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ENVIRONMENTAL and EFFLUENT MONITORING at LUCAS HEIGHTS RESEARCH LABORATORIES, 1994

by

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ENVIRONMENTAL AND EFFLUENT MONITORING AT LUCAS HEIGHTS 1994

EXECUTIVE SUMMARY

The environmental and effluent monitoring results for 1994 show that ANSTO complied with existing effluent discharge authorisations and relevant environmental regulations. Radionuclide concentrations in liquid effluent discharged to the Sydney Water Corporation sewer were well below the limits specified for the most restrictive alpha and beta emitters and tritium prescribed in the NSW Radioactive Substances Regulations (1959). The mean monthly radionuclide concentration quotient for liquid effluent discharged to the sewer during 1994 was 0.152 representing 15.2% of the limit, with the individual monthly quotients ranging from 0.073 to 0.391.

Potential effective doses to local members of the public from controlled airborne discharges from Lucas Heights Research Laboratories (LHRL) stacks were all estimated to be less than 0.015 mSv / year for receptor locations on the 1.6 km radius buffer zone boundary around HIFAR. This value represents 1.5% of the annual dose limit of 1 mSv for members of the public recommended by the National Health and Medical Research Council (NH&MRC) and 5% of the dose constraint of 0.3 mSv / year adopted by ANSTO.

Stormwater drainage from LHRL complied with the NSW Clean Waters Regulations (1972) at the agreed sampling points on the three small creeks receiving most of the run-off from the site. Environmental samples collected from the Woronora River and Forbes Creek did not detect radionuclides attributable to operations at LHRL.

Environmental monitoring at the Little Forest Burial Ground (LFBG) indicated similar trends to past years with the exception that low levels of cobalt-60 were detected for the first time in monitoring bore OS2 situated at the south-eastern margin of the disposal trenches area at LFBG. Radiological exposures to members of the public from the LFBG continue to be assessed as negligible.

During the year, ambient gamma radiation thermoluminescent dosimeters were installed at various locations around the LHRL perimeter fence and at three private residences in the nearby suburbs of Lucas Heights, Engadine and Woronora. Measurements of absorbed dose in air at the three residential locations showed an average integrated absorbed dose of 0.84 mGy/year. This level is consistent with figures reported in a survey conducted by the Australian Radiation Laboratory of ambient levels in the various State / Territory capitals around Australia due to radiation from naturally occurring terrestrial gamma emitting radionuclides in the environment.

Elevated absorbed dose levels of up to 2.13 mGy/year were registered at some locations in the western sector of the LHRL perimeter fence. These higher readings are a result of gamma shine from some nuclear material stored in the south western part of the site and are areas that are not readily accessed by the general public. ANSTO is planning to relocate this nuclear material on site and provide extra shielding in order to reduce the elevated gamma radiation levels at the perimeter fence.

A systematic study of the dynamics of the transport of effluent from LHRL, through the sewer system to the Cronulla sewage treatment plant (CSTP) and thence to the ocean outfall at Potter Point, was conducted during 1993 and the results are presented in this report. The study was undertaken to address concerns raised by public interest groups during the Research Reactor Review and to confirm that members of the public recreating in the ocean off Potter Point would not be exposed to unacceptable radiation doses as a result of any radionuclides released at the Potter Point outfall. The study results were also used to devise a regular seawater monitoring program off Potter Point and also provide information for establishing a biological sampling program in the near future.

The transit time for the passage of effluent from LHRL to the CSTP, based on the use of tritium as a tracer, was estimated to be 10.5 hours. The dilution ratio within the CSTP was estimated to be 25, while dilution ratios in the ocean at the Potter Point outfall and in the effluent plume some hundreds of metres away from the outfall were around 24 and 21 respectively, for the sea conditions prevalent at the time of the study. This gives a calculated total dilution ratio for the liquid effluent from LHRL to the ocean off Potter Point of 13,600.

Monitoring during 1994 for tritium and gamma emitting radionuclides in seawater samples collected along the shoreline south of Potter Point, showed tritium levels within the range of the very low levels normally found in the upper layer of seawater and the only gamma emitter detected was potassium-40 which occurs naturally in seawater at about the measured concentrations. The monitoring results confirm that the potential radiation dose to members of the general public as a result of ANSTO's discharges to the sewer is very low and well below the NH&MRC recommended dose limits for members of the public and the lower dose constraint level adopted by ANSTO.

ENVIRONMENTAL AND EFFLUENT MONITORING AT LUCAS HEIGHTS

1.0 INTRODUCTION

Radioactivity levels in environmental samples collected in the vicinity of the Lucas Heights Research Laboratories (LHRL) are routinely measured by the Australian Nuclear Science and Technology Organisation (ANSTO) to determine whether the operations at LHRL have complied with the applicable environmental standards and effluent control requirements, and to assess any impact on human health and the environment.

The environmental and effluent monitoring programs are aimed at detecting and quantifying any radioactive contaminants, released from LHRL either routinely as authorised discharges or as a result of accidental release, and to verify that such releases do not result in radiation exposure 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 and effluent surveys during 1994 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 ENVIRONMENTAL PATHWAYS

The main pathways by which radionuclides enter or could potentially enter the environment from LHRL and could potentially lead to radiation exposure of members of the general public 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 Sydney Water Corporation Ltd sewer system;
- radionuclide transport by surface/ground water and/or contaminated airborne particulate dispersion from the Little Forest low-level radioactive waste Burial Ground (LFBG);
- accidental releases or spillages.

2.1 Atmospheric Discharges

Atmospheric discharges 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 is a potentially significant pathway for the transfer of airborne radioactivity to people.

The critical group for the pathway of milk consumption is assumed to be one year old infants living adjacent to LHRL at Steven's Hall Motel (shown on **Figure 2**) who obtain all their milk (0.7 L per day) from a hypothetical local dairy. The closest registered dairy herd to LHRL is at Glenfield, approximately 13 km away (NSW Dairy Corporation, 1995). In previous years, milk samples have been obtained from a cow belonging to a family living at Lucas Heights. However, as the cow was no longer available after February 1993, no further milk sampling was undertaken after that time.

A hypothetical critical group for inhalation of airborne activity is assumed to consist of people living close to the LHRL perimeter. Accordingly, continuous air samplers are located close to the site perimeter fence at sites 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.

Levels of external radiation at the LHRL and in nearby suburban locations, were also measured during 1994 using dosimeters issued by the Australian Radiation Laboratory.

2.2 The discharge of low-level liquid effluent

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

Low-level liquid effluent discharged at ANSTO passes through the Cronulla Sewage Treatment Plant (CSTP) and along with other effluent from that plant is discharged to the ocean at the Potter Point outfall. Potential exposure scenarios for members of the public would include ingestion of contaminated fish caught around the Potter Point outfall and ingestion of contaminated seawater by swimmers and surfers recreating in the ocean near the outfall. The large dilution effects in both the sewer system and the ocean, ensure that levels of radioactivity from ANSTO in the ocean are at negligible levels and of no radiological consequence for members of the public and employees of Sydney Water Corporation.

Studies to confirm the negligable level of radionuclides from LHRL in seawater a short distance from the Potter Point outfall were undertaken during 1993. Routine seawater monitoring was commenced during 1994 and a biological monitoring program is planned for 1995.

2.3 The Little Forest Burial Ground (LFBG)

Between 1960 and 1968 the then Australian Atomic Energy Commission (AAEC) used a small 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.

Near surface disposal is widely accepted internationally as a safe and practical way to dispose of low level solid radioactive waste, provided the possible return of radionuclides via the human food chain, water, inhaled air or external radiation is controlled. Any potential or actual radiation doses to members of the general public must also be within the limits recommended by international bodies and adopted by Australian regulatory authorities. The disposal site was selected and wastes disposed of using international guidelines prevalent at the time.

Potential exposure pathways to members of the general public from wastes buried at LFBG would be associated with the off-site transport of radionuclides by surface/ground waters or by windborne movement of contaminated surface particulates.

Possible human exposure scenarios associated with off-site transport of radionuclides would include the use of contaminated surface/ground waters for drinking purposes and irrigation of vegetable gardens, eating of contaminated freshwater or saltwater fish or shellfish, and inhalation of toxic or radioactive airborne particulate matter.

Areas adjacent to LFBG have been used by various government agencies and private companies for the disposal of liquid industrial wastes, solid municipal wastes, and nightsoil. The area was also mined for clay and shale for brick making.

Ground water and surface water associated with the LFBG and surrounding area is not currently utilised as a potable water supply, and the ephemeral nature of the 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 low-level wastes is very slow and most radionuclides, with the exception of tritium, are readily adsorbed onto the clay subsoil of the LFBG site.

Airborne contamination at LFBG could potentially occur through wind suspension/resuspension of radioactive particulates at the ground surface. Surface contamination could arise following erosion of cover material, or the movement of contaminated ground water to the surface, followed by precipitation of radionuclides. The airborne particulate pathway requires special consideration at LFBG since the site was also used for the disposal of beryllium oxide. Beryllium is not radioactive but is chemically toxic if inhaled as a fine dust.

The vegetative and clay/shale trench cover at LFBG is regularly inspected, and any sign of erosion or deterioration is remedied as soon as possible.

The radiation levels over the disposal trench area are close to background levels. Direct exposure to external radiation from buried waste would only become a consideration if the waste was exposed through erosion or subsidence of the cover, or transport of dissolved radionuclides to the surface by ground water.

3.0 DISCHARGE AUTHORISATIONS

Since the 1960's the AAEC and 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, and were set to ensure that any potential exposures were below the dose limits specified in the NSW Radioactive Substances Act and Regulations.

However, as reported in the LHRL Environmental Survey Report for 1993, during 1993, 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 for 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 former NSW Radioactive Substances Regulations (1959).

Summaries of levels of radioactivity in authorised discharges from LHRL are presented in the 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 Sydney Water sewer, all liquid effluent discharges are required to comply with the Sydney Water Corporation Ltd's requirements for acceptance of liquid trade waste, including the radioactivity concentration limits specified in the NSW Radioactive Substances Regulations (1959) as amended. In September 1993 the NSW Radiation Control Regulation (1993) came into force, however this regulation does not specify generic radioactivity concentration limits for liquid discharges to the sewer.

In lieu of the proposed regulatory arrangements involving the AIRP, during 1994 ANSTO continued its policy of ensuring that all liquid effluent discharges conform with the concentration limits specified in the former NSW Radioactive Substances Regulations (1959).

Compliance with the discharge limits was routinely monitored by ANSTO and compliance auditing of ANSTO's liquid effluent discharges was undertaken by the Australian Radiation Laboratory in Melbourne, which as indicated above will form the basis of the proposed AIRP. Sydney Water Corporation also collects random liquid effluent samples from the ANSTO discharge pipeline, to assess compliance with their requirements for the acceptance of liquid trade waste.

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. The revision was proposed because of changes to ICRP and NH&MRC recommendations occurring in the intervening 20 years, 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 effective dose to any member of the public from all stack 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 by the use of an independently-reviewed, ANSTO-developed, computer-based, atmospheric 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.

Site dose constraint

In August 1993, the Research Reactor Review Panel recommended that ANSTO should commit itself to emission targets and, in particular, a single source dose constraint of 0.3 mSv (see **Section 4.2** for the definition of dose constraint). This recommendation has been adopted by ANSTO.

