ansto

ANSTO / E 716

ENVIRONMENTAL SURVEY AT LUCAS HEIGHTS RESEARCH LABORATORIES 1993

by

E.L.HOFFMANN
T.LOOSZ

APRIL 1995
ISSN 1030-7745
ISBN 0 642 59956 6

REPORT E

ANSTO / E-716

AUSTRALIAN NUCLEAR SCIENCE
AND TECHNOLOGY ORGANISATION

LUCAS HEIGHTS RESEARCH LABORATORIES

ENVIRONMENTAL SURVEY AT LUCAS HEIGHTS RESEARCH LABORATORIES, 1993

BY

E.L.HOFFMANN
T.LOOSZ

ABSTRACT

Results are presented of the environmental survey conducted in the neighbourhood of the Lucas Heights Research Laboratories during 1993. 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 discharges during this period is estimated to be less than 0.01 mSv, which is one per cent of the dose limit for long term exposure that is recommended by the National Health and Medical Research Council.

ISSN 1030-7745

ISBN 0 642 59956 6

The following descriptors have been assigned from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS: Manual for Indexing) and IAEA-INIS-13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

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.

CONTENTS

Contents continued...

Contents continued...

* * *

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 1993 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 Regulations. The discharge limits are based on a consideration of the possible routes, termed *exposure pathways*, through which members of the public could be exposed to activity from LHRL origin. The resulting dose to the *critical group* (a relatively homogeneous group of members of the public who receive the highest radiation doses from a particular practice) 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 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 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). Low-level liquid effluent passes through the Cronulla Sewage Treatment Plant and is discharged at its Potter Point ocean outfall. The very large dilution effects in both the Water Board sewer and the ocean, ensure that levels of radioactivity from ANSTO in the ocean are below limits of detection and the levels of naturally occurring radionuclides in seawater.

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 controlled and any resulting radiation doses are within the limits recommended by international bodies and regulatory authorities as acceptable for

members of the general public. The site was selected and wastes disposed of using international guidelines prevalent at the time.

The possible exposure scenarios for the movement of radionuclides from buried waste depend upon the characteristics of the disposal site and the nature of the waste. They fall into three general categories. Two are associated with the possible off site transport of particulate and/or dissolved radionuclides by water and air, respectively. The third is related to the radiation field of the waste.

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

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

The disposal site is signposted, fenced and routinely patrolled, ensuring that inadvertent intrusion on the site does not occur.

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.

The thickness of the soil cover is more than enough to attenuate the radiation shine from the buried waste to near background levels. Therefore, 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, or if ground water transports the dissolved radionuclides to the surface.

3.0 DISCHARGE AUTHORISATIONS

Since the 1960's the AAEC and then ANSTO have discharged radioactive effluents from LHRL in compliance with authorisations approved at various times by the NSW Radiological Advisory Council (NSW RAC) in accordance with the NSW Radioactive Substances Regulations (1959) as amended. The 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, relevant at the time, whereby members of the public could potentially be exposed to radiation doses.

There were a number of developments during 1993 which had implications for the future regulation and authorisation of radioactive discharges from LHRL. In September 1993, the Radioactive substances Regulation (1959) as amended was repealed and replaced with the Radiation Control Regulation (1993) under the Radiation Control Act (1990). The regulation is administered by the Director General of the NSW Environment Protection Authority (NSW EPA) through an expanded NSW Radiation Advisory Council.

During the year, the Director General of the NSW EPA indicated that the NSW EPA no longer had a regulatory function in relation to the operations of ANSTO, following the amendments made to the ANSTO Act in June 1992.

Following the Commonwealth Government's consideration of the finding of the Research Reactor Review, the Government announced in November 1993, its intention to form a new body, the Australian Institute of Radiation Protection (AIRP). The AIRP will be an amalgamation of the Australian Radiation Laboratory and the Nuclear Safety Bureau, and will have regulatory and licensing powers in respect of nuclear and radiation related activities of the Commonwealth. This new body will be responsible for authorising and regulating ANSTO's radioactive discharges once it is established.

ANSTO has advised the Director General of the NSW EPA that until the new commonwealth regulatory agency is established and any new requirement or discharge limits are prescribed, ANSTO will continue to comply with the authorisations issued by the NSW RAC and discharge limits prescribed in the NSW Radioactive Substances Regulations (1959).

Summaries of radioactive discharge data have been published in annual environmental survey reports (**Appendix A**).

3.1 Low Level Liquid Effluent

Since mid-1980 when the then AAEC's liquid effluent discharges were directed to the Water Board sewer, all liquid effluent discharges are required to comply with the Water Board's requirements for acceptance of liquid trade waste, including the radioactivity concentration limits specified in the NSW Radioactive Substances Regulations (1959) as amended. As indicated earlier, in September 1993 the NSW Radiation Control Regulation (1993) came into force, however this regulation does not include a schedule specifying generic radioactivity concentration limits for liquid discharges to the sewer.

Until the abovementioned regulatory arrangements involving AIRP are established in 1995, ANSTO will continue a policy of ensuring that all liquid effluent discharges conform with the concentration limits specified in the previous 1959 NSW Radioactive Substances Regulations.

Compliance with the discharge limits was routinely monitored by ANSTO and compliance auditing of ANSTO's liquid effluent discharges was undertaken by the Radiation Control Section of the NSW EPA which replaced the former Radiation

Health Services Section of the Department of Health during 1992. The Water Board also conducted random auditing of ANSTO's liquid effluent discharges.

3.2 Gaseous Emissions

From 1968, radioactive emissions from AAEC / ANSTO were subject to a discharge authorisation approved by the NSW RAC. This specified the maximum amount of radioactivity which could be discharged from each of the stacks at LHRL at the time.

In 1988, ANSTO proposed to the NSW RAC a revised site-wide airborne radioactive effluent discharge limit for LHRL, based on changes occurring in the intervening 20 years to ICRP and NHMRC recommendations, site operational changes, developments in radiation dosimetry, and increased knowledge of the local meteorology at LHRL.

The proposal for a revised authorisation was based on limiting the total amount of radioactivity discharged to the atmosphere from LHRL, such that the sum of the potential external doses and committed doses to any member of the public from the discharges would not exceed 0.5 mSv. This is half of the annual effective dose limit for members of the general public recommended by the NH&MRC and specified in the NSW Radiation Control Regulation (1993).

The basis of the proposed new discharge authorisation is the demonstration of compliance with the discharge limit by the use of an independently-reviewed ANSTO-developed computer-based air dispersion, transport and dosimetry model (ADDCOR) which requires stack discharge monitoring information as well as local meteorological data and internationally accepted dosimetry parameters.

In December 1988, the NSW Radiological Advisory Council accepted the proposal subject to a number of conditions.

In August 1993 the Research Reactor Review recommended that ANSTO should commit itself to emission targets and, in particular, a single source dose constraint of 0.3 mSv. This recommendation is being considered by ANSTO and is likely to be adopted.

Ansto monitored all stack discharges during the period and regular compliance auditing of ANSTO's stack discharge samples continued to be carried out by the NSW EPA Radiation Control Section.

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

3.3 Surface Waters

The NSW Clean Waters Regulations (1972) as amended, limit the gross alpha and gross beta activity in class C 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. These creeks surround the site and are 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 methods used for sample analyses are described in **Appendix D**, and 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 . 0performed. These concentrated samples can be stored for long periods, in case 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. The ratio of the sample ash weight to dry weight is determined, so that results may be expressed in terms of the dry or ashed state.

Soils
Soils are sampled with a scoop to take the first 4 cm from the surface. About 1kg is collected. Samples are then dried, and passed through a quarter-inch mesh sieve to remove large stones and vegetative matter. After weighing, the samples are ashed, and counted for gross beta activity. For gamma spectrometry, a 65 mm petri dish is packed with approximately 40 to 50 grams of sample. The remaining ash is sieved to yield a particle size range of 125 to 250 microns, which is used for alpha counting. Results are recorded as Bq/g dry weight (DW) of sample.

Sediments
Sediment samples are collected from creek beds and also from stormwater outlets which tend to accumulate suspended sediments. These samples are collected, prepared and counted in the same manner as soils.

Vegetation, biota
The vegetation samples are only available in sufficient quantities at sites where the stormwater drains are large enough to retain enough water to support plant growth. The plant species sampled is Crofton Weed (*Eupatorium adenophorum*), and 2-3 kg are collected. The whole, unwashed vegetation is dried, weighed and ashed.

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 and gamma detectors in uniform dimensions. Results are expressed in terms of the fresh weight (FW) of the sample.

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.

Air Samples: iodine-131
Four (4) continuous air sampling stations are situated along the eastern fence boundary of the site (where suburban residences are closest) in order to monitor concentrations of iodine-131 in air. The locations of these samplers are shown on **Figure 2**. At each station the air is sampled by means of a vacuum pump drawing air through a pair of Maypacks (activated charcoal filter cartridges), so that duplicate samples are available. Air is sampled at a rate of approximately 35 m^3 per day. Filters are replaced and analysed weekly, with air flow rates through the filters being checked at the same time.

Dust on aerosol filters - LFBG
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 μm 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.

