate samples are available. The set of four duplicate samples are submitted to each week for independant checking by officers of the NSW EPA, who report the results of their analyses to the NSW Radiation Advisory Council.

The other set of filters is analysed by ANSTO, and is counted simultaneously on a large (8x4 inch) sodium-iodide gamma detector for iodine-131 activity. If an iodine-131 peak is detected then the filters are analysed individually to determine which filters are the source of the activity.

Results are reported in units of iodine-131 activity per volume of air sampled (Bq/m^3). The results are calculated in an extremely conservative manner, using the following assumptions:

- that all the activity was released on the first day of the seven-day sampling period
- that all the measured activity was released at one point (when in fact there are four locations being measured).

Iodine-131 results are corrected for decay (due to the 8 day half-life) back to the first day of the sampling period.

Little Forest Burial Ground Air Filters

A solar-powered, remotely operating air sampler was set up at LFBG in 1984 to monitor possible aerial dust dispersion of contaminants from the site. The air sampler is located adjacent to the burial trenches, as shown on **Figure 3**.

The system is triggered by wind speeds of 3 m s^{-1} or more. Below this speed, surface dusts are not raised from this type of well-grassed landform. Air is sampled at approximately 8 litres per minute onto millipore (0.8 um pore) aerosol filters. The Millipore filters are approved by the National Institute for Occupational Safety and Health (NIOSH) for monitoring airborne beryllium and other compounds (NIOSH 1977). The filters are replaced every three months. There are two filters sampling simultaneously, in order to provide a duplicate sample for the analyses required.

The filters are analysed for beryllium by ANSTO's Occupational Health and Safety Program by the standard method recommended by the US Department of Energy's Radiological and Environmental Sciences Laboratory (RESL 1982).

The duplicate sample is initially checked for its gross alpha activity, and is retained together with the other samples for the year to form a composite sample for plutonium analysis by radiochemical separation and alpha spectrometry.

Past Methods

Prior to 1988, a sodium-iodide crystal was used for gamma spectrometry. This type of detector has a higher efficiency of counting than the HPGe (detects a higher proportion of the activity present in the sample). However the resolution (ability to separate peaks which are close together in the spectrum) is much poorer. Therefore the use of the HPGe crystal has resulted in more accurate identification of isotopes in the samples.