ANSTO monitored all stack discharges during the period and regular compliance auditing of ANSTO's stack discharge samples has been undertaken by the Australian Radiation Laboratory.

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, shown on **Figure 2,** receive most of the stormwater running off the LHRL area.

4.0 RADIOACTIVITY AND RADIATION DOSE

This section gives explanations of the types of radioactivity mentioned in this report, definitions of the units for radioactivity and dose, and an introduction to natural radioactivity in environmental samples.

The radioisotope symbols used in this report are listed in **Appendix C**.

4.1 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 a semi-conductor detector made of a high purity germanium crystal. A spectrum of counts for each sample is accumulated in an energy range from 1 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 a radioisotope of hydrogen , with a half-life of 12.26 years. It decays by the emission of a weak beta particle, with a maximum energy of 18.6 keV and an average energy of 5.69 keV. The penetration of the tritium beta is consequently low (the stopping distance 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 more energetic radionuclides (see **Section 4.4**).

4.2 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: a measure of radiation received or 'absorbed' by a target. The quantities termed absorbed dose, organ dose, equivalent dose, effective dose, committed equivalent dose or committed effective dose are used depending on the context.

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 is joules per kilogram, 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 unit of equivalent dose is joules per kilogram, termed the *sievert* (Sv). Dose is most commonly expressed as millisieverts (mSv).

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 of effective dose is also joules per kilogram, termed the *sievert* (Sv).

The ***dose limit*** for members of the general public recommended by the ICRP(1990a) and adopted by the NH&MRC (1995) is 1 mSv/year. **Section 6** discusses the potential effective doses to humans from activities at LHRL based on the results of environmental monitoring in 1994, and the airborne effluent stack release data.

Dose constraint : for public exposure, the dose constraint is the upper bound on the annual dose that members of the public may be allowed to receive from the planned operation of any specific source of radioactivity. The exposure to which the dose constraint applies is the annual dose to any critical group summed over all exposure pathways arising from the predicted operation of the controlled source. The dose constraint for each source is intended to ensure that the sum of doses to the critical group from all controlled sources remains within the public dose limit.

4.3 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 of the parent nuclides (4.5×10^9 and 1.4×10^{10} years respectively) 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. Levels of the uranium-238 and thorium-232 series in LHRL environmental survey samples have not been quantified, considering the natural origin of such activity, and the extensive and costly procedures required. If daughters of the uranium-238 and thorium-232 decay series are detected during gamma spectroscopy of samples, their presence is reported in the relevant tables simply as "U & Th series". Typical activities of uranium and thorium and each of their 24 radioactive daughters range from 0.001 to 0.520 Bq/g in different soil types (adapted from UNSCEAR 1993:Table 5, p 65).

Potassium-40

Potassium-40 is a primordial radioisotope of potassium, and since potassium is an essential element for humans (absorbed mainly from food) it is found in all living and formerly living things. 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). 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.

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 natural potassium-40 deducted.

Beryllium-7: Beryllium-7 is a cosmic spallation product, mainly seen in vegetation and soils.

4.4 Radionuclide Concentrations for Drinking Water[*]

Reference values for safe levels of radionuclides in drinking water can be derived as follows, in line with the approach used in the World Health Organisation (WHO) Guidelines for Drinking Water Quality (1993):

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

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[*] Section 4.4 from the NH&MRC 1994 draft revision of the Australian Drinking Water Guidelines.

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 1993);

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 reference concentration is then calculated as follows:

$$\begin{aligned}\text{Reference concentration for Tritium (Bq/L)} &= \frac{0.1\,\text{mSv}}{730\,\text{L} \times 1.8 \times 10^{-8}\,\text{mSv/Bq}} \\ &= 7600\ \text{Bq/L} \\ &= 7.6\ \text{Bq/mL}\end{aligned}$$

Similar calculations yield reference concentrations of 10.5 Bq/L for caesium-137[1], and 7.2 Bq/L for caesium-134.

5.0 ENVIRONMENTAL & EFFLUENT MONITORING AT LUCAS HEIGHTS

The monitoring programs at LHRL involve measurements of the radioactivity in local environmental samples, and in liquid and airborne effluents discharged from the site. The on-site meteorological station also collects data all year round.

In addition to these regular monitoring programs, a survey of the integrated annual external gamma radiation levels around LHRL was commenced during 1994. A comprehensive study of liquid effluent released to sewer which was conducted in 1993 is also included in this report.

The various programs are carried out by several separate groups within ANSTO. In **Sections 5.1 to 5.3** of this report, the monitoring programs carried out at Lucas Heights and Potter Point are defined and the results are presented and discussed.

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[1] The caesium-137 reference concentration was erroneously reported as 365 Bq/L in previous Environmental Survey reports, from 1991 to 1993 inclusive. This error does not affect the reported results or final conclusions in the stated reports.

5.1 Environmental Monitoring

The Environmental Monitoring group is located in the low-background laboratory outside the fenced LHRL site boundary, and performs the routine environmental surveys of the site and surrounding areas.

Samples of soil, sediment, groundwater, air, surface water, and seawater were collected during 1994 at the sites shown in **Figures 1,2,3 & 5** and analysed for radioactivity. Sampling locations included the Woronora River, Mill Creek, Bardens Creek, Forbes Creek, Potter Point ocean outfall, LHRL stormwater outlets, the creeks draining LHRL and Little Forest Burial Ground.

The sample collection and preparation schedule is shown in **Table 1**. More detailed information on the collection, preparation and analysis of environmental samples is available in **Appendix D**.

Environmental survey results for 1994 are presented in **Tables 2 to 16**.

5.1.1 Woronora River

Routine water samples are collected weekly from the Woronora River, at the boat ramp in Jannali Reserve. These water samples are analysed for tritium as an indicator of possible pipeline leaks. No tritium was detected in these samples during 1994 (see **Table 2**).

Discharges of treated liquid effluent 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. Further sampling of biological materials from the Woronora Estuary was undertaken in 1992. No radioactivity above background levels was found in any of these samples, except for a small amount of cobalt-60 in ribbon weed, *Zostera spp.*(see report ANSTO/ E-709).

5.1.2 Forbes Creek (new sample point in 1994)

Forbes Creek is a tributary of the Woronora River, which is sampled monthly (after rain, if possible) and analysed for tritium. The water sample is taken at the point where the Sydney Water supply pipeline crosses the creek, the location is shown on **Figure 1**.

Sampling at Forbes Creek was initiated in response to the concerns of some local residents, that occasional overflows from the upstream sewer mains during periods of heavy rainfall, may contain radioactivity of LHRL origin. The samples are analysed for tritium, as it is the radionuclide most likely to be detectable under such circumstances.

No tritium was detected in any of the samples collected during 1994 (see **Table 3**).

5.1.3 Potter Point Ocean Outfall

Samples of sea-water were collected from an accessible point at the shoreline, approximately 200m south of the Potter point ocean outfall for the Cronulla Sewage Treatment Plant (CSTP). The samples were collected approximately every 3 months to determine whether any radioactivity of LHRL origin could be detected. The sampling location is shown on **Figure 5**.

Sampling at the outfall is performed about 11.5 hours after discharge of treated liquid effluent into the Sydney Water sewer at LHRL. This is approximately the time it takes LHRL effluent to reach and pass through the CSTP and discharge at the ocean outfall at Potter Point. Samples are therefore collected when the possibility of detecting effluent from LHRL is greatest (see **Section 5.3** for information on effluent retention times and dilution factors in the sewer and the sea).

The seawater samples were analysed for tritium after concentration by electrolysis, and by direct gamma spectrometry of samples counted for 23 hours. The results are presented in **Table 4** and show that no gamma-emitters other than natural potassium-40 were detected in any sample during the year. Traces of tritium between 0.00009 and 0.00034 Bq/mL were found using a very sensitive electrolysis method (described in **Appendix D**). These tritium levels are within the range of tritium values measured in the top layer of seawater off Sydney in studies conducted in 1979 (Harries *et al.*)The environmental levels of tritium found at Potter Point have no health significance for persons using this area.

5.1.4 Stormwater outlets

New bunding systems and changes to stormwater sampling points

During the year, small capacity concrete stormwater retention/monitoring bunds were constructed on the three main stormwater outlet points for the LHRL site. The bunds, which were at various stages of commissioning, were designed to retain stormwater/ groundwater seepage temporarily before its release off site. They will enable the on-site containment and treatment of any small accidental spills or releases of contaminated liquid which enter the site stormwater system. They will also be used as environmental monitoring points.

The bunds are normally valved shut during dry weather. They are regularly inspected and discharged when necessary in order to leave capacity for any spills that may occur. The bunds are left to discharge during rain periods.

Many of the stormwater pipes were re-routed to ensure that most of the LHRL stormwater passes through one of the three bunds.

The locations of the bunds are shown on **Figure 2**.

The construction of the bunds has eliminated the necessity for stormwater sampling at the following points: drain behind Bld 1; drain on West Fence Road; drain opposite Fermi Street; drain opposite Bld.23; drains No.1 & 2 opposite Strassman Cres.; drain opposite the Meteorological Tower; 20m and 60m from stormwater outlet No.1.

Sample collections in the latter half of 1994 were erratic at these locations, due to the extensive earthworks in progress. Sampling of the bunds will commence in 1995 when all bunds are fully operational.

Vegetation & sediment

Sampling of vegetation and sediment from stormwater drains is normally carried out every three months, however control of Crofton Weed growing in the larger stormwater outlets, was undertaken during 1994 by the application of a weedicide. As a consequence, no Crofton Weed vegetation was collected during the period.

Results for samples of sediment collected in stormwater drains are shown in **Table 5**. Measurable amounts of radioactivity were detected in sediment samples collected at stormwater outlet No.1. Traces of caesium-137, and cobalt-60 were found in sediment from the drains in the area opposite Bld. 23, where disturbance of the soil occurred due to earthworks.

The low levels of activities found at both locations do not have any health consequences.

Stormwater

Water samples are collected from most stormwater outlets every three months, after rain if possible, and analysed for tritium (results in **Table 6**). Stormwater outlet No.1 however, is sampled and analysed for tritium on a weekly basis. The remaining sample (approx. 3 litres) is combined each week to make a monthly composite for gross alpha, beta and gamma spectrometry analyses (**Table 7**). Stormwater outlet No.1 drains the SE corner of the site into a small tributary of MDP creek (**Figure 2**), and has experienced some low-level radioactivity contamination of sediment and vegetation in the past.

Tritium in stormwater

The tritium results for all the stormwater samples are shown in **Table 6.**

Tritium was occasionally detected in stormwater drains, at levels well below the WHO drinking water reference concentration of 7.6 Bq/mL (**Section 4.4**). 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 to air from HIFAR operation, will exchange with rain water and other free water surfaces.

Tritium levels in the weekly samples from stormwater outlet No.1 were elevated during December (peaking at 4.6 Bq/mL). Gamma spectrometry of the December composite sample revealed no beta-gamma emitters apart from the usual Cs-137 at low levels.

Gamma spectrometry (stormwater outlet No.1 only)

Caesium-137 and caesium-134 were identified by gamma spectrometry, at very low levels, in water samples from stormwater outlet No.1.

When compared with the WHO drinking water reference concentrations (**Section 4.4**), the average caesium-134 and caesium-137 activity measured during 1994 (**Table** 7) represent less than 0.01 % and 0.1% of the guideline values respectively.

The levels of radioactivity found are well below the gross alpha/beta limits specified in the 1972 Regulations of the NSW Clean Waters Act.