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 unit of absorbed dose in joules per kilogram, is called the *gray* (Gy).

The *equivalent dose* is a weighted dose in an organ or tissue, and is the product of absorbed dose in the organ or tissue and the radiation weighting factor (determined by the type and energy of the radiation to which the organ or tissue is exposed). This measurement enables the dose received by exposed persons to be expressed on a scale common to all ionising radiation.

The *effective dose* is the sum of weighted equivalent doses to all organs and tissues of the body, where the equivalent dose to each organ and tissue is multiplied by the weighting factor for that organ or tissue.

The unit for dose equivalent and effective dose is the *sievert* (Sv). This dose is most commonly expressed as millisieverts (mSv). The dose limit for members of 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 1993, 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 particle-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 the measurement of unspecified beta particle-emitting nuclides in a sample.

Gamma activity: Gamma photons emitted from radionuclides are detected by semi-conductor detectors made of high purity germanium crystals. A spectrum of counts for each sample is accumulated in the energy range 0 to 2000 keV. The gamma 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 5.69KeV. The penetration of the tritium beta is consequently low (the stopping distance is about 7 mm in air; 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 one 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 (*ie.* the effect of a given dose on specific organs) must be considered. This yields the dose conversion factor, which is the committed 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:

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

$$= 7610\text{ Bq/L or } \mathbf{7.61\ Bq/mL}$$

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 is 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 of 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 in **Figure 1**.
The meteorological tower and associated laboratory are shown in **Figure 4**.

6.0 RESULTS

Environmental survey measurements during 1993 are presented in **Tables 2 to 14**.

Authorised airborne release data are given in **Tables 15 & 16**.

Authorised liquid effluent discharges to the Water Board sewer are summarised in **Table 17**.

7.0 DISCUSSION OF RESULTS

7.1 Woronora estuary samples

Routine water samples are collected on a weekly basis from the Woronora estuary, at the boat ramp in Jannali Reserve, throughout the year. These water samples are analysed for tritium as a precaution against unknown accidental releases or pipeline leaks. No tritium was detected in these samples during 1993 (see **Table 2**).

Discharges of radioactivity 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 significant radioactivity associated with discharges from LHRL could be measured.

7.2 Stormwater outlets and creeks draining LHRL

Results for samples of soil and vegetation collected in stormwater drains are shown in **Table 3**. Results for water samples collected at the same sites are shown in **Tables 4 and 5**. Samples from most drains are collected every three months, after rain, if possible. Water from stormwater outlet No.1 however, is sampled weekly. Tritium analysis is then performed (**Table 4**) and the remainder of the sample combined to make a monthly composite for gross alpha, beta and gamma analyses(**Table 5**).

Stormwater
Caesium-137 was 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 1993 (**Table 5**) represents less than 0.01% 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 & sediment
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, ruthenium-106 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 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 do not have any health consequences for humans.

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 6**. Here the gross beta activity results include the contribution of natural potassium-40. All results were well below the NSW Clean Waters Regulations 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 also collected from the SPCC sampling weir on Bardens Creek at weekly intervals during 1993 for tritium analysis. The results are shown in **Table 7**. The highest value recorded during the year was 0.186 Bq/mL, which is 2.4% of the guideline value for tritium in drinking water (**Section 5.2**). The average weekly concentration at this location was 0.055 Bq/mL, which is 0.73% of the guideline value. It should be noted that water from Bardens Creek is not part of any known drinking water supply.

7.3 Effluent discharge pipeline

The ANSTO liquid effluent disposal pipeline, which runs above ground for much of its length, is shown on **Figure 2**. Surveys of the dose rates along this pipeline were carried out in 1993, and the results are summarised in **Table 8**. These surveys were performed as part of the regular program of care and maintenance of the pipeline.

The dose rates recorded along the pipeline during 1993 were less than 0.14μSv/hour, which is consistent with background readings around most of Sydney. The maximum annual effective dose for continuously exposed members of the public is 1 mSv (ICRP 1990b). 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 this limit would not be exceeded.

7.4 Little Forest Burial Ground (LFBG)

Results of sampling at the LFBG are given in **Tables 9, 10, 11, 12** and **13**. The locations of the sampling points and the burial trenches are shown in **Figure 3**.

Radiation survey
Annual surveys of the burial trenches are carried out using field dose rate monitors to check for surface contamination (**Table 9**). Dose rates over the trenches generally range from 0.08 to 0.10 μSv/hour, which are consistent with normal background readings. However, past surveys have identified two localised points, #5 and #6, which show readings higher than background levels. Results for this year are consistent with those previously measured in these locations.

Soil
Samples of soil were collected from the area near MB16, to monitor for any expression of buried activity at the surface(**Table 10**). 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 the localised sites, points #5 and #6, were consistent with those measured in previous years, indicating some expression of these radionuclides which has not changed significantly in the recent past.

The general area encompassing points #5 & #6 was filled with a soil/shale mixture to prevent removal of the cover due to regular sampling.

Groundwater Monitoring
Groundwaters from bores located inside the LFBG and outside the fenced area were analysed for tritium, gross alpha, gross beta and gamma activities(**Table 11**).

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 (0.045 Bq/mL). 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, MB16 and MB17 are similar to those measured in the past. The detected concentrations are of no health significance and 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 bores which contained gamma activity associated with the buried waste were MB16 and OS2. The activity expressed in bore MB16 is not unexpected since it is in the centre of the burial trench area. A measurable amount of cobalt-60 activity was found in the OS2 bore, due to improvements in analysis sensitivity.

Creeks draining LFBG
Annual samples of surface water and sand were collected from station T2 (junction of Mill Creek and Bardens Creek, **Figure 1**), as a check on possible movement of contaminants from the LFBG. The results of gross alpha and beta, tritium and gamma analyses on these samples are given in **Table 12**. No radioactivity above background levels was found.

Air sampling
No beryllium (Be) or plutonium-239 was detected on aerosol filters from the air sampling station near the burial trenches (**Table 13**). The minimum detectable level for Be is 0.0025 mg (total per filter) and for plutonium-239 is 0.0001 Bq (total).

7.5 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 in **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 around 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 1993 (**Table 14**). The highest reading , registered for the week ending 20 July 1993, was 7.0×10^{-2} Bq /m^3. The average iodine-131 concentration in air for the year was 1.0×10^{-2} Bq/m^3. The effective dose to a hypothetical member of the critical group living at Stevens Hall Motel, and receiving continuous exposure to iodine-131 at the average concentration recorded, would be less than 0.01 mSv per year. This figure is based on the committed effective dose per unit activity given in the IAEA Basic Safety Standard (IAEA,1994).

The only milk sample for the year was collected on 22 February 1993, from which date there have not been any milking cows kept in the vicinity of the LHRL. No caesium-137 or iodine-131 activity was detected in this sample.

Table 15 presents the quarterly airborne emissions for the individual stack release points, and **Table 16** lists the same figures expressed as percentages of the quarterly working limits. Where values in **Tables 15 & 16** 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 determination of 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.

For internal monitoring purposes, working levels are set for individual stack discharges at ANSTO. Discharge records for the period 1977 to 1993 show that the majority of airborne emissions from LHRL have been well below the working levels and, in most instances, 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 working levels. Comparing the discharges for the whole year with the NSW RAC authorisation for annual discharge limits, shows that the authorisation has never been exceeded.

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 emissions and low level liquid effluent discharges. These sources 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 well 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. **Tables 18** and **19** summarise the calculated public doses at LHRL at 1.6 km and 4.8 km radii around HIFAR, based on the actual stack discharges and meteorological data measured during 1993. 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 20 and 21**. It can be readily shown 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 and the recommended annual dose limit to members of the general public of 1 mSv. If the dose restraint limit of 0.5 mSv annual dose is adopted, then the estimated committed doses are less than 2% of the limit.

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 (**Tables 15 and 16**) were within the NSW RAC authorised limits when averaged over the year. The effective dose to the most sensitive members of the public from iodine-131 releases, calculated from the results in **Table 14**, was less than 0.01 mSv/year and the calculated dose from released noble gases to the most exposed individuals was also less than 0.01 mSv/year. These figures represent less than one per cent of the limits recommended by the NH&MRC.

The monthly average concentration of radioactivity in liquid effluent discharges to the Water Board Sewer during 1993 (**Table 17**) was less than 65 per cent of the permitted level for all periods. For tritium, the monthly average concentrations were less than 0.4 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 doses 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.

10 ACKNOWLEDGMENTS

The authors thank Yvonne Farrar for her assistance in typing suggested corrections to the draft report, and both Alex Camilleri and John Fardy for their advice and technical editing of this report.

Beryllium levels on the LFBG air filters and iodine-131 levels in air samples were determined by ANSTO's Occupational Health and Safety Program.

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 15**) were supplied by ANSTO's Health and Safety Program.

Liquid effluent release data (**Table 17**) 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.

11 REFERENCES

Australian Nuclear Science and Technology Organisation (ANSTO), 1989. *Radioactive airborne Effluent Working Party on a Revised Radioactive Effluent Discharge Limit for the Lucas Heights Research Laboratories.* M.C.E. Petersen, G.H.Clark, G.M.Bailey, F.M.May. ANSTO/DR25, September 1989.