Gross alpha/ beta measurements (stormwater outlet No.1 only)
Monthly gross alpha/beta radioactivity results for stormwater outlet No.1 were at background levels throughout the year until mid-December, when the composite water sample gave a gross beta reading of 21 Bq/L. This value is around twice the NSW Clean Waters Regulations (1972) limit for gross beta, although the sample collected from the specified SPCC weir sampling point on MDP creek (see **Section 5.1.5**) during December was below the Clean Waters Regulations (1972) limits for both gross alpha and beta activity, and gamma spectrometry revealed no radionuclides other than natural potassium-40.

The combination of higher than normal gross beta and tritium radioactivity tends to indicate the possibility that a release of a small volume of treated liquid effluent occurred from the Waste Management area. However, no accidental releases were noted or reported by the Waste Management section.

The levels of tritium, caesium-134 and caesium-137 found in stormwater at LHRL and associated drainage lines, are very low when compared to the WHO drinking water quality guidelines and are below the gross alpha/beta limits specified in the NSW Clean Waters Regulations (1972). Coupled with the fact that the stormwater does not enter any known human drinking water supply, it is concluded that there are no health consequences to humans from the measured radioactivity in stormwater from LHRL.

5.1.5 Creeks draining LHRL

SPCC weir 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 Regulations (1972). In 1975, 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 NSW Clean Waters Regulations (1972). Sampling points on Strassman Creek, Bardens Creek and MDP Creek (**Figure 2**) are sampled and analysed for gross alpha and beta activity. This data is presented in **Table 8**. The gross beta results include the contribution of natural potassium-40 activity. 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.

Samples of water were also collected from the SPCC sampling weir on Bardens Creek at weekly intervals during 1994 for tritium analysis. The results are shown in **Table 9**. The highest value recorded during the year was 0.23 Bq/mL, which is 3% of the reference concentration for tritium in drinking water (**Section 4.4**). The average weekly concentration at this location was 0.068 Bq/mL, which is less than 1% of the reference value. It should be noted that water from Bardens Creek is not part of any known drinking water supply.

5.1.6 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 1994, and the results are summarised in **Table 10**. These surveys were performed as part of the regular program of inspection and maintenance of the pipeline.

The dose rates recorded along the pipeline during 1994 were less than 0.12 μSv/hour, which is consistent with background readings.

5.1.7 Little Forest Burial Ground (LFBG)

Results of sampling at the LFBG are given in **Tables 11, 12, 13** and **14**. 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 11**). Dose rates over the trenches ranged from 0.08 to 0.10 μSv/hour, which are consistent with normal background readings. However, of the two localised points #5 and #6, which have shown elevated readings in the past, only point #6 is now slightly above background levels. Results for this year are lower than those previously measured in these locations.

Soil
In 1993, the general area encompassing points #5 & #6 was top-dressed with a clay/shale mixture to replace cover material removed during regular sampling. The 1994 gamma radiation survey did not indicate any areas which were greater than three times the background, therefore no soil samples were collected.

Groundwater Monitoring
Groundwaters from monitoring bores located inside the LFBG and outside the fenced area were analysed for tritium, gross alpha, gross beta and gamma activities. Results are given in **Table 12**.

Tritium, as tritiated water, does not undergo geochemical processes such as ion exchange, adsorption or precipitation when it flows through geologic media. Accordingly, it is readily transported by groundwater.

Tritium is readily detectable inside the burial ground with higher values adjacent to the disposal trenches. Levels of tritium found in bores BHF, BH10, OS2, OS3, MB12, MB13, MB16, MB17 and MB19 are similar to those measured in the past, peaking at 15.6 Bq/mL in MB16, which is located in the centre of the burial trench area. Tritium levels in monitoring bores outside the fenced area were less than the limit of detection (0.050 Bq/mL) and the concentrations present are of no health significance. The groundwater at LFBG is not used for any purpose, and the general quality of groundwater in the 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 naturally occurring 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 very low level of cobalt-60 activity was found for the first time in the OS2 monitoring bore, which is located close to the south-eastern corner of the disposal trenches, and wholly within the fenced area.

In contrast to tritium, cobalt-60 and most other radionuclides dissolved in groundwater are subject to various physical and chemical reactions (including adsorption) when passing through geological media, and clay-rich soil or rock in particular. These reactions retard the movement of radionuclides and consequently they migrate at a slower rate than the groundwater.

The results of bore OS2 tend to indicate that there has been a slow migration of cobalt-60 from the waste trenches towards this borehole.

Cobalt-60 has a half-life of 5.3 years, so that more than 95 % of the cobalt-60 contained in the wastes disposed of at LFBG between 1960-68 has decayed away. Within another 25 years the amount of cobalt-60 remaining at LFBG will be less than 0.1% of the original amount contained in the buried wastes.

Creeks Receiving runoff from the LFBG area

Annual samples of surface water and sand were collected from creeks just above the confluence of Mill Creek and Bardens Creek, (station T2, **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 13**. 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 14**). The minimum detectable level for Be is 0.0025 mg (total per filter) and for plutonium-239 is 0.0001 Bq (total).

5.1.8 Ambient Iodine-131 in Air

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 ambient 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.

Measurable quantities of iodine-131 were occasionally recorded in the air samplers on the site perimeter, during 1994 (**Table 15**). The highest reading, registered for the week ending 27 February 1994, was 6.1×10^{-2} Bq/m^3. The average iodine-131 concentration in air for the year was 5.5×10^{-3} 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[2].

5.1.9 Meteorological Monitoring

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 location of monitoring stations used for the collection of local meteorological data are shown in **Figure 1**.

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

Wind Direction
The winds which predominate at Lucas Heights during summer and winter are shown in the table below.

Prevailing winds at Lucas Heights

Season	Time of Day	Prevailing Winds
SUMMER	Daytime seabreezes	from NE to ENE and SE to SSE sectors
WINTER	Daytime	from W to NW and S to SE
	Night / early morning	S to WSW

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[2] Based on the committed effective dose per unit activity given in the IAEA Basic Safety Standard (IAEA,1994).

Winds during autumn and spring represent a transition between the summer and winter seasons, with sea breezes observed later and nocturnal winds indicative of regional drainage of cool air from the WSW to SSW sectors.

Rainfall

The total rainfall at Lucas Heights in 1994 was 576 mm, recorded on 87 rainy days. The wettest month was March, with 152mm of rainfall.

5.1.10 External Gamma Radiation at Lucas Heights

Levels of external gamma radiation at and in the vicinity of the Lucas Heights Research Laboratories were measured during 1994 using thermoluminescent dosimeters (TLD's) issued by the Australian Radiation Laboratory (ARL). The dosimeters issued by ARL for environmental monitoring are the same as those issued for personal monitoring, and consist of calcium sulphate thermoluminescent material with three filtered areas and an open window.

Table 16 shows the integrated annual absorbed dose to air, in milligrays, for the calendar year 1994, as determined from the ARL dosimeters for various locations. **Figure 6** shows the locations of dosimeters 1 to 15. Measurements were made over four consecutive exposure periods, the TLD's were returned to ARL for measurement, and the readings are reported as annual absorbed dose to air.

The data in **Table 16** indicate that the annual absorbed dose to air due to external radiation measured outside several homes in the vicinity of the LHRL, is between 0.8 and 0.9 mGy. The annual environmental doses measured at or within the LHRL perimeter fence, have a minimum of 0.82 mGy and a maximum of 2.13 mGy. The enhanced doses on the southern and western sides of the HIFAR security fence are due mainly to nuclear materials stored in this area. Although there is no public occupancy in this area plans are underway to relocate some of the nuclear material to a new shielded storage facility to be constructed on site.

When the annual environmental absorbed doses in air around homes in the vicinity of LHRL are converted to hourly rates, they correspond with the average hourly absorbed dose rate in air from terrestrial gamma radiation reported for capital cities around Australia (UNSCEAR 1993).

5.2 Effluent Monitoring

The routine monitoring of the airborne effluent released from LHRL stacks is performed by ANSTO's Occupational Health and Safety Program .

The Waste Management group within Nuclear Technology Program is responsible for the handling, treatment, routine monitoring and authorised discharge of liquid effluent arising from operations at LHRL

Descriptions of the effluent sampling and analysis procedures are given in the following sections. For more detailed information on stack sampling procedures, see **Appendix E**.

5.2.1 Airborne Effluent Stack Discharges

The authorised airborne effluent discharges from LHRL stacks are monitored weekly by ANSTO's Occupational Health and Safety Program. Samples of effluent airstreams are analysed for gamma emitters, noble gases, gross alpha and beta activity and tritium.

The locations of these discharge stacks around the site are shown on **Figure 4**.

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

Stack Sampling
During 1994, 12 discharge stacks were monitored on a weekly basis. For most gases, fumes and particulate emissions, filter cartridges called Maypacks are used with vacuum pumps to sample the effluent airstreams. The Maypacks consist of a charcoal section to trap gases and vapours and a particulate filter trap. The flow rate of air through the Maypack samplers is limited by means of a critical orifice. The stack flow rates are measured every three months, and whenever the ventilation system is altered in any way (*ie* new fans, change of filters, changes to ducting).

After initial analysis both components of the Maypacks are stored for 13 weeks when some of the particulate filters are measured again for gross alpha and beta activity. This is to confirm that any particulate activity previously measured was principally due to short-lived radioisotopes.

Tritiated water in the airborne effluent is sampled using a tritium bubbler. A proportion of the stack airstream is drawn through a series of four bottles filled with demineralised water, trapping the tritiated water. A liquid scintillation counter is then used to measure the tritium levels in the sample.

Noble gases are measured in situ by a gamma spectrometer as the effluent passes through a 250 mL sampling flask.

Results
Authorised airborne release data are given in **Tables 17 & 18**.

'Working levels' are set for individual stack discharges at ANSTO and are used for operational purposes to assess trends in the discharges. **Table 17** presents the quarterly airborne emissions for the individual stack release points, and **Table 18** lists the same figures expressed as percentages of the quarterly operational working levels.

Discharge records for the period 1977 to 1994 show that the majority of airborne emissions from LHRL have been well below the quarterly working levels and, in most instances, can be regarded as negligible. During 1994, discharges of noble gases from HIFAR occasionally exceeded the quarterly working levels. This is due mainly to the increase in silicon semi-conductor material irradiation in HIFAR and subsequent release of argon-41.

The airborne effluent stack discharge data are used to estimate possible doses to members of the public due to airborne releases from LHRL, by utilisation of the ADDCOR atmospheric dispersion and dosimetry computer model (see **Section 6.1**).

5.2.2 Low-level Liquid Effluent Discharges

The Waste Management group (of Nuclear Technology Program) at ANSTO is responsible for the handling, treatment, routine monitoring and authorised discharge of liquid effluent arising from operations at LHRL.

The Waste Management facilities are located on the South-East corner of the site and are shown on **Figure 2**.

Liquid effluent treatment and discharge
To facilitate treatment, waste waters are segregated into 3 categories:

- the liquid effluent from radioactive laboratories, which has a low level of radioactivity;
- the trade effluent from laboratories and workshops in which radioactive and toxic materials are not handled;
- the non-radioactive sewage from toilet facilities and the animal house.

The waste water drains into three separate sets of auto-pumping pits, depending upon its origins, from which it moves through one of three different effluent treatment systems, as shown in the following flowchart.