Fry, R.M.,1966. *Reformulation of the Lucas Heights Liquid Effluent Discharge Authorisation.* AAEC/E156.

International Atomic Energy Agency (IAEA), 1977. *Radiation protection.* Publication 26. Pergamon press, Oxford.

International Atomic Energy Agency (IAEA), 1981. *Shallow ground disposal of radioactive wastes - A guidebook.* Safety series No. 53, Vienna.

International Atomic Energy Agency (IAEA), 1994. *International Basic Safety Standard (BSS) for protection against ionising radiation and for the safety of radiation sources.* Safety Series No.115-I, Vienna.

International Commission on Radiological Protection (ICRP), 1975. *Report of the Task Group on Reference Man.* ICRP Publication 23. Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP), 1990(a). *Recommendations.* ICRP Publication 60, Pergamon Press, Oxford.

International Commission on Radiological Protection (ICRP), 1990(b). *Annual limits on Intake of Radionuclides by Workers based on the 1990 Recommendations.* ICRP Publication 61, Pergamon Press, Oxford.

Kathren, R.L., 1984. *Radioactivity in the Environment - Sources, Distribution and Surveillance.* pp 160-162. University of Washington Joint Centre for Graduate Study, Richland, Washington. Harwood Academic Publishers.

National Health and Medical Research Council (NH&MRC), 1989. *Recommended radiation protection standards for individuals exposed to ionising radiation.* Radiation Health Series No.27.

National Health and Medical Research Council & Australian Water Resources Council (NH&MRC and AWRC), 1987. *Guidelines for Drinking Water Quality in Australia.* Australian Government Publishing Service, Canberra.

National Institute for Occupational Safety and Health (NIOSH).1977. *Manual of Air Sampling Data, Sheet 9 (SDS).* Washington, DC.

National Radiological Protection Board (NRPB), 1991. *Committed equivalent organ doses and committed effective doses from intakes of radionuclides.* Part I, Chapter 4.3.3, Table 4.1. Report NRPB-R245, Chilton, UK.

NSW Clean Waters Act 1972. Regulations as amended. Government Gazette, NSW Government Printery, Australia.

NSW Radioactive Substances Regulations 1959, as amended. Radioactive Substances Act, 1957. Government Gazette, NSW Government Printery, Australia.

Radiation Control Regulation, 1993. Radiation Control Act 1990 - Regulation. Government Gazette No. 94, NSW Government Printery, Australia.

Radiological and Environmental Sciences Laboratory (RESL), 1982. *Analytical Chemistry Branch Procedures Manual.*(Editors Bodnar,L.Z., Percival, D. R.) Analytical Chemistry Branch, US Department of Energy , Idaho. IDO/12096

Standards Association of Australia (SAA), 1990. *Waters - Determination of Gross Alpha and Gross Beta Activities*. AS 3550.5-1990, Sydney.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1977. *Sources and Effects of Ionising Radiation*. United Nations document E.77.IX.1, New York.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), 1988. *Sources, effects and risks of ionising radiation*. Report ISBN 92-1-142143-8, New York.

Wilson, A.R.W., 1957. *Radiation survey - Lucas Heights*. AAEC/K116.

Wilson, A.R.W., 1959. *Safe levels for the discharge of radioactive effluent into the Woronora estuary*. AAEC/K260.

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 at 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. 250 mL distilled for tritium
Sand / Soil	LFBG	If indicated by dose rate survey	1 kg, from surface	Gamma spectrometry of sieved & ashed sample. Gross α β counting also
	LHRL stormwater outlets	Quarterly	At drain outlet	as above
	T2: Barden & Mill Creeks	Yearly	From creek bed	as above

continued next page...

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

*No milk samples were available after February 1993, this sampling has therefore been discontinued until further notice.

TABLE 2

TRITIUM IN WORONORA ESTUARY WATER SAMPLES
STATION E5.9, 1993

Date	Tritium (Bq/mL)	Date	Tritium (Bq/mL)
5.1.93	LLD	6.7.93	LLD
12.1.93	LLD	13.7.93	LLD
19.1.93	LLD	20.7.93	LLD
28.1.93	LLD	27.7.93	LLD
4.2.93	LLD	3.7.93	LLD
9.2.93	LLD	10.8.93	LLD
16.2.93	LLD	17.8.93	LLD
23.2.93	LLD	24.8.93	LLD
2.3.93	LLD	31.8.93	LLD
9.3.93	LLD	7.9.93	LLD
16.3.93	LLD	14.9.93	LLD
23.3.93	LLD	21.9.93	LLD
30.3.93	LLD	28.9.93	LLD
6.4.93	LLD	5.10.93	LLD
13.4.93	LLD	12.10.93	LLD
20.4.93	LLD	19.10.93	LLD
27.4.93	LLD	26.10.93	LLD
4.4.93	LLD	2.11.93	LLD
11.5.93	LLD	9.11.93	LLD
18.5.93	LLD	16.11.93	LLD
25.5.93	LLD	22.11.93	LLD
1.6.93	LLD	29.11.93	LLD
8.6.93	LLD	7.12.93	LLD
15.6.93	LLD	15.12.93	LLD
22.6.93	LLD	21.12.93	LLD
29.6.93	LLD	30.12.93	LLD

Notes:
LLD = less than the limit of detection for tritium,which is 0.04 Bq/mL.

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

TABLE 3

RADIOACTIVITY IN SAMPLES OF SOIL AND VEGETATION FROM STORMWATER OUTLETS, 1993

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	18.2.93	soil	0.66	0.33	U & Th series	ND
	14.5.93	soil	0.38	0.15	U & Th series	ND
	22.7.93	soil	0.92	0.22	U & Th series	0.05
	7.10.93	soil	0.48	0.20	U & Th series	0.02
Drain opposite Fermi Street	18.2.93	soil	0.31	0.05	U & Th series ^{137}Cs=0.003	0.14
	14.5.93	soil	0.27	0.18	U & Th series	ND
	22.7.93	soil	0.22	0.15	U & Th series ^{7}Be=0.03 ^{137}Cs= 0.002	0.08
	7.10.93	soil	0.33	0.19	U & Th series ^{60}Co=0.005 ^{137}Cs= 0.003	0.05
Drain opposite Bld 23	18.2.93	soil	0.60	0.24	U & Th series ^{7}Be=0.03 ^{60}Co=0.014 ^{137}Cs=0.004	0.05
	14.5.93	soil	0.45	0.16	U & Th series ^{60}Co=0.02 ^{137}Cs=0.017	0.08
	22.7.93	soil	0.59	0.31	U & Th series ^{7}Be=0.02 ^{60}Co=0.047 ^{137}Cs=0.01	0.10
	7.10.93	soil	0.58	0.42	U & Th series ^{60}Co=0.05 ^{137}Cs=0.01	0.11
Drain No.1 opp. Strassman Crescent	18.2.93	soil	0.39	0.22	U & Th series ^{7}Be=0.107	0.12
		vegetation	< 0.01	ND	U & Th series ^{7}Be=0.058	0.14
	14.5.93	soil	0.49	0.21	U & Th series ^{7}Be=0.20	0.11
		vegetation	<0.01	ND	U & Th series ^{7}Be=0.031	0.14
	22.7.93	soil	0.41	0.07	U & Th series ^{7}Be=0.03 ^{137}Cs=0.001	0.12
		vegetation	0.01	0.11	U & Th series ^{7}Be=0.025	0.13
	7.10.93	soil	0.24	0.19	U & Th series ^{7}Be=0.003	0.07
		vegetation	0.01	ND	U & Th series ^{7}Be=0.13	0.61

Continued next page.

TABLE 3 continued ...

Sample Location	Date	Sample Type	RADIOACTIVITY (Bq/g DW or FW#)			
			Gross α	Gross β *	γ-emitters	^{40}K
Drain opposite meteorological tower	18.2.93	soil	0.65	0.24	U & Th series ^{7}Be=0.016 ^{137}Cs= 0.007	0.13
	14.5.93	soil	1.08	0.26	U & Th series	0.12
	22.7.93	soil	1.00	0.33	U & Th series	0.07
	7.10.93	soil	0.69	0.29	U & Th series	0.08
20m from Stormwater Outlet No. 1	18.2.93	soil	1.09	3.06	U & Th series ^{60}Co=0.008 ^{134}Cs=0.010 ^{137}Cs=0.86 ^{144}Ce=0.155	0.22
		vegetation	0.01	0.05	^{7}Be=0.076 ^{134}Cs=0.001 ^{137}Cs=0.033	0.13
	14.5.93	soil	1.00	5.08	U & Th series ^{60}Co=0.009 ^{134}Cs=0.02 ^{137}Cs= 0.86 ^{144}Ce=0.09 ^{241}Am=0.04	0.17
		vegetation	0.004	0.06	^{7}Be=0.031 ^{134}Cs=0.001 ^{137}Cs=0.032	0.13
	22.7.93	soil	1.00	5.26	U & Th series ^{60}Co=0.015 ^{106}Ru=0.58 ^{134}Cs=0.028 ^{137}Cs=2.42 ^{144}Ce=0.098 ^{241}Am=0.10	0.23
		vegetation	0.004	ND	^{7}Be=0.035 ^{134}Cs=0.023 ^{137}Cs=0.07 ^{144}Ce=0.002	0.15
	7.10.93	soil	0.78	1.45	U & Th series ^{60}Co=0.003 ^{134}Cs=0.004 ^{137}Cs=0.33 ^{144}Ce=0.02 ^{241}Am=0.03	0.16
	**	vegetation				

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.
** No vegetation collected from this area due to weed poisoning.

TABLE 4

TRITIUM IN WATER SAMPLES FROM STORMWATER OUTLETS 1993

Sample Location	Date	Tritium Bq/mL	Sample Location	Date	Tritium Bq/mL
Drain behind Bld.1	18.2.93	0.070	60m from LHRL Stormwater Outlet No.1	2.3.93	0.13
	14.5.93	0.530		9.3.93	0.08
	16.7.93	LLD		16.3.93	0.13
	7.10.93	0.055		23.3.93	0.15
				30.3.93	0.16
Drain near road on West fence	18.2.93	LLD		6.4.93	0.13
	14.5.93	LLD		13.4.93	0.13
	16.7.93	LLD		20.4.93	0.17
	7.10.93	LLD		27.4.93	0.116
				4.5.93	0.144
Drain opposite Fermi Street	18.2.93	0.060		11.5.93	0.127
	14.5.93	0.164		18.5.93	0.145
	16.7.93	0.114		25.5.93	0.152
	7.10.93	0.090		1.6.93	0.156
				8.6.93	0.178
Drain opposite Bld. 23	18.2.93	0.040		15.6.93	0.177
	14.5.93	0.102		22.6.93	0.326
	-	-		29.6.93	0.185
	7.10.93	0.054		6.7.93	0.094
				13.7.93	0.097
Drain No.1 opp. Strassman Crescent	18.2.93	LLD		20.7.93	0.065
	14.5.93	0.830		27.7.93	0.061
	16.7.93	0.054		3.8.93	0.082
	7.10.93	0.056		10.8.93	0.109
				17.8.93	0.089
Drain opposite meteorological tower	18.2.93	LLD		24.8.93	0.078
	14.5.93	0.051		31.8.93	0.076
	16.7.93	LLD		7.9.93	0.051
	7.10.93	LLD		14.9.93	LLD
				21.9.93	0.088
20m from LHRL Stormwater Outlet No.1	18.2.93	LLD		28.9.93	0.111
	14.5.93	0.174		5.10.93	0.098
	16.7.93	LLD		12.10.93	0.084
	7.10.93	LLD		19.10.93	0.100
				26.10.93	0.087
60m from LHRL Stormwater Outlet No.1	5.1.93	0.13		2.11.93	0.086
	12.1.93	0.16		9.11.93	0.065
	19.1.93	2.23		16.11.93	0.083
	28.1.93	0.24		22.11.93	0.098
	4.2.93	0.19		29.11.93	0.090
	9.2.93	0.27		7.12.93	0.142
	16.2.93	0.14		15.12.93	0.103
	23.2.93	0.18		21.12.93	0.099
				30.12.93	0.118

Notes:
Refer to Figure 2 for the location of these sampling points.
LLD = less than the limit of detection for tritium, which is 0.045 Bq/mL.

TABLE 5

RADIOACTIVITY IN WATER SAMPLES, 60m FROM STORMWATER OUTLET No. 1, 1993

Sample Location	Date	RADIOACTIVITY (Bq/L)		
		Gross α	Gross β (incl. ^{40}K)	γ-emitters
60m from LHRL Stormwater Outlet No. 1*	January	0.20	0.60	U & Th series ^{137}Cs=0.032
	February	0.23	0.86	^{137}Cs=0.038
	March	0.13	0.78	^{137}Cs=0.024
	April	0.26	0.65	^{137}Cs=0.018
	May	0.14	0.47	^{137}Cs=0.013
	June	0.28	0.44	^{137}Cs=0.013
	July	0.20	0.36	^{137}Cs=0.007
	August	0.14	0.34	^{137}Cs=0.007
	September	0.12	0.26	^{137}Cs=0.007
	October	0.15	0.31	^{137}Cs=0.010
	November	0.05	0.30	^{137}Cs= 0.006
	December	0.08	0.30	^{137}Cs= 0.012

Notes:
* This location is sampled weekly for tritium (see Table 5), with the remainder of the weekly samples being combined to make a monthly composite water sample for gross alpha, beta and gamma analysis.
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.
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 SPCC SAMPLING POINTS, 1993

Date	Radioactivity (Bq/L)					
	Strassman Creek		Bardens Creek weir		MDP creek weir	
	Gross α	Gross β*	Gross α	Gross β*	Gross α	Gross β*
19.1.93	LLD	0.19	LLD	0.24	0.04	0.50
19.2.93	LLD	0.11	LLD	0.10	0.06	0.37
23.3.93	LLD	0.14	LLD	0.18	LLD	0.30
28.4.93	LLD	0.29	LLD	0.30	LLD	0.56
12.5.93	LLD	0.33	LLD	0.40	LLD	0.60
**						
13.7.93	LLD	LLD	LLD	LLD	LLD	0.22
9.8.93	LLD	0.10	0.04	0.12	LLD	0.24
15.9.93	0.10	0.10	LLD	0.19	LLD	0.23
28.10.93	0.03	0.06	0.09	0.16	LLD	0.20
11.11.93	LLD	LLD	LLD	LLD	LLD	0.21
13.12.93	LLD	0.10	0.04	LLD	LLD	0.22

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.

** No samples collected in June

TABLE 7

TRITIUM IN WATER FROM BARDENS CREEK WEIR
(at SPCC sampling point)
1993

Date	Tritium Bq/mL	Date	Tritium Bq/mL
5.1.93	LLD	6.7.93	0.157
12.1.93	LLD	13.7.93	0.050
19.1.93	0.10	20.7.93	0.164
28.1.93	0.09	27.7.93	LLD
4.2.93	0.07	3.8.93	0.052
9.2.93	0.08	10.8.93	0.055
16.2.93	LLD	17.8.93	0.046
23.2.93	LLD	24.8.93	0.046
2.3.93	LLD	31.8.93	0.041
9.3.93	0.060	7.9.93	0.051
16.3.93	LLD	14.9.93	0.083
23.3.93	0.050	21.9.93	0.040
30.3.93	0.060	28.9.93	0.053
6.4.93	LLD	5.10.93	LLD
13.4.93	LLD	12.10.93	LLD
20.4.93	0.056	19.10.93	0.046
27.4.93	LLD	26.10.93	LLD
4.5.93	LLD	2.11.93	LLD
11.5.93	LLD	9.11.93	LLD
18.5.93	LLD	16.11.93	0.041
25.5.93	0.056	22.11.93	LLD
1.6.93	0.052	29.11.93	LLD
8.6.93	0.042	7.12.93	LLD
15.6.93	LLD	15.12.93	LLD
22.6.93	0.042	21.12.93	LLD
29.6.93	0.186	30.12.93	LLD

Notes:
LLD = Less than the limit of detection for tritium, which is 0.04 Bq/mL.
The guideline value for tritium in drinking water is 7.61 Bq/mL (WHO, NH&MRC Drinking Water Guidelines).

TABLE 8

GAMMA SURVEY - EFFLUENT DISCHARGE PIPELINE, 1993

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 (μSv/hour)		Background range (μSv/hour)
		ground below joint	pipe joint	
26.5.93	Joints #1-17	< 0.10	< 0.11	0.05 - 0.11
	Joints # 20-22	< 0.07	< 0.08	0.06 - 0.08
17.11.93	Joints #1-17	< 0.09	< 0.14	0.05 - 0.11
17.11.93	Joints #20 -22	< 0.07	< 0.06	0.06 - 0.07

* Joints # 18 & 19 are inaccessible.

TABLE 9

GAMMA SURVEY of BURIAL TRENCHES, LITTLE FOREST BURIAL GROUND, 1993

Date	Location	Dose range (μSv/hour)
12 Oct.1993	Background outside fence	0.07 - 0.10
	Readings over all trenches	0.08 - 0.10
	Point #5	0.10 - 0.15
	Point #6	0.50 - 0.60

See figure 3 for the location of the trenches and sampling points.
Survey performed using a calibrated Eberline PRM-7 field rate meter, suspended 5-10 cm above the ground surface.

TABLE 10

RADIOACTIVITY IN SOIL FROM LITTLE FOREST BURIAL GROUND
1993

Date	Sample Location	SOIL RADIOACTIVITY (Bq/g DW)			
		Gross α	Gross β (less ^{40}K)	γ-emitters	^{40}K
12.7.93	Point # 5	1.0	0.71	U & Th series ^{60}Co = 0.0043	0.37
12.7.93	Point # 6	0.95	3.96	U & Th series ^{60}Co = 0.420 ^{137}Cs = 0.042	0.51

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

After these soil samples were collected, the area was covered with a shale-soil mixture. Sampling at these points will therefore be discontinued, however dose rates will still be monitored regularly.