The treated effluent is transferred to holding tanks where levels of radioactivity are checked prior to discharge to the sewer. Proportional samples from the discharge pipeline are collected during the release of the treated effluent to the sewer over a period of 3 to 4 days, and are analysed for gross alpha and beta radioactivity, pH, ammonia and total chromium. A volume weighted monthly composite sample is produced from all discharge samples for the month (usually 8 or 9). This monthly composite sample is then analysed for gross alpha, beta, tritium and gamma activity and assessed for compliance with the liquid effluent discharge authorisation.

Discharge Authorisation
The NSW Radioactive Substances Regulations (1959) require that the average concentration of each radionuclide (C_i) in the liquid effluent at the point of discharge, must not exceed the Maximum Permissible Concentration (MPC_i) defined for that radionuclide.

The general form of the discharge authorisation is expressed:

$$\Sigma_i \frac{C_i}{MPC_i} \leq 1$$

Where more than one radionuclide is present, the sum of the average concentrations of all radionuclides (expressed as a fraction of the relevant MPC), termed the *concentration quotient*, must be no greater than one.

In practice, since analysis of the effluent for each nuclide is very time-consuming and costly, only undifferentiated (gross) alpha and beta nuclides and tritium are analysed. It is assumed that all alpha and beta radiation come from the most restrictive nuclide of each type. Therefore, the radionuclide with the lowest maximum permissible concentration, Ra-226, is used for alpha-emitting nuclides and Sr-90 for beta-emitting nuclides.

The discharge authorisation then becomes:

$$\frac{\alpha}{\text{MPC Ra-226}} + \frac{\beta}{\text{MPC Sr-90}} + \frac{^{3}\text{H}}{\text{MPC }^{3}\text{H}} \leq 1$$

where α = average gross alpha concentration in effluent discharged;
β = average gross beta concentration in effluent discharged;
^{3}H = average tritium concentration in effluent discharged.
MPC = Maximum Permissible Concentration for the radionuclide, specified by the NSW Radioactive Substances Regulations (1959).

As some radioactivity arises from less restrictive isotopes than Ra-226 and Sr-90, there is an additional margin of safety.

Results

Authorised liquid effluent discharges to the Sydney Water sewer are summarised in **Table 19**. The radionuclide concentration quotients for all monthly discharges for the year were less than one, indicating compliance with the NSW Radioactive Substances Regulations. Had more individual nuclide analyses been performed on the effluent discharges, the calculated concentration quotients for each month would have been much lower than the values shown in **Table 19**.

All discharges for the year complied with the standards of acceptance of trade wastes to the sewers, as required by Sydney Water Corporation Ltd.

5.3 Studies of Liquid Effluent Released to Sewer

During the Commonwealth Government Research Reactor Review (1992), public interest groups such as the Sutherland Shire Council and the Surfriders Association raised concerns and made claims that ANSTO liquid effluent may be a radiation hazard to swimmers and surfers in the vicinity of the Potter Point outfall. A single set of data submitted by ANSTO to the Review showed that tritium levels at the CSTP and off Potter Point were very low and undetectable respectively, and the Report of the Research Reactor Review stated that the reported levels of tritium in discharges influent to the CSTP and samples from Potter Point ocean outfall are lower than considered safe for drinking water. (Commonwealth Government, 1993).

Nevertheless, in order to address the concerns raised by the public during the Research Reactor Review, ANSTO initiated a systematic study of the dynamics of the transport of effluent from LHRL, through the sewer system to the CSTP and thence to the cliff face ocean outfall at Potter Point The results of the study will also be used to develop a regular six monthly monitoring program at Potter Point. The study and subsequent monitoring program are aimed at confirming that members of the public are not exposed to unacceptable radiation doses from ANSTO liquid effluent discharges to the sewer and that any potential exposures would comply with the relevant regulations or guidelines promulgated from time to time by the NSW authorities, the National Health and Medical Research Council and the International Commission for Radiological Protection.

The initial studies reported here were undertaken by ANSTO's Ecological Impacts group.

The technical objectives of the overall investigation were:

1. to measure the transit time for the passage of effluent from Lucas Heights to the CSTP;
2. to study the variation of the transit time as a function of the total flow rate of the effluent;
3. to measure the dilution factors between Lucas Heights and the CSTP;
4. to study the dispersion of tritium in the vicinity of the outfall;
5. to detect and if possible measure the level indicator gamma emitting isotopes such as caesium-137 and cobalt-60;
6. to implement a program of biological sampling;
7. to undertake intercomparison measurements as appropriate with the Australian Radiation Laboratory.

The first stage of the study was undertaken during June/July 1993 and was primarily concerned with measurement of the transit time of flow of discharges from LHRL to the CSTP and comparative analysis of radionuclides in samples collected from CSTP and in the ocean off Potter Point.

The second stage of the study was conducted on 30-31 August, 1993 and was aimed at obtaining supplementary data on transit times and in-line dilution , but principally to measure the initial dilution that occurs when the effluent from CSTP is discharged into the ocean through the Potter Point outfall and further dilution which occurs by oceanic dispersion processes as the effluent plume moves away from the outfall.

Further investigations were undertaken during 1995 and these are to be reported in the 1995 "Environmental and Effluent Monitoring at LHRL" report.

5.3.1 Transit times and dilution between LHRL and the CSTP

For these investigations the levels of tritium and other radionuclides which are present in routine batches of liquid effluent discharged from LHRL were measured at the CSTP and at Potter Point. The tritium in the ANSTO effluent acted as a tracer and is commonly used in environmental tracer experiments. In one of the investigations a known small amount of a second non-radioactive tracer, lithium chloride was added to the effluent. A summary of the investigated effluent releases is given in the following table.

Potter Point Investigations - Effluent Release Conditions

No	Date	Vol release kL	Time of release	Tritium conc. kBq/L
1	29 June 93	500	10:30 to 17:40	4.74
1a	29 June 93	97	16:15 to 17:40	Note
2	30-31 Aug 93	600	21:00 to 05:00	7.05

Note: Five kg lithium chloride released over a 1hr 25min period in the preliminary investigation phase.

The *transit time* for the passage of the effluent from ANSTO to the CSTP is defined as the time interval between the midpoint of the release from the holding tanks to the to the time at which the maximum concentration of the tritium is observed at the CSTP. The transit times which were in the range 9.6 hr to 11.8 hr and some data on the daily total flows, are listed in the following table. They would obviously vary with the flow conditions within the sewage system.

Transit Times and Dilution Factors

No	Date	Daily Total Flow at CSTP (ML)(1)	Volume released (L)	Transit Time ANSTO to CSTP (hours)	Dilution Ratio(2)
1	29 June 93(3)	Note 4	500	9.6	22.6
1a	29 June 93(3)	Note 4	97	10.5	100
2	30-31 Aug 93	57.3	600	11.8	26.9

Notes:

1) Data from the Sydney Water Board.
2) The Dilution Ratio is defined as the ratio of the concentration of the effluent component released to the sewer at Lucas Heights to the peak concentration measured at the CSTP.
3) Release No 1 (tritium) and release No 1a (lithium) were between 1030 h and 1740 h and between 1615 h and 1740 h respectively.
4) The hourly discharge rates were estimated at 2140 (release No 1) and 1940 (release No 1a) respectively.

During the period of the investigations the ratio of the day flows to the night flows through the CSTP varied from about 1.3 to 2.1. Variations in the ratios between the maximum and the minimum hourly discharges over a 24 hour period would be greater still.

Taking into account the above variations, it is recommended that an average transit time of 10.5 hours be used.

Transit time between the CSTP and outfall: On 31 August 1993, the time taken for the tritium maximum to move from the CSTP to the Potter Point outfall was about 1 hour. This is also the average travel time nominated by CSTP staff for treated effluent discharged from the CSTP to the Potter Point outfall.

It should be noted that based on the above data, it is estimated that it would take about 11.5 hours for the maximum radionuclide concentration to be registered at the Potter Point outfall, relative to the midpoint of the release time from LHRL.

Since liquid effluent is discharged from LHRL on a batch basis during normal working hours on weekdays only, this would result in most of the radioactivity contained in ANSTO effluent reaching the ocean at Potter Point in the late night and early morning hours. The number of members of the general public recreating in the ocean off Potter Point at these times would therefore be at a minimum.

5.3.2 Dilution ratios

A *dilution factor* is defined as the ratio of the effluent concentration released to the sewer at Lucas Heights to that at the CSTP after steady state conditions have been achieved. The longer the duration of effluent release at Lucas Heights, the greater the probability of achieving steady state conditions at the CSTP. Since the tritium was released at a steady rate, it would be expected that the concentration of the tritium in the sewage stream at the CSTP would increase from a background value to a plateau value and then decrease. A plateau value was never observed, due to a combination of dispersion processes within the sewage system and the large variations in sewage discharge rates over the daily cycle.

In view of these complicating factors, it has been decided to report the *dilution ratio* (D1), which is defined as the ratio of the concentration of the tritium at release to the maximum concentration at the CSTP.

There is a trend towards a value of about 25 as the volume of effluent (*ie* the time for effluent release) increases. Considerable variations are revealed due to differences in daily sewage discharges, but more importantly to the large hourly variations during the average 10.5 hour transit time.

In addition to the dilution ratio D_1 between Lucas Heights and the CSTP there is further dilution D_2 between the CSTP and the outfall at Potter Point and between the cliff face outfall and the ocean sampling location D_3.

During the August, 1993 investigations ocean water samples were collected at the outfall and in a grid pattern over the effluent plume moving away from the outfall. These samples were analysed for tritium and the maximum levels detected at the outfall and in the plume were used to calculate the Dilution Ratios D_2 and D_3 respectively.

The overall *Dilution Ratio* D is calculated as follows;

$$D = D_1 \times D_2 \times D_3$$

D1 was calculated as 26.9, D2 as 23.8 and D3 as 21.2.

The overall Dilution Ratio D is estimated as 13,600. This is a measure of the minimum dilution for ANSTO effluent between the discharge point at LHRL and the ocean off Potter Point for the sea conditions prevalent during the August 1993 investigations.

The maximum levels of tritium measured in the plume off Potter Point during the investigation was 0.72 Bq/L which is similar to the naturally occurring tritium concentration commonly detected in rainfall throughout Australia. These levels are a factor of around ten thousand below the WHO drinking water reference concentration for tritium (see **Section 4.4**).

5.3.3 Measurement of gamma ray emitting radionuclides

Various alpha, beta and gamma emitting radionuclides are also usually released as components of the treated liquid effluent discharged from LHRL at concentration levels several orders of magnitude below the tritium levels. These radionuclides principally comprise heavy metals which may behave differently from the tritium in the sewage system. They have been measured separately and a summary of the data is presented in the table below. For intercomparison purposes the gamma spectrometry analysis was undertaken by the Australian Radiation Laboratory as well as ANSTO.

Gamma emitting radionuclides (ARL)(1)

Sample ID	Radionuclide Concentration (Bq/L)							
	Cr-51	Co-60	Mo-99	Ru-103	I-125	I-131	Cs-134	Cs-137
3329A Composite	<3 [1]	0.6(1)[2]	<1	0.8(2)	12(1)	<1	0.9(1)	42(2) **34**
3341A	<1	<0.6(1)	<1	<0.5	1.7(8)	<1	<0.5	2.1(3) **<0.3**
3343A	<1	<0.5	<1	<0.5	<1	<1	<0.5	2.0(2)
3381A Composite	190(6) **155**	1.8(2) **1.8**	2.2(6)	<0.5	2.5(2)	53(6) **56**	1.9(2)	13.7(8) **10.8**

Notes:

1 Data were reported by the Australian Radiation Laboratory, except those in bold type which were reported by ANSTO.

2 The figures in parenthesis is the estimated uncertainty (1σ) in the least significant digit of the nuclide concentration. Naturally occurring gamma emitters for which the uncertainty in the activity exceeds 50% have not been recorded.