The gross beta results DO NOT include the contribution from natural potassium-40.

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, 1993

Borehole No.	Date	RADIOACTIVITY (Bq/g sediment) Gross α	Gross β *	γ-emitters	Tritiun Bq/mL
BHF	25.6.93	1.03	3.24	U & Th series	0.66
BH10	"	0.61	1.31	U & Th series	3.90
OS2	"	2.93	1.16	U & Th series ^{60}Co = 0.032	2.79
OS3	"	1.26	3.36	U & Th series	3.84
MB11	"	1.15	0.33	U & Th series	LLD
MB12	"	0.93	0.32	U & Th series	LLD
MB13	"	1.00	1.43	U & Th series	4.11
MB14	"	1.78	0.62	U & Th series	LLD
MB15	"	1.49	0.39	U & Th series	LLD
MB16	"	4.43	6.69	U & Th series ^{60}Co = 1.08 ^{137}Cs = 0.068	12.4
MB17	"	1.49	0.81	U & Th series	1.82
MB18	"	1.94	0.76	U & Th series	LLD
MB19	"	0.81	0.40	U & Th series	LLD
MB20	"	1.60	0.94	U & Th series	LLD
MB21	"	0.89	0.53	U & Th series	LLD
BHF	20.12.93	1.22	2.67	U & Th series	0.72
BH10	"	0.43	1.37	U & Th series	5.02
OS2	"	4.19	1.03	U & Th series	2.77
OS3	"	3.24	2.15	U & Th series	4.57
MB11	"	0.33	0.12	U & Th series	LLD
MB12	"	0.89	0.27	U & Th series	0.07
MB13	"	1.58	1.26	U & Th series	5.75
MB14	"	1.34	0.39	U & Th series	LLD
MB15	"	1.41	0.55	U & Th series	LLD
MB16	"	4.99	8.92	U & Th series ^{60}Co = 1.04 ^{137}Cs = 0.037	12.4
MB17	"	1.20	0.85	U & Th series	1.95
MB18	"	2.56	0.79	U & Th series	0.06
MB19	"	0.78	0.33	U & Th series	LLD
MB20	"	1.32	0.89	U & Th series	LLD
MB21	"	1.01	0.49	U & Th series	LLD

Notes: * The gross beta results include the contribution from natural potassium-40.
Small amounts of beryllium-7 (of natural origin) were also detected in some samples.
"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.
LLD = less than the limit of detection, which is 0.045 Bq/mL for tritium.

TABLE 12

RADIOACTIVITY IN SAMPLES TAKEN FROM CREEKS NORTH OF LITTLE FOREST BURIAL GROUND, 1993

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)	24.11.93	1.15	0.27	U & Th series	0.11
Bardens Creek (before it joins Mill Creek)	24.11.93	0.69	0.08	U & Th series	0.10

WATER					
Sample Location	Date	RADIOACTIVITY (Bq/L)			Tritium
		Gross α	Gross β	γ-emitters	(Bq/mL)
Mill Creek (before it joins Bardens Creek)	24.11.93	0.25	0.16	U & Th series	LLD
Bardens Creek (before it joins Mill Creek)	24.11.93	0.06	0.07	U & Th series ^{40}K = 0.10	LLD

Notes: See 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.
LLD = less than the limit of detection which is 0.040 Bq/mL for tritium.
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 13

RESULTS OF AIR SAMPLING AT LITTLE FOREST BURIAL GROUND, 1993

Sampling period	Air volume sampled (m^3)	Beryllium (μg/filter)	^{239}Pu (Bq/m^3)
21.12.92 to 10.3.93	81.3	<0.5	-
10.3.93 to 24.6.93	72.7	<2.5	-
24.6.93 to 22.9.93	69.1	<0.5	-
22.9.93 to 22.12.93	184	<0.3	-
1993 Composite of B filters *	415.9	-	LLD

Notes:
* Composite sample of duplicate set of air filters for 1993. Result determined by alpha spectrometry.
LLD = less than the limit of detection. The limit of detection for beryllium varied due to the implementation of a new analyses technique. The maximum limit was 2.5 μg (total).
The limit of detection for ^{239}Pu is 0.0001 Bq (total).

TABLE 14

RADIOACTIVE IODINE IN AIR, 1993

Sampled during the week ending :	Iodine-131 in air (Bq/m^3)	Sampled during the week ending :	Iodine-131 in air (Bq/m^3)
5.1.93	LLD	7.7.93	0.004
12.1.93	LLD	13.7.93	0.004
19.1.93	LLD	20.7.93	0.070
28.1.93	0.005	27.7.93	0.003
4.2.93	0.007	3.8.93	LLD
9.2.93	LLD	10.8.93	0.003
16.2.93	0.006	17.8.93	LLD
23.2.93	0.016	24.8.93	LLD
2.3.93	0.026	31.8.93	LLD
9.3.93	0.012	7.9.93	0.011
16.3.93	LLD	14.9.93	0.015
23.3.93	0.006	21.9.93	0.023
30.3.93	0.023	28.9.93	0.003
6.4.93	0.015	5.10.93	0.038
13.4.93	0.021	12.10.93	0.006
20.4.93	0.011	19.10.93	0.010
27.4.93	0.007	26.10.93	0.017
4.5.93	0.007	2.11.93	0.008
11.5.93	0.047	9.11.93	LLD
18.5.93	LLD	16.11.93	0.005
25.5.93	0.012	22.11.93	0.007
1.6.93	0.009	29.11.93	LLD
8.6.93	0.014	7.12.93	0.004
15.6.93	0.013	15.12.93	-
22.6.93	0.016	22.12.93	LLD
29.6.93	0.008	30.12.93	0.004

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 15

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, 1993

Discharge stack Bld. No.	Gross α (kBq)	^{131}I (MBq)	Gross β (MBq)	^{3}H (GBq)	Noble gases (TBq)	Other activity (MBq)
1st Quarter 1993						
Bld 54 (hotcells)	7	39 680	0.20	-	118	335 610
3	4	1	0.10	-	-	-
15 (HIFAR)	2	2	0.27	420	21	84
19	11	2	0.29	-	-	ND
20	5	1	0.17	2	-	-
21A	2	1	0.06	-	-	-
21B	1	1	0.01	-	--	-
23A	10	1 921	0.57	-	-	-
23B	1	1	0.03	-	-	-
41	4	1	0.10	-	-	-
56	13	13	0.37	-	-	-
57	1	1	0.50	1	-	-
2nd Quarter 1993						
Bld 54 (hotcells)	7	22 987	0.20	-	106	154 384
3	4	1	0.11	-	-	-
15 (HIFAR)	0.4	2	0.35	422	21	58
19	12	63	0.36	-	-	ND
20	5	1	0.23	1	-	-
21A	2	1	0.06	-	-	-
21B	1	ND	0.01	-	-	-
23A	12	63	0.36	-	-	-
23B	1	1	0.03	-	-	-
41	3	1	0.08	-	-	-
56	12	3	0.35	-	-	-
57	2	1	0.04	44	-	-

continued next page...

TABLE 15 continued ...

Discharge stack Bld No.	Gross α (kBq)	^{131}I (MBq)	Gross β (MBq)	^{3}H (GBq)	Noble gases (TBq)	Other activity (MBq)
3rd Quarter 1993						
Bld 54 (hotcells)	10	12 931	0.20	-	128	96 341
3	5	ND	0.11	-	-	3 330
15 (HIFAR)	2	1	0.35	479	23	72
19	12	6	0.39	-	-	547
20	6	3	0.22	ND	-	-
21A	2	ND	0.22	-	-	-
21B	ND	ND	0.013	-	-	-
23A	12	7 470	0.46	-	-	-
23B	1	2	0.32	-	-	-
41	4	2	0.14	-	-	-
56	10	4	0.32	-	-	-
57	2	1	0.06	57	-	-
4th Quarter 1993						
Bld 54 (hotcells)	6	17 469	0.20	-	126	179 460
3	5	1	0.11	-	-	-
15 (HIFAR)	2	2	0.62	406	23	64
19	13	2	0.40	-	-	1 308
20	12	1	0.21	1	-	-
21A	2	ND	0.06	-	-	-
21B	ND	ND	0.01	-	-	-
23A	13	1 494	0.86	-	-	-
23B	1	ND	0.03	-	-	-
41	4	1	0.14	-	-	-
56	11	5	0.33	-	-	-
57	2	1	0.06	25	-	-

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 determination of the long-lived alpha and beta activities. In past reports, the gross beta activity was reported as strontium-90, assuming 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.

TABLE 16

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, EXPRESSED AS PERCENTAGES OF QUARTERLY WORKING LEVELS, 1993

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
1st Quarter 1993						
Bld. 54 (hotcells)	0.0011	60.1	0.00003	-	69.4	21.0
3	0.25	0.006	0.008	-	-	-
15 (HIFAR)	0.0061	0.013	0.0010	0.323	77.8	0.13
19	0.0033	0.006	0.0011	-	-	ND
20	0.18	0.006	0.041	0.025	-	-
21A	0.20	0.017	0.043	-	-	-
21B	0.43	0.077	0.030	-	-	-
23A	0.063	12.0	0.0044	-	-	-
23B	0.015	0.006	0.0005	-	-	-
41	0.0012	0.006	0.0004	-	-	-
56	0.17	0.002	0.034	-	-	-
57	0.16	0.028	0.006	0.056	-	-
2nd Quarter 1993						
Bld. 54 (hotcells)	0.0011	34.8	0.00003	-	62.4	9.6
3	0.25	0.006	0.0085	-	-	-
15 (HIFAR)	0.0012	0.013	0.0013	0.32	77.8	0.09
19	0.0036	0.19	0.0014	-	-	ND
20	0.18	0.006	0.056	0.012	-	-
21A	0.20	0.017	0.043	-	-	-
21B	0.43	ND	0.030	-	-	-
23A	0.075	20.5	0.0053	-	-	-
23B	0.015	0.006	0.0005	-	-	-
41	0.0009	0.006	0.0003	-	-	-
56	0.16	0.007	0.032	-	-	-
57	0.32	0.027	0.044	2.4	-	-

continued next page...

TABLE 16 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
3rd Quarter 1993						
Bld. 54 (hotcells)	0.0015	19.6	0.00003	-	75.3	6.02
3	0.31	ND	0.0085	-	-	-
15 (HIFAR)	0.006	0.006	0.0014	0.37	85.2	0.11
19	0.0036	0.018	0.0015	-	-	0.08
20	0.21	0.019	0.054	ND	-	-
21A	0.20	ND	0.157	-	-	-
21B	ND	ND	0.039	-	-	-
23A	0.075	46.7	0.0036	-	-	-
23B	0.015	0.13	0.0032	-	-	-
41	0.0012	0.13	0.0005	-	-	-
56	0.13	0.009	0.029	-	-	-
57	0.32	0.03	0.0067	3.2	-	-
4th Quarter 1993						
Bld. 54 (hotcells)	0.0009	26.5	0.00003	-	74.1	11.2
3	0.31	0.006	0.0085	-	-	-
15 (HIFAR)	0.006	0.013	0.0024	0.31	85.2	0.10
19	0.0039	0.006	0.0015	-	-	0.20
20	0.43	0.006	0.051	0.012	-	-
21A	0.20	ND	0.043	-	-	-
21B	ND	ND	0.030	-	-	-
23A	0.082	9.3	0.0066	-	-	-
23B	0.015	ND	0.0005	-	-	-
41	0.0012	0.006	0.0005	-	-	-
56	0.14	0.011	0.030	-	-	-
57	0.32	0.028	0.067	1.4	-	-

TABLE 17

LIQUID RADIOACTIVE EFFLUENT DISCHARGED TO WATER BOARD SEWER, 1993

MONTH	VOLUME m^3	ALPHA $^{\alpha}$ MBq	BETA $^{\beta}$ MBq	TRITIUM GBq	FRACTION OF LIMIT*
January	7239	6.16	66.80	87.59	0.18
February	7536	5.16	98.42	91.18	0.20
March	8993	3.96	120.09	130.40	0.18
April	7820	4.60	172.28	116.52	0.28
May	6219	8.69	292.24	56.59	0.61
June	7802	7.06	226.62	17.94	0.38
July	6941	5.43	126.53	68.72	0.26
August	8800	9.06	174.28	22.70	0.30
September	8102	16.25	361.13	16.40	0.65
October	7146	9.32	279.86	13.36	0.52
November	6197	8.30	224.78	11.77	0.50
December	6667	3.48	90.58	18.27	0.19

Notes:

α = A mixture of unidentified alpha-emitting nuclides, assumed to be all radium-226 (i.e. the worst possible case) when calculating the fraction of authorised limit.

β = A mixture of unidentified beta-emitting nuclides, assumed to be all strontium-90 (i.e. the worst possible case) when calculating the fraction of authorised limit.

* In the case of discharge to the Water Board sewer, the authorised limit is outlined in the Regulations to the NSW Radioactive Substances Act published in Government Gazette No.136, 19 September 1980.

TABLE 18

ESTIMATED WHOLE BODY DOSES AT LHRL, 1993

Receptor Location	Airborne whole body dose 1993[#] (mSv/yr)
Library	0.0068
Outside HIFAR	0.0020
Building 9	0.0091
Main gate	0.0071
Stevens Hall	0.0068
MWDA Depot	0.0059
BMX track	0.0074
Woronora Valley	0.0011

TABLE 19

ESTIMATED AIRBORNE WHOLE BODY DOSES
at 1.6 km and 4.8 km radii around HIFAR, 1993

Receptor Locations	Airborne whole body dose 1993 (mSv/yr)[#]	
	1.6 km from HIFAR	**4.8 km** from HIFAR
NORTH	0.0053	0.0014
NNE	0.0065	0.0018
NE	0.0043	0.0013
ENE	0.0051	0.0016
EAST	0.0045	0.0014
ESE	0.0034	0.0010
SE	0.0027	0.00086
SSE	0.0024	0.00072
SOUTH	0.0022	0.00066
SSW	0.0021	0.00067
SW	0.0022	0.00070
WSW	0.0022	0.00069
WEST	0.0022	0.00069
WNW	0.0020	0.00062
NW	0.0031	0.00097
NNW	0.0042	0.0012

Notes:
[#] Estimated airborne whole body doses were calculated using actual 1993 stack discharge figures and meteorological data for 1993.
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 20