The sample listed as 3329A Composite was released on 29 June 1993. The levels of alpha, beta isotopes and tritium in this composite sample were respectively 1.14, 28.54 and 4,740 Bq/L. The sample 3381A Composite was released on 1 July 1993. The levels of alpha, beta emitters and tritium were respectively 1.71, 70.38 and 35,100 Bq/L. Overall, agreement between the ARL and ANSTO measurements is acceptable. Possible reasons are given below for discrepancies that occur between the two sets of results.

Samples 3341A and 3343A were collected at the CSTP following release of the effluent with the composition listed as 3329A. The samples were taken near the maximum of the tritium pulse. The Cs-137 values were 2.1 and 2.0 Bq/L. These are in good agreement with the ARL's estimate of the Cs-137 in the waste water (42 Bq/L) and the dilution factor of 22.6 estimated from the tritium data. ANSTO, however, measured a much lower value (<0.3 Bq/L). The reason for this discrepancy is not clear, however, it should be noted that caesium has a high adsorption coefficient and would be associated with particulates and colloids in the sample. Hence the result would be sensitive to the adventitious presence of such particles in different samples and to sample pre-treatment.

Differences in sample form and geometry, counting equipment sensitivity and spectral resolution will also account for some of the discrepancies in results.

The maximum concentration of gamma emitters measured at the CSTP were very low and once the dilution that occurs at the Potter Point outfall and out in the plume away from the outfall is taken into account the levels of alpha, beta and gamma emitters are below the limit of detection and well below WHO drinking water reference levels for radionuclides.

5.3.4 Current and Future Monitoring at Potter Point

Following on from the investigations at CSTP and Potter Point, quarterly samples of seawater from accessible points near the shoreline were collected for tritium analysis to determine any radiological impact to bathing members of the public. The results of this monitoring were presented in **Section 5.1.3** of this report.

A preliminary program of biological sampling is planned for 1995. One objective of this program is to sample environmental concentrators such as limpets to determine the presence and water concentration of alpha emitting radionuclides. Their use will maximise the chances of detecting radionuclides if they are present. Another objective is to measure the levels of radionuclides in human food, such as blackfish, to evaluate the radiological significance of their possible consumption by members of the public. Biological monitoring will become a regular part of the program for Potter Point anticipated to be undertaken twice a year.

6.0 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 to sewer. These sources are controlled in compliance with discharge authorisations given previously by the NSW Radiological Advisory Council or concentration limits specified in the former NSW Radioactive Substances Regulations (1959) as amended. The authorised discharge limits are based on limiting the doses to hypothetical critical group members to levels well below the public dose limits, and below the 0.3 mSv dose constraint adopted by ANSTO. At no time in the operation of the LHRL facilities have these dose limits been exceeded.

6.1 Airborne Emissions

As indicated in **Section 3.2**, the ADDCOR atmospheric transport, dispersion and dosimetry computer code is used to evaluate potential doses to members of the public at various receptor locations, based on measured stack discharges and local meteorological data. Effective doses to ANSTO staff from stack discharges are also calculated by the same method. **Tables 20 and 21** give a summary of the estimated public and occupational effective doses due to airborne discharges at specified locations and distances from the HIFAR reactor.

The results show that the potential effective doses to critical group members of the public within the 1.6 km radius ANSTO buffer zone, were estimated to be 0.02 mSv per year; *ie* 2% of the NH&MRC recommended annual dose limit of 1 mSv and less than 7% of the dose constraint of 0.3 mSv adopted by ANSTO. For members of the general public residing at the 1.6 km radius ANSTO Buffer Zone boundary and beyond, the most exposed individual was estimated to receive 0.013 mSv/year, *ie* less than 1.5% of the NH&MRC recommended annual dose limit and less than 4.5% of the ANSTO dose constraint.

The results of the monitoring of iodine-131 emissions at the LHRL perimeter fence also show that critical group members of the public would potentially receive an effective dose of less than 0.01 mSv from iodine-131 releases from ANSTO. This figure represents 1% of the NH&MRC recommended annual dose limit and about 3% of the dose constraint adopted by ANSTO, and was calculated in an extremely conservative manner.

It can be readily shown that the potential dose estimates to members of the general public from airborne discharges at LHRL are only a very small fraction, less than 1%, of the radiation dose received by every member of the public each year from naturally occurring sources of radiation.

Table 22, taken from UNSCEAR, 1993, shows the average annual effective doses to adults from the various natural sources of radiation which result in an estimated total annual dose of 2.4 mSv. This figure will vary with local geological conditions and with height above sea level.

6.2 Low level liquid effluent

Radioactive liquid waste is chemically treated and analysed before controlled discharge to the Sydney Water Corporation Ltd 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.

The recent studies conducted by ANSTO at the CSTP, the Potter Point outfall and the surrounding ocean area (see **Section 5.3**) confirm the expected very large dilution effects on any radionuclide contained in the treated effluent discharged by ANSTO to the sewer. The studies and the routine sampling undertaken quarterly also confirm that the levels of tritium measured in the ocean a short distance from the outfall are negligible and do not pose any public health risk to members of the public recreating in the ocean in the vicinity of the outfall.

6.3 External radiation

The levels of external gamma radiation measured by thermoluminescent dosimeters located at private residences in Lucas Heights, Engadine and Woronora (see **Table 16**) all indicated annual absorbed doses in air similar to annualised levels recorded by similar dosimeters sited at capital cities around Australia for surveys carried out by the Australian Radiation Laboratory and reported by UNSCEAR (1993).

The results indicate that the external gamma radiation levels at residential locations in the vicinity of LHRL are not noticeably affected by the operations at LHRL.

There are elevated levels of external gamma radiation at some locations on the LHRL perimeter fence, particularly in the western sector. However, these locations are not readily accessed by the general public. The external gamma doses registered by the dosimeters placed at these positions would only be received by persons occupying these areas for the entire year, which is not a credible scenario.

However, as indicated in **Section 5.1.10**, ANSTO is to take steps to relocate some stored nuclear material in order to reduce the elevated doses at these locations.

6.4 Little Forest Burial Ground

The environmental survey results for the LFBG show elevated levels of tritium in the groundwater in the centre of the burial trenches area and lower levels at some other monitoring bores inside the fenced area. Cobalt-60 and caesium-137 are also found in sediment suspended in groundwater in the centre of the burial trenches and cobalt-60 is found in one monitoring bore adjacent to the trenches area.

All groundwater monitoring bores outside the LFBG fenced area show background levels of radioactivity and surface water sampling from Mill and Barden Creeks also show only naturally-occurring radionuclides.

These results confirm that potential radiation exposure to members of the public from groundwater and surface water in the vicinity of LFBG is negligible. It should be noted that contaminants from other wastes disposed of in the area adjacent to LFBG make the groundwater unsuitable for human consumption.

Samples of airborne particulates at LFBG showed no detectable levels of radionuclides or beryllium, so that possible radiation exposure to members of the general public via the inhalation pathway is negligible.

External radiation readings over the trenches are consistent with normal background levels except for one small localised area. Radiation readings around the LFBG site boundary fence are all at background levels, so that possible doses to members of the public from external radiation are also regarded as negligible. The LFBG is appropriately signposted and daily security patrols are conducted to ensure that the area is not frequented by unauthorised persons.

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The report on the Studies of Liquid Effluent Released to Sewer (**Section 5.3**) was contributed by Dr Peter Airey, of ANSTO's Environmental Science Program.

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

Details of airborne effluent sampling and analysis procedures were supplied 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.

Dosimeter readings for environmental Radiation at LHRL (**Table 16**) and airborne effluent release data (**Table 17**) were supplied by ANSTO's Occupational Health and Safety Program.

Liquid effluent release data (**Table 19**) were supplied by Waste Management (Nuclear Technology Program).

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TABLE 1

ENVIRONMENTAL MONITORING
SAMPLE COLLECTION AND PREPARATION SCHEDULE, 1994

Sample	Station	Frequency	Collection Details	Sample preparation and analysis
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 weekly and distilled for tritium.
	Others (see Figure 2)	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
Sea water	200m south of Potter Point ocean outfall	Quarterly	1 Litre, collected 11 hours after effluent discharge from LHRL into the sewer.	Gamma spectrometry on fresh sample. Low-level tritium analysis by electrolysis.
Creek water	Bardens Creek Weir	Weekly	250 mL sampled from weir overflow	Distilled for tritium
	Weirs on Bardens Ck & MDP Ck; Strassman Ck	Monthly	1 Litre sampled after rain.	Gross α β according to Clean Waters Act Regulations: AS 3550.0 (1990).
	Forbes Creek	Monthly	1 Litre sampled after rain	Distilled for tritium analysis.
	T2: Barden & Mill Creek (above junction)	Yearly	5 Litres of surface water	Evaporated to dryness, and residue counted for α,β,γ. 250mL distilled for tritium analysis.
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.

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Sample	Station	Frequency	Collection Details	Sample preparation and analysis
Dust on air filters	Little Forest Burial Ground	Quarterly	Duplicate samples collected on 0.8 μm aerosol filters.	Sub-sampled for Be analysis. Composite of quarterly samples for ^{239}Pu analysis by alpha spectrometry.
Ambient iodine-131 in air	Along the eastern boundary of the site (stations 1,2,3,4)	Weekly	Collected on Maypacks (charcoal filters).	Gamma spectrometry of Maypacks.
Sand / Soil	LHRL stormwater outlets	Quarterly	At drain outlet.	Gamma spectrometry of sieved & ashed sample. Gross α β counting.
	LFBG	If indicated by annual dose rate survey	1 kg, from surface	as above
	Effluent pipeline	If indicated by six-monthly dose rate survey	1 kg, from surface	as above
	T2: Barden and Mill Creek (above junction)	Yearly	From creek bed	as above
Gamma Survey (dose rate)*	Effluent Pipeline	Six monthly	Pipe joints and ground surveyed. Soil is sampled if indicated by dose rate survey.	If collected, soils are sieved and ashed, then counted for α,β,γ activity.
	Little Forest Burial Ground	Yearly	Burial trench system surveyed in 1m wide sweeps. Soil is sampled if indicated by dose rate survey.	as above
External Gamma Radiation (TLD)	sites 1-15 at LHRL, sites 16-18 in local suburbs (see Figure 6)	Quarterly	Thermoluminescent Dosimeter (TLD) badges, exposed to ambient gamma radiation.	Sent to ARL for analysis, reported as average integrated absorbed dose to air, in mGy/year.

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* measurements of gamma radiation dose rate were made using an Eberline-PRM 7 field rate monitor.

TABLE 2

TRITIUM IN WORONORA ESTUARY WATER SAMPLES STATION E5.9, 1994

Date	Tritium (Bq/mL)	Date	Tritium (Bq/mL)
4.1.94	LLD	5.7.94	LLD
11.1.94	LLD	12.7.94	LLD
18.1.94	LLD	19.7.94	LLD
25.1.94	LLD	26.7.94	LLD
1.2.94	LLD	2.8.94	LLD
8.2.94	LLD	8.8.94	LLD
16.2.94	LLD	16.8.94	LLD
22.2.94	LLD	23.8.94	LLD
1.3.94	LLD	29.8.94	LLD
8.3.94	LLD	7.9.94	LLD
15.3.94	LLD	13.9.94	LLD
22.3.94	LLD	20.9.94	LLD
29.3.94	LLD	27.9.94	LLD
5.4.94	LLD	4.10.94	LLD
12.4.94	LLD	11.10.94	LLD
19.4.94	LLD	18.10.94	LLD
26.4.94	LLD	25.10.94	LLD
3.5.94	LLD	1.11.94	LLD
10.5.94	LLD	8.11.94	LLD
17.5.94	LLD	15.11.94	LLD
24.5.94	LLD	22.11.94	LLD
31.5.94	LLD	1.12.94	LLD
7.6.94	LLD	6.12.94	LLD
14.6.94	LLD	13.12.94	LLD
21.6.94	LLD	20.12.94	LLD
28.6.94	LLD	29.12.94	LLD

Notes:
LLD = less than the limit of detection for tritium,which is 0.050 Bq/mL.

The guideline value for tritium in drinking water is 7.6 Bq/mL (WHO, 1993).

TABLE 3

TRITIUM IN FORBES CREEK WATER SAMPLES
(a tributary of the Woronora River)
1994

Date	Tritium (Bq/mL)
11.1.94	LLD
24.2.94	LLD
23.3.94	LLD
20.4.94	LLD
10.5.94	LLD
8.6.94	LLD
26.7.94	LLD
16.8.94	LLD
13.9.94	LLD
25.10.94	LLD
15.11.94	LLD
13.12.94	LLD

Notes:
LLD = less than the limit of detection for tritium, which is 0.050 Bq/mL.
The guideline value for tritium in drinking water is 7.6 Bq/mL (WHO,1993).
See Figure 1 for the location of this sampling point.

TABLE 4

RADIOACTIVITY IN WATER SAMPLES FROM POTTER POINT
(200m South of ocean outfall from Cronulla STP)
1993 -1994

Date	Gamma emitters (Bq/L)	* Tritium (Bq/mL)
8.9.93	^{40}K = 20	0.00034
8.3.94	^{40}K = 16.3	0.00021
21.6.94	^{40}K = 16.8	0.00013
17.8.94	^{40}K = 14.5	0.00019
14.12.94	^{40}K = 14.0	0.00009

Notes:
* Low-level tritium analysis by electrolysis method, see Appendix D.
Samples are collected about 11.5 hours after discharge of low-level liquid effluent into the Sydney Water sewer at Lucas Heights. This is the average transit time for discharges from LHRL to reach the Potter point ocean outfall (see Section 5.3).
Figure 5 shows the sampling location.
STP= Sewerage Treatment Plant.

TABLE 5

RADIOACTIVITY IN SEDIMENT FROM STORMWATER OUTLETS at LHRL, 1994

Sample Location	Date	RADIOACTIVITY in SEDIMENT (Bq/g DW)			
		Gross α	Gross β *	γ-emitters	^{40}K
Drain on road at west fence	1-3-94	0.78	0.24	^{238}U & ^{232}Th series	0.08
	19-4-94	0.56	0.58	^{238}U & ^{232}Th series	0.06
	27-7-94	0.72	0.12	^{238}U & ^{232}Th series	0.06
	20-11-94	0.80	0.20	^{238}U & ^{232}Th series	0.07
Drain opposite Fermi Street	1-3-94	0.41	0.12	^{238}U & ^{232}Th series ^{137}Cs = 0.005 ^{60}Co = 0.003	0.12
	19-4-94	0.40	0.58	^{238}U & ^{232}Th series ^{137}Cs = 0.007 ^{60}Co = 0.002 ^{7}Be = 0.034	0.09
	27-7-94	**			
	20-11-94	**			
Drain opposite Bld 23	1-3-94	0.68	0.36	^{238}U & ^{232}Th series ^{137}Cs = 0 .04 ^{60}Co = 0.13 ^{7}Be = 0.06	0.18
	19-4-94	0.74	0.72	^{238}U & ^{232}Th series ^{137}Cs = 0.016 ^{60}Co = 0.047	0.15
	27-7-94	**			
	20-11-94	**			
Drain No.1 opp. Strassman Cresent	1-3-94	0.51	1.94	^{238}U & ^{232}Th series ^{137}Cs = 0.006 ^{60}Co = 0.006 ^{7}Be = 0.0.8	0.08
	19-4-94	0.70	0.66	^{238}U & ^{232}Th series ^{60}Co = 0.002 ^{7}Be = 0.068	0.13
	27-7-94	**			
	20-11-94	**			

Continued next page...

TABLE 5 continued ...

Sample Location	Date	RADIOACTIVITY in SEDIMENT (Bq/g DW)			
		Gross α	Gross β *	γ-emitters	^{40}K
Drain opposite meteorological tower	1-3-94	0.53	0.17	^{238}U & ^{232}Th series ^{137}Cs = 0.006 ^{7}Be = 0.04	0.15
	19-4-94	0.82	0.56	^{238}U & ^{232}Th series ^{7}Be = 0.013	0.17
	27-7-94	**			
	20-11-94	**			
20m from Stormwater Outlet No. 1	1-3-94	0.91	0.22	^{238}U & ^{232}Th series ^{134}Cs = 0.03 ^{137}Cs = 1.8 ^{60}Co = 0.01 ^{144}Ce = 0.31	0.07
	19-4-94	0.90	2.40	^{238}U & ^{232}Th series ^{134}Cs = 0.11 ^{137}Cs = 0.48 ^{60}Co = 0.004 ^{7}Be = 0.018 ^{144}Ce = 0.25 ^{241}Am = 0.015	0.18
	27-7-94	0.73	0.31	^{238}U & ^{232}Th series ^{134}Cs = 0.005 ^{137}Cs = 0.13 ^{144}Ce = 0.014 ^{241}Am = 0.006	0.21
	20-11-94	0.57	0.17	^{238}U & ^{232}Th series ^{134}Cs = 0.008 ^{137}Cs = 0.28 ^{60}Co = 0.002 ^{7}Be = 0.031 ^{144}Ce = 0.017 ^{241}Am = 0.017	0.27

Notes:
* The gross beta results do not include the contribution from potassium-40 (a natural beta-gamma emitter), this has been deducted.
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. Be-7 is a cosmic spallation product.
** No sediment collected from this area due to earthworks.
See Section 5.1.4 for discussion of results.

TABLE 6

TRITIUM IN WATER SAMPLES FROM STORMWATER OUTLETS, 1994

Sample Location	Date	Tritium Bq/mL
Drain behind Bld.1	28.2.94	0.160
	15.4.94	0.550
	27.7.94	Dry
	20.10.94	0.196
Drain near road on West fence	28.2.94	LLD
	15.4.94	0.090
	27.7.94	Dry
	20.10.94	LLD
Drain opposite Fermi Street	28.2.94	LLD
	15.4.94	0.130
	27.7.94	Dry
	20.10.94	**
Drain opposite Bld. 23	28.2.94	LLD
	15.4.94	0.110
	27.7.94	Dry
	20.10.94	**
Drain No.1 opp. Strassman Crescent	28.2.94	LLD
	15.4.94	0.080
	27.7.94	Dry
	20.10.94	**
Drain opposite meteorological tower	28.2.94	LLD
	15.4.94	0.070
	27.7.94	Dry
	20.10.94	**
20m from LHRL Stormwater Outlet No.1	28.2.94	LLD
	15.4.94	0.080
	27.7.94	Dry
	20.10.94	LLD
60m from LHRL Stormwater Outlet No.1	4.1.94	0.108
	11.1.94	0.103
	18.1.94	0.096
	25.1.94	0.116
	1.2.94	0.114
	8.2.94	0.123
	16.2.94	0.158
	22.2.94	0.117
	1.3.94	0.115
	8.3.94	0.162
60m from LHRL Stormwater Outlet No.1	15.3.94	0.158
	22.3.94	0.128
	29.3.94	0.094
	5.4.94	0.164
	12.4.94	0.250
	19.4.94	0.250
	26.4.94	0.158
	3.5.94	0.108
	10.5.94	0.121
	17.5.94	0.086
	24.5.94	0.074
	31.5.94	0.079
	7.6.94	0.064
	14.6.94	LLD
	21.6.94	0.061
	28.6.94	0.066
	5.7.94	0.050
	12.7.94	0.056
	19.7.94	0.056
	26.7.94	0.050
	2.8.94	0.055
	8.8.94	0.050
	16.8.94	LLD
	23.8.94	0.146
	29.8.94	0.199
	7.9.94	0.194
	13.9.94	0.220
	20.9.94	0.247
	27.9.94	0.248
	4.10.94	0.215
	11.10.94	0.231
	18.10.94	0.238
	25.10.94	0.256
	1.11.94	0.263
	8.11.94	0.258
	15.11.94	0.232
	22.11.94	0.226
	1.12.94	0.228
	6.12.94	0.242
	13.12.94	4.544
	15.12.94	2.32
	19.12.94	1.21
	20.12.94	1.03
	23.12.94	0.065
	29.12.94	0.576

Notes:
Refer to Figure 2 for the location of these sampling points.
LLD = less than the limit of detection for tritium, which is 0.050 Bq/mL.
The guideline value for tritium in drinking water is 7.6 Bq/mL (WHO, 1993).
** indicates that the location could not be sampled due to disturbance by earthworks.

TABLE 7

RADIOACTIVITY IN WATER SAMPLES, 60m FROM STORMWATER OUTLET No. 1, 1994

Sample Location	Date	RADIOACTIVITY (Bq/L)		
		Gross α	Gross β (incl. ^{40}K)	γ-emitters
60m from LHRL Stormwater Outlet No. 1*	January	0.14	0.50	^{238}U & ^{232}Th series ^{137}Cs = 0.015 ^{40}K = 0.026
	February	0.13	0.42	^{137}Cs = 0.007 ^{134}Cs = 0.003 ^{40}K = 0.09
	March	0.08	0.62	^{137}Cs = 0.02 ^{134}Cs = 0.004 ^{40}K = 0.06
	April	0.09	0.49	^{137}Cs = 0.014
	May	< 0.01	0.29	^{137}Cs = 0.009 ^{40}K = 0.037
	June	0.01	0.26	^{137}Cs = 0.007 ^{40}K = 0.004
	July	0.15	0.15	^{40}K = 0.025
	August	0.01	0.21	^{137}Cs = 0.008 ^{40}K = 0.030
	September	0.04	0.04	^{137}Cs = 0.010 ^{40}K = 0.035
	October	0.09	0.26	^{137}Cs = 0.007 ^{40}K = 0.06
	November	0.22	0.34	^{137}Cs = 0.019 ^{40}K = 0.05
	December	0.15	21	^{137}Cs = 0.020 ^{40}K = 0.06

Notes:

* This location is sampled weekly for tritium (see Table 4), 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 potassium-40 (a natural beta-gamma emitter).

"^{238}U & ^{232}Th series" refers to the presence of daughter products from the decay of the natural uranium-238 and thorium-232 series.

The average ^{137}Cs level in 1994 was 0.011 Bq/L, which is 0.11% of the reference value for ^{137}Cs in drinking water, given in Section 4.4. Similarly, the average ^{134}Cs concentration for the year was 0.00058 Bq/L, or 0.008% of the reference value.