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 21

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

* UNSCEAR, 1988

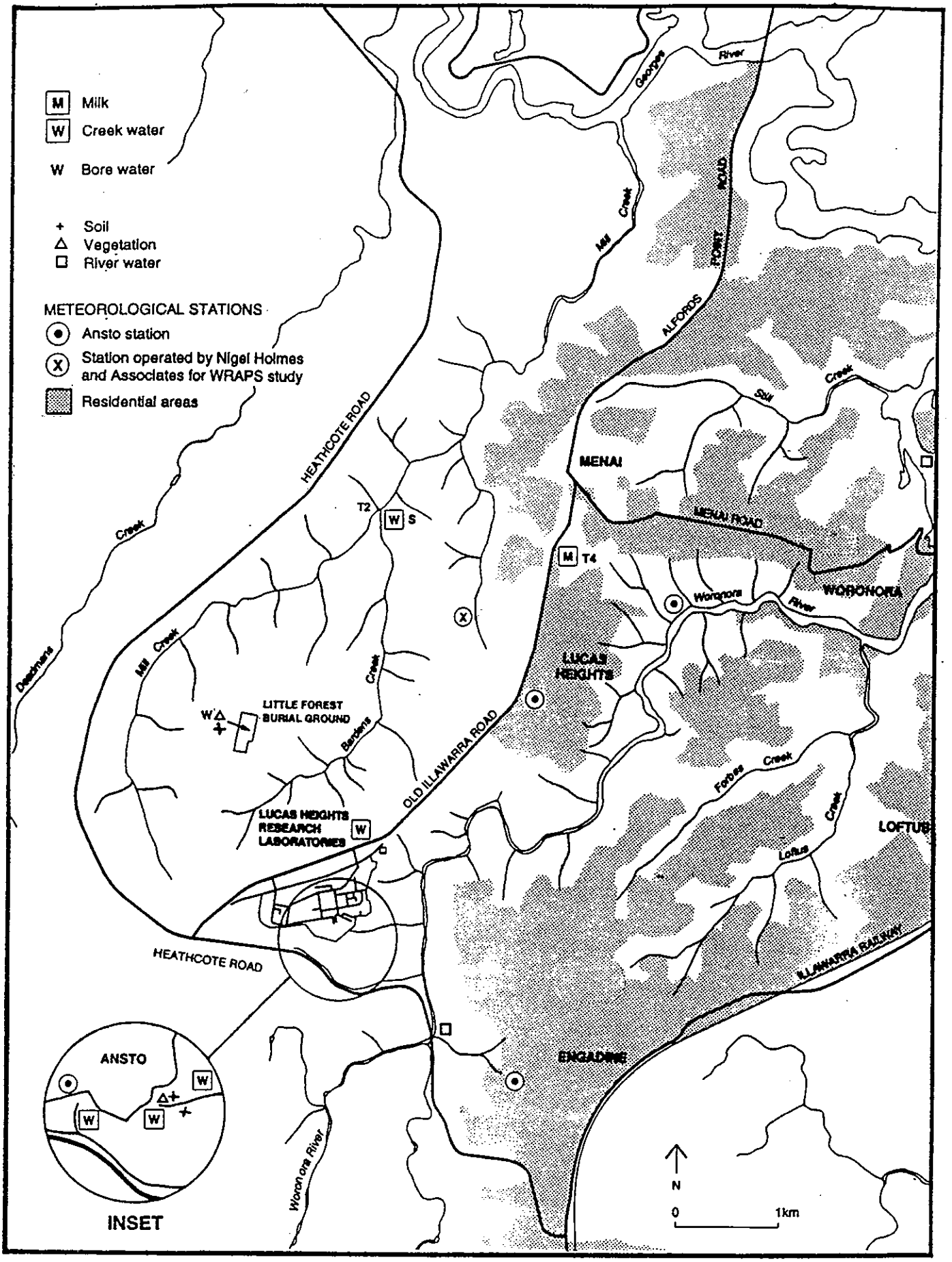
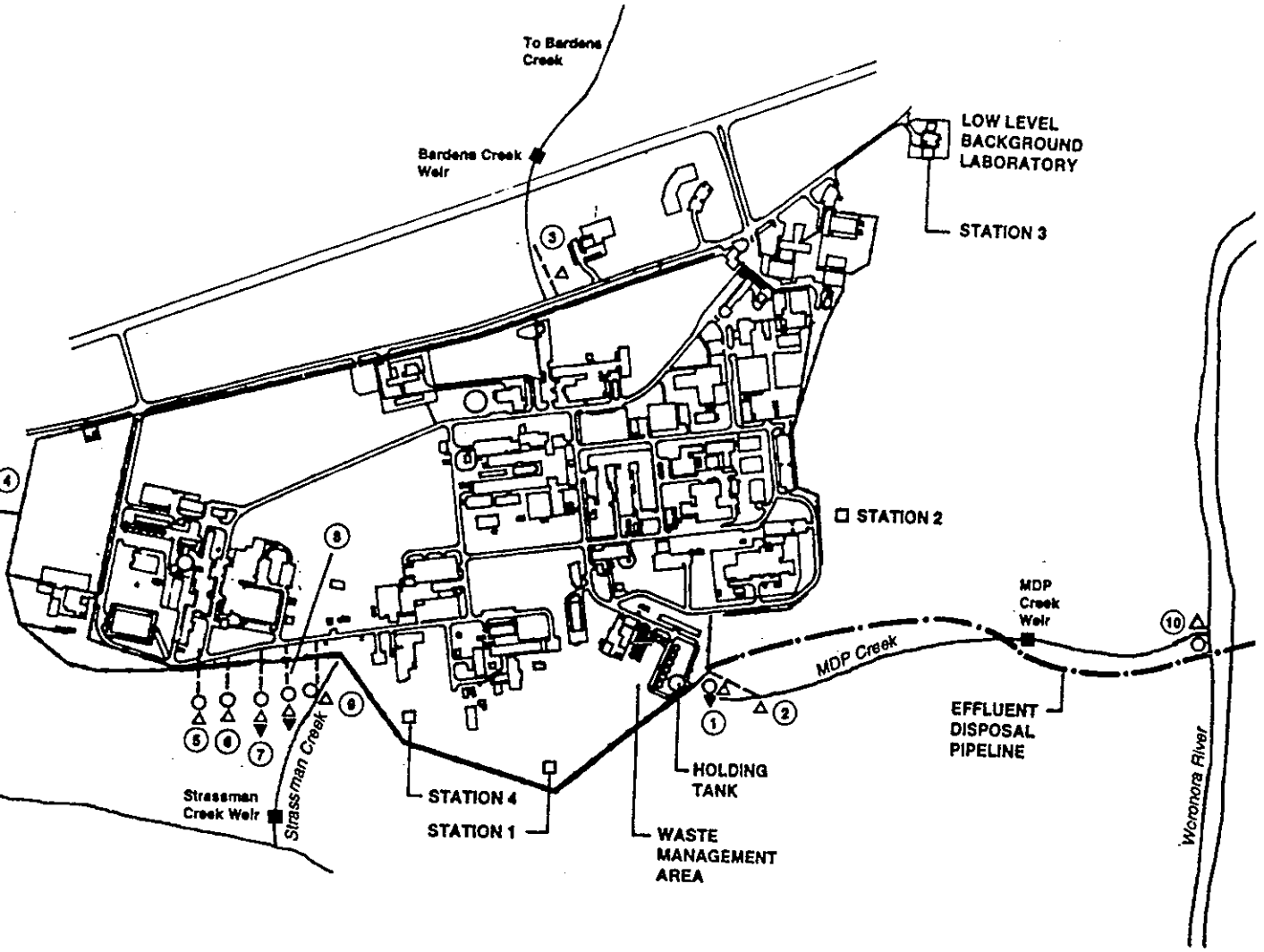