TABLE 8

RADIOACTIVITY IN WATER SAMPLES FROM SPCC SAMPLING POINTS, 1994

Date	Radioactivity (Bq/L)					
	Strassman Creek		Bardens Creek Weir		MDP Creek Weir	
	Gross α	Gross β*	Gross α	Gross β*	Gross α	Gross β*
19-1-94	dry	dry	LLD	0.10	LLD	0.35
17-2-94	LLD	LLD	LLD	LLD	LLD	0.25
22-3-94	LLD	LLD	LLD	LLD	LLD	0.18
20-4-94	LLD	0.12	LLD	0.13	LLD	0.39
12-5-94	LLD	0.13	LLD	0.22	LLD	0.28
8-6-94	LLD	LLD	LLD	0.15	LLD	0.17
22-7-94	LLD	LLD	LLD	LLD	LLD	0.24
22-8-94	LLD	0.12	LLD	0.29	LLD	0.17
19-9-94	LLD	LLD	LLD	0.29	LLD	0.30
24-10-94	LLD	LLD	LLD	0.14	LLD	0.25
1-12-94	LLD	LLD	LLD	0.15	LLD	0.25
13-12-94	LLD	LLD	LLD	0.18	LLD	0.65

Notes:

See Figure 2 for the location of the SPCC sampling points.

* All gross beta results include the contribution from natural potassium-40 (a beta-gamma emitter).

LLD = Less than the limit of detection. The limit of detection is 0.10 Bq/L for gross α and gross β activity.

The NSW Clean Waters Regulations (1972) specify limits for radioactivity in class C waters as follows: gross α = 1.1 Bq/L
gross β = 11.1 Bq/L.

TABLE 9

TRITIUM IN WATER FROM BARDENS CREEK WEIR
(at SPCC sampling point)
1994

Date	Tritium Bq/mL	Date	Tritium Bq/mL
4.1.94	LLD	5.7.94	LLD
11.1.94	LLD	12.7.94	LLD
18.1.94	LLD	19.7.94	LLD
25.1.94	LLD	26.7.94	LLD
1.2.94	LLD	2.8.94	0.050
8.2.94	LLD	8.8.94	LLD
16.2.94	LLD	16.8.94	LLD
22.2.94	LLD	23.8.94	LLD
1.3.94	LLD	29.8.94	LLD
8.3.94	0.072	7.9.94	0.087
15.3.94	LLD	13.9.94	0.073
22.3.94	0.050	20.9.94	LLD
29.3.94	0.081	27.9.94	0.050
5.4.94	0.063	4.10.94	0.069
12.4.94	0.12	11.10.94	LLD
19.4.94	0.14	18.10.94	LLD
26.4.94	0.050	25.10.94	0.23
3.5.94	0.10	1.11.94	0.080
10.5.94	0.080	8.11.94	0.090
17.5.94	LLD	15.11.94	0.17
24.5.94	LLD	22.11.94	0.073
31.5.94	LLD	1.12.94	0.14
7.6.94	LLD	6.12.94	0.064
14.6.94	LLD	13.12.94	0.054
21.6.94	LLD	20.12.94	0.068
28.6.94	0.086	29.12.94	0.051

Notes:
LLD = Less than the limit of detection for tritium, which is 0.050 Bq/mL.
The reference value for tritium in drinking water is 7.6 Bq/mL (WHO, 1993).
The average tritium concentration at Bardens creek weir during 1994 was 0.068 Bq/mL, which is less than 1% of the drinking water reference value (see Section 4.4).

TABLE 10

GAMMA SURVEY - EFFLUENT DISCHARGE PIPELINE, 1994

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	
13.5.94	Joints #1-17	<0.05 - 0.11	<0.05 - 0.12	0.04 - 0.12
	Joints # 20-22	<0.05 - 0.06	<0.06 - 0.07	0.05 - 0.06
8.11.94	Joints #1-17	<0.05 - 0.09	<0.05 - 0.10	0.04 - 0.11
	Joints #20 -22	<0.06 - 0.07	<0.06	0.05 - 0.06

* Joints # 18 & 19 are inaccessible.

TABLE 11

GAMMA SURVEY - BURIAL TRENCHES LITTLE FOREST BURIAL GROUND, 1994

Date	Location	Dose range (μSv/hour)
13 Sept. 1994	Background outside fence	0.07
	Readings over all trenches	0.08 - 0.10
	Point #5	0.08 - 0.10
	Point #6	0.15 - 0.20

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

TABLE 12

RADIOACTIVITY IN GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1994

Bore	Date	RADIOACTIVITY (Bq/g sediment)*				Tritium Bq/mL
		Gross α	Gross β (incl.^{40}K)	γ-emitters	^{40}K	
BHF	15-6-94	0.85	2.52	^{238}U & ^{232}Th series	0.26	0.56
BH10	"	0.61	1.38	^{238}U & ^{232}Th series	0.22	1.62
OS2	"	2.72	1.01	^{238}U & ^{232}Th series	0.64	1.82
OS3	"	2.82	2.10	^{238}U & ^{232}Th series	0.25	1.69
MB11	"	1.12	0.17	^{238}U & ^{232}Th series	0.07	LLD
MB12	"	1.44	0.19	^{238}U & ^{232}Th series	0.37	LLD
MB13	"	1.48	0.28	^{238}U & ^{232}Th series	0.51	4.03
MB14	"	1.53	0.55	^{238}U & ^{232}Th series	0.52	LLD
MB15	"	0.33	0.15	^{238}U & ^{232}Th series	0.45	LLD
MB16	"	3.62	3.54	^{238}U & ^{232}Th series ^{60}Co = 1.46 ^{137}Cs = 0.021	0.36	13.2
MB17	"	1.09	0.44	^{238}U & ^{232}Th series	0.01	1.55
MB18	"	1.16	0.15	^{238}U & ^{232}Th series	0.52	LLD
MB19	"	0.86	0.52	^{238}U & ^{232}Th series	0.26	0.62
MB20	"	1.18	0.69	^{238}U & ^{232}Th series	0.48	LLD
MB21	"	0.89	0.53	^{238}U & ^{232}Th series	0.53	LLD
BHF	19-12-94	1.09	1.91	^{238}U & ^{232}Th series	0.22	1.09
BH10	"	0.82	1.50	^{238}U & ^{232}Th series	0.24	5.70
OS2	"	5.36	1.23	^{238}U & ^{232}Th series ^{60}Co = 0.023	0.62	5.66
OS3	"	2.89	1.51	^{238}U & ^{232}Th series	0.28	3.72
MB11	"	0.32	0.13	^{238}U & ^{232}Th series	0.01	LLD
MB12	"	1.58	0.49	^{238}U & ^{232}Th series	0.15	1.43
MB13	"	2.89	1.01	^{238}U & ^{232}Th series	0.25	7.42
MB14	"	0.70	0.20	^{238}U & ^{232}Th series	0.05	LLD
MB15	"	1.56	0.50	^{238}U & ^{232}Th series	0.42	LLD
MB16	"	5.14	7.14	^{238}U & ^{232}Th series ^{60}Co = 0.69 ^{137}Cs = 0.030	0.22	15.6
MB17	"	3.02	0.87	^{238}U & ^{232}Th series	0.35	2.24
MB18	"	1.01	0.53	^{238}U & ^{232}Th series	0.37	LLD
MB19	"	1.17	0.34	^{238}U & ^{232}Th series	0.23	LLD
MB20	"	1.01	0.53	^{238}U & ^{232}Th series	0.41	LLD
MB21	"	0.85	0.34	^{238}U & ^{232}Th series	0.21	LLD

Notes: See Figure 3 for the location of the sampling bores.

* refers to the radioactivity of the borewater, after evaporation of the unfiltered sample and counting of the residue. The gross beta results include the contribution from natural potassium-40.

"U & Th series" refers to the presence of daughter products from the natural uranium-238 and thorium-232 series.

LLD = less than the limit of detection, which is 0.050 Bq/mL for tritium.

TABLE 13

RADIOACTIVITY IN CREEKS RECEIVING RUNOFF FROM THE LITTLE FOREST BURIAL GROUND AREA, 1994

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)	10.11.94	1.0	0.10	U & Th series	0.27
Bardens Creek (before it joins Mill Creek)	10.11.94	0.53	0.05	U & Th series	0.03

WATER

Sample Location	Date	RADIOACTIVITY (Bq/L)			Tritium
		Gross α	Gross β	γ-emitters	(Bq/mL)
Mill Creek (before it joins Bardens Creek)	15.12.94	0.11	0.21	ND	LLD
Bardens Creek (before it joins Mill Creek)	15.12.94	0.12	0.14	ND	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 0.050 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 14

RESULTS OF AIR SAMPLING AT LITTLE FOREST BURIAL GROUND, 1994

Sampling period	Air volume sampled (m^3)	Beryllium (μg / filter)	^{239}Pu (Bq / m^3)
21.12.93 to 23.3.94	215.06	<0.1	-
23.3.94 to 24.6.94	68.63	<0.1	-
24.6.94 to 14.9.94	42.82	<0.1	-
14.9.94 to 7.12.94	132.82	<0.1	-
1994 Composite of B filters *	453.93	-	LLD

Notes:
* Composite sample of duplicate set of air filters for 1994. 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 15

AMBIENT IODINE-131 IN AIR, 1994

Sampled during the week ending :	Iodine-131 in air (Bq / m^3)	Sampled during the week ending :	Iodine-131 in air (Bq / m^3)
4.1.94	LLD	5.7.94	0.0038
11.1.94	LLD	12.7.94	0.0063
18.1.94	LLD	19.7.94	LLD
25.1.94	LLD	27.7.94	0.0073
1.2.94	LLD	1.8.94	0.0092
8.2.94	LLD	9.8.94	0.0094
15.2.94	LLD	16.8.94	0.0026
22.2.94	0.061	23.8.94	0.0042
1.3.94	0.0055	30.8.94	LLD
8.3.94	LLD	7.9.94	0.027
15.3.94	LLD	13.9.94	0.011
22.3.94	LLD	20.9.94	0.0034
29.3.94	LLD	27.9.94	LLD
5.4.94	LLD	4.10.94	LLD
12.4.94	LLD	11.10.94	LLD
19.4.94	0.0036	18.10.94	LLD
26.4.94	0.0094	25.10.94	LLD
3.5.94	0.0039	1.11.94	LLD
10.5.94	0.0027	8.11.94	LLD
17.5.94	0.0061	15.11.94	LLD
24.5.94	0.011	22.11.94	LLD
30.5.94	0.0088	1.12.94	LLD
7.6.94	LLD	6.12.94	LLD
14.6.94	LLD	13.12.94	LLD
21.6.94	0.012	20.12.94	LLD
28.6.94	LLD	29.12.94	LLD

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

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

The average iodine-131 concentration in air for the year was 0.0055 Bq/m^3 (assigning each LLD reading a value of 0.0025 Bq/ m^3). A person receiving continuous exposure to iodine - 131 at the average concentration recorded would receive an effective dose of less than 0.01 mSv per year (IAEA, 1994).