Figure 1: **LUCAS HEIGHTS - Location of sampling points**



□ 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**

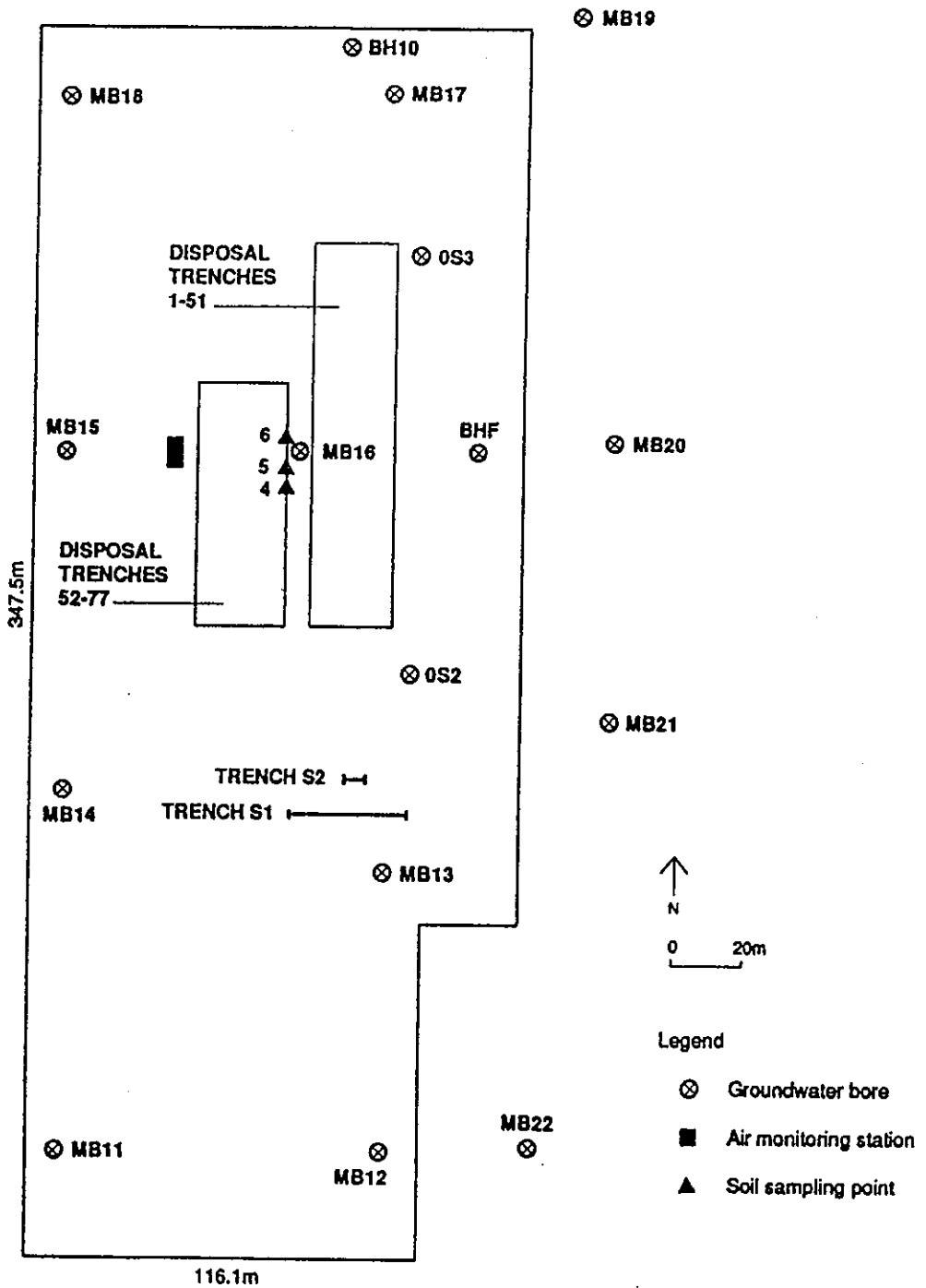


Figure 3: **LITTLE FOREST BURIAL GROUND: LOCATIONS OF TRENCHES, GROUNDWATER BORES AND SOIL SAMPLING POINTS**

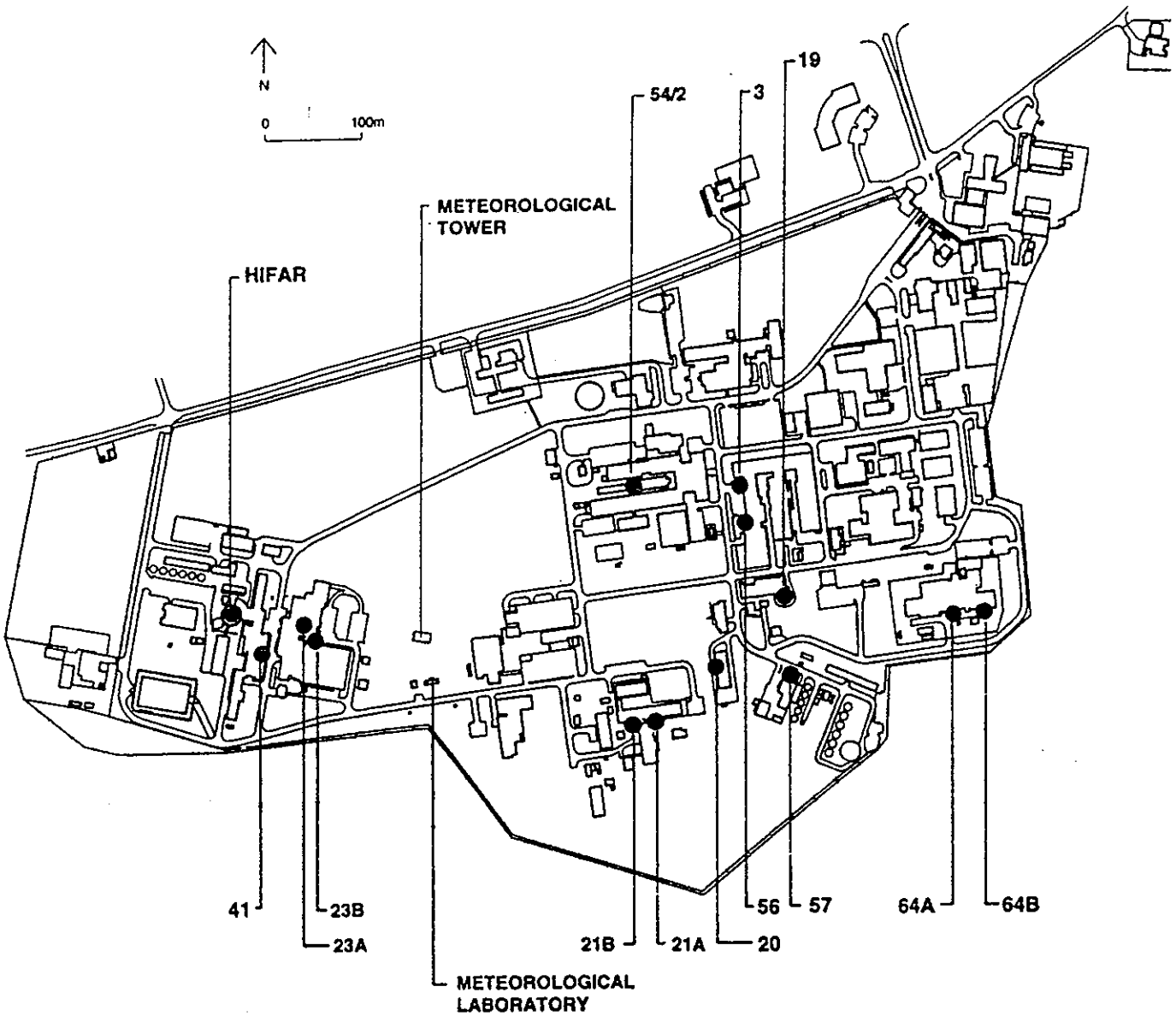


Figure 4: **LOCATION OF AIRBORNE EFFLUENT RELEASE STACKS AND METEOROLOGICAL FACILITIES**

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 Programme*. 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.

Cook, J.E., Dudaitis, A., Giles, M.S., (1969). *Environmental survey at AAEC Research Lucas Heights. Results for 1965, 1966 and 1967*. AAEC/E151 Supplement No.1.

Cook, J.E., Dudaitis, A., (1970). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1968*. AAEC/E151 Supplement No.2.

Cook, J.E., Dudaitis, A., (1970). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1969*. AAEC/E151 Supplement No.3.

Conway, N.F., Dudaitis, A., (1972). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for the Period January-July 1970*. AAEC/E246.

Dudaitis, A., (1973). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for the Period August 1970 to December 1971*. AAEC/E271.

Dudaitis, A., (1974). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1972*. AAEC/E201.

Davy, D.R., Dudaitis, A., (1974). *Environmental Survey at the Research Establishment, Lucas Heights. Results for 1973*. AAEC/E335.

Davy, D.R., Dudaitis, A., (1976). *Environmental Survey at the Research Establishment, Lucas Heights. Results for 1974*. AAEC/E375.

Hespe, E.D., (1979). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1975, 1976 and 1977*. AAEC/E467.

Hespe, E.D., (1979). *Results of the 1978 Environmental Survey at the AAEC Research Establishment, Lucas Heights*. AAEC/E494.

Giles, M.S., Dudaitis, A., (1980). *Environmental Survey at the Research Establishment, Lucas Heights. Results for 1979*. AAEC/E508.

Giles, M.S., Dudaitis, A., (1982). *Environmental Survey at the Research Establishment, Lucas Heights. Results for 1980*. AAEC/E542.

Williams, A.R., Dudaitis, A., (1983). *Environmental Survey at the Research Establishment, Lucas Heights, 1981.* AAEC/E563.

Giles, M.S., Dudaitis, A., (1984). *Environmental Survey at the Research Establishment, Lucas Heights, 1982.* AAEC/E591.

Giles, M.S., Dudaitis, A., (1985). *Environmental Survey st the Research Establishment, Lucas Heights, 1983.* AAEC/E622.

Giles, M.S., Dudaitis, A., (1986). *Environmental Survey At the Research Establishment, Lucas Heights, 1984.* AAEC/E638.

Giles, M.S., Foy, J.J., Hoffmann, E.L., (1988). *Environmental Survey at the Research Establishment, Lucas Heights, 1985.* AAEC/E677.

Giles, M.S., Foy, J.J., Hoffmann, E.L., (1989). *Environmental Survey at Lucas Heights Research Laboratories, 1986.* ANSTO/E687.

Giles, M.S., Foy, J.J., Hoffmann, E.L., (1989). *Environmental Survey at Lucas Heights Research Laboratories, 1987.* ANSTO/E688.

Giles, M.S., Foy, J.J., Hoffmann, E.L., (1990). *Environmental Survey at Lucas Heights Research Laboratories, 1988.* ANSTO/E689.

Hoffmann, E.L., Arthur, A., (1990). *Environmental Survey at Lucas Heights Research Laboratories, 1989.* ANSTO/E694.

Hoffmann, E.L., (1991). *Environmental Survey at Lucas Heights Research Laboratories, 1990.* ANSTO/E704.

Hoffmann, E.L., Loosz, T.,(1994). *Environmental Survey at Lucas Heights Research Laboratories, 1991.* ANSTO/E708.

Hoffmann, E.L., Loosz, T., (1994). *Environmental Survey at Lucas Heights Research Laboratories, 1992* ANSTO/E709.

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 HIFAR coolant water, are 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
^{131}I	iodine-131
K	potassium(stable)
^{40}K	potassium-40
^{95}Nb	niobium-95
^{239}Pu	plutonium-239
^{226}Ra	radium-226
^{106}Ru	ruthenium-106
^{90}Sr	strontium-90
^{232}Th	thorium-232
^{3}H	tritium
^{238}U	uranium-238
^{95}Zr	zirconium-95

PREFIXES USED IN REPORT

K (Kilo) = 10^3 =1 000	m (milli) = 10^{-3} = 0.001
M (Mega) = 10^6 = 1 000 000	u (micro) = 10^{-6} = 0.000001
G (Giga) = 10^9 = 1 000 000 000	n (nano) = 10^{-9} = 0.000000001
T (Tera) = 10^{12} = 1 000 000 000 000	p (pico) = 10^{-12} = 0.000000000001

APPENDIX D - ANALYTICAL PROCEDURES

Tritium in waters
Water samples to be analysed for tritium are prepared by distillation according to the International Standards Organisation (ISO) standard 9698 1989(E). 10ml of distilled sample is combined with 11 mL of Instagel 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 0.045 to 0.050 Bq/mL (based on 2 standard deviations of the background).

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 125 to 250 microns, 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 aliquots 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 prepared samples onto the Ortec high-purity germanium (HPGe) semiconductor detector, and acquiring counts over a 16 to 48 hour period. A multi-channel analyser sorts the spectra according to the energy of the gamma photons. Peaks at certain energies in the spectrum are used to 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
Four continuous air sampling stations are situated along the eastern fence boundary of the site (where suburban residences are closest) in order to monitor concentrations of iodine-131 in air. The locations of these samplers are shown on **Figure 2**. At each station the air is sampled by means of a vacuum pump drawing air through a pair of Maypacks (activated charcoal filter cartridges), so that duplicate samples are available. Air is sampled at a rate of approximately 35 m^3 per day, flow rates are checked and filters are replaced weekly.

One set of Maypacks are submitted each week for independent checking by officers of the NSW EPA, who report the results of their analyses to the NSW Radiation Advisory Council. The other set is analysed at ANSTO, by placing the four cartridges simultaneously on a large (8x4 inch) sodium-iodide gamma detector and counting for 5 hours. 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 μm 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.

One of the filters is digested using the US-EPA method 3050, and analysed for beryllium with an Inductively Coupled Plasma Atomic Emission Spectroscope. The duplicate sample is retained together with the other samples for the year to form a composite sample for plutonium analysis by radiochemical separation and alpha spectrometry.