TABLE 16

EXTERNAL GAMMA RADIATION AT LHRL
ARL Dosimeter Results, 1994

	Dosimeter Location: on-site	**Effective Dose** (mGy / year)
1	Hifar fence - South East	0.91
2	Hifar fence - South	2.13
3	Perimeter fence - West	1.20
4	Hifar Fence - West	1.49
5	Hifar fence - North west	1.44
6	Perimeter fence - North A	0.91
7	Internal fence - North	0.86
8	Perimeter fence - North B	0.91
9	Perimeter fence - North east	0.86
10	Perimeter fence - East	1.00
11	Perimeter fence - South East	1.01
12	Corner of Curie and Roentgen Sts	1.18
13	Perimeter fence - South	0.82
14	Hifar fence - East	0.98
15	Hifar fence - North east	1.11
	Dosimeter Location: off-site	**Effective Dose** (mGy / year)
16	Private house - Lucas Heights	0.85
17	Private house - Engadine	0.82
18	Private house - Woronora	0.85

Notes:
Refer to Figure 6 for the location of dosimeters 1 to 15.

The data in Table 16 indicate that the natural annual background in the vicinity of the Lucas Heights Research Laboratories (off-site) is between 0.8 and 0.9 mGy. The annual environmental doses measured on site have a minimum of 0.82 mGy and a maximum of 2.13 mGy. The enhanced doses on the southern and western sides of the Hifar fence are mainly due to stored nuclear materials in this area. Although there is no public occupancy in this area, relocation of these materials is planned to a new shielded storage facility to be constructed on site.

TABLE 17

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, 1994

Discharge stack Bld. No.	Gross α (kBq)	^{131}I (MBq)	Gross β (MBq)	^{3}H (GBq)	Noble gases (TBq)	Other activity (MBq)
1st Quarter (Jan - Mar) 1994						
Bld 54 (hotcells)	7	3 421	0.22	-	126	13 253
3	4	LLD	0.11	-	-	-
15A (HIFAR)	2	2	0.62	281	22	54
19	13	2	0.42	-	-	19
20	5	LLD	0.19	77	-	-
21A	2	LLD	0.06	-	-	-
21B	LLD	LLD	0.01	-	-	-
23A	13	5 215	0.99	-	-	-
23B	LLD	LLD	0.03	-	-	-
41	2	1	0.14	-	-	-
56	11	3	0.34	-	-	-
57	2	LLD	0.06	3	-	-
2nd Quarter (Apr - Jun) 1994						
Bld 54 (hotcells)	9	2 993	0.28	-	124	11 131
3	6	LLD	0.13	-	-	-
15A (HIFAR)	2	2	0.50	389	29	81
19	18	3	0.56	-	-	219
20	9	2	0.01	358	-	-
21A	2	LLD	0.05	-	-	-
21B	LLD	LLD	0.01	-	-	-
23A	13	7 113	0.72	-	-	-
23B	1	0.93	0.03	-	-	-
41	5 832	2	0.18	-	-	-
56	13	2	0.39	-	-	-
57	2	LLD	0.07	336	-	-

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TABLE 17 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 (Jul - Sep) 1994						
Bld 54 (hotcells)	11	952	0.27	-	125	6 621
3	6	LLD	0.13	-	-	-
15A (HIFAR)	2	2	0.67	512	29	80
19	17	LLD	0.56	-	-	209
20	8	2	0.38	9	-	-
21A	2	LLD	0.38	-	-	-
21B	LLD	LLD	0.01	-	-	-
23A	13	3 630	0.63	-	-	-
23B	1	1	0.03	-	-	-
41	7	12	0.24	-	-	-
56	11	1	0.38	-	-	-
57	2	1	0.07	7	-	-
4th Quarter (Oct - Dec) 1994						
Bld 54 (hotcells)	9	1 474	0.27	-	110	10 731
3	6	1	0.13	-	-	-
15A (HIFAR)	2	2	0.32	295	25	69
19	22	10	0.65	-	-	157
20	7	LLD	0.43	310	-	-
21A	2	1	0.05	-	-	-
21B	LLD	LLD	0.01	-	-	-
23A	13	3 102	1.43	-	-	-
23B	1	LLD	0.03	-	-	-
41	8	34	0.27	-	-	-
56	12	1	0.38	-	-	-
57	2	LLD	0.08	5	-	-

Notes:
LLD = Less than the limit of detection, which varies with each stack and the type of activity.

See Figure 4 for the location of the discharge stacks.

See Appendix B for a listing of the different types of airborne discharges and their origins.

TABLE 18

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, EXPRESSED AS PERCENTAGES OF QUARTERLY WORKING LEVELS, 1994

Period & Bld. No.	**Gross α** % of working level	**^{131}I** % of working level	**Gross β** % of working level	**^{3}H** % of working level	**Noble gases** % of working level	**Other activity** % of working level
1st Quarter (Jan - Mar) 1994						
Bld. 54 (hotcells)	0.0011	5.18	0.000034	-	74.1	0.83
3	0.25	LLD	0.0085	-	-	-
15A (HIFAR)	0.006	0.01	0.0024	0.22	81.5	0.082
19	0.004	0.0061	0.0016	-	-	0.0029
20	0.18	LLD	0.046	0.95	-	-
21A	0.20	LLD	0.043	-	-	-
21B	LLD	LLD	0.030	-	-	-
23A	0.081	32.6	0.008	-	-	-
23B	LLD	LLD	0.0005	-	-	-
41	0.0006	0.006	0.00054	-	-	-
56	0.14	0.007	0.031	-	-	-
57	0.32	LLD	0.07	0.17	-	-
2nd Quarter (Apr - May) 1994						
Bld. 54 (hotcells)	0.0014	4.5	0.000044	-	73	0.70
3	0.375	LLD	0.004	-	-	-
15A (HIFAR)	0.006	0.01	0.0019	0.30	107.4	0.12
19	0.0055	0.0091	0.0002	-	-	0.033
20	0.32	0.012	0.0024	4.4	-	-
21A	0.2	LLD	0.04	-	-	-
21B	LLD	LLD	0.03	-	-	-
23A	0.081	44.5	0.0055	-	-	-
23B	0.015	0.0058	0.00047	-	-	-
41	1.77	0.01	0.00007	-	-	-
56	0.17	0.0045	0.035	-	-	-
57	0.32	LLD	0.08	18.7	-	-

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TABLE 18 continued ...

Period & Bld. No.	Gross α % of working level	^{131}I % of working level	Gross β % of working level	^{3}H % of working level	Noble gases % of working level	Other activity % of working level
3rd Quarter (Jul - Sep) 1994						
Bld. 54 (hotcells)	0.0017	1.44	0.000042	-	73.5	0.41
3	0.38	LLD	0.01	-	-	-
15A (HIFAR)	0.006	0.01	0.0026	0.39	107.4	0.12
19	0.0051	LLD	0.0022	-	-	0.032
20	0.29	0.012	0.093	0.11	-	-
21A	0.2	LLD	0.27	-	-	-
21B	LLD	LLD	0.03	-	-	-
23A	0.081	22.7	0.005	-	-	-
23B	0.015	0.006	0.0005	-	-	-
41	0.002	0.075	0.00092	-	-	-
56	0.14	0.002	0.034	-	-	-
57	0.32	0.03	0.08	0.4	-	-
4th Quarter (Oct - Dec) 1994						
Bld. 54 (hotcells)	0.0014	2.23	0.000042	-	64.7	0.67
3	0.38	0.006	0.010	-	-	-
15A (HIFAR)	0.006	0.01	0.0012	0.23	93	0.10
19	0.0067	0.030	0.0025	-	-	0.023
20	0.25	LLD	0.10	3.83	-	-
21A	0.2	0.017	0.036	-	-	-
21B	LLD	LLD	0.03	-	-	-
23A	0.081	19.4	0.011	-	-	-
23B	0.015	LLD	0.00047	-	-	-
41	0.0024	0.213	1.04	-	-	-
56	0.15	0.0023	0.034	-	-	-
57	0.32	LLD	0.089	0.28	-	-

Notes: The quarterly working levels referred to above, are self-imposed operational levels which are used to assess trends in the airborne discharges. Doses resulting from the discharges during the period were calculated to be well below the public dose limits and the site dose constraint of 0.3 mSv/ year. See Section 6.0 of this report.

TABLE 19

LIQUID RADIOACTIVE EFFLUENT DISCHARGED TO SYDNEY WATER SEWER, 1994

MONTH	VOLUME Discharged m^3	TOTAL ALPHA $^\alpha$ MBq	TOTAL BETA $^\beta$ MBq	TOTAL TRITIUM GBq	MEAN MONTHLY Concentration QUOTIENT*
January	6825	2.09	63.86	21.36	0.126
February	6059	1.88	39.85	17.39	0.098
March	9059	4.77	98.33	52.36	0.163
April	7760	4.08	45.91	32.90	0.113
May	7543	4.03	40.18	159.16	0.111
June	6017	3.59	34.52	37.55	0.119
July	7038	3.11	128.49	44.41	0.229
August	7158	3.14	48.92	19.61	0.113
September	6374	2.7	26.73	21.03	0.085
October	5772	2.14	20.26	20.14	0.073
November	6047	6.46	57.45	99.17	0.207
December	7326	9.41	191.4	45.49	0.391

Notes:

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

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

* Concentration Quotient: the sum of the mean monthly concentrations of α, β and tritium radioactivity in the liquid effluent expressed as fractions of their respective maximum permissible concentrations (see Section 5.2.2). The quotient term must be no greater than unity to comply with the requirements of the NSW Radioactive Substances Regulations (1959).

All discharges for 1994 were well below the NSW Radioactive Substances Regulations concentration limits.

TABLE 20

ESTIMATED EFFECTIVE DOSES FROM AIRBORNE DISCHARGES, 1994

Receptor Location	Effective dose 1994# (mSv/yr)
Library	0.024
Outside HIFAR	0.0017
Building 9	0.030
Main gate	0.022
Stevens Hall	0.019
MWDA Depot *	0.012
BMX track *	0.014
Woronora Valley *	0.0021

* these locations are off-site, but within the ANSTO 1.6 km Buffer Zone.

TABLE 21

ESTIMATED EFFECTIVE DOSES FROM AIRBORNE DISCHARGES at 1.6 km and 4.8 km radii around HIFAR, 1994

Receptor Locations	Effective dose 1994 (mSv/yr) #	
	1.6 km from HIFAR	**4.8 km** from HIFAR
NORTH	0.011	0.0027
NNE	0.012	0.0031
NE	0.0090	0.0026
ENE	0.013	0.0039
EAST	0.011	0.0033
ESE	0.0089	0.0025
SE	0.0063	0.0019
SSE	0.0063	0.0017
SOUTH	0.0060	0.0016
SSW	0.0037	0.0011
SW	0.0036	0.0011
WSW	0.0037	0.0011
WEST	0.0037	0.0011
WNW	0.0031	0.0010
NW	0.0059	0.0018
NNW	0.0077	0.0022

Estimated airborne effective doses were calculated using the ADDCOR program, stack discharge figures and meteorological data for 1994.

TABLE 22

ANNUAL EFFECTIVE DOSES TO ADULTS FROM NATURAL SOURCES[1]

Source of exposure	Annual effective dose (mSv)	
	Typical	Elevated *
Cosmic rays	0.23	2.0
Terrestrial gamma rays	1.3	4.3
Radionuclides in the body (except radon)	0.23	0.6
Radon and its decay products	1.3	10
Total (rounded)	2.4	

1 Table taken from UNSCEAR (1993), Table 1, page 18.

* The elevated values are representative of large regions. Even higher values occur locally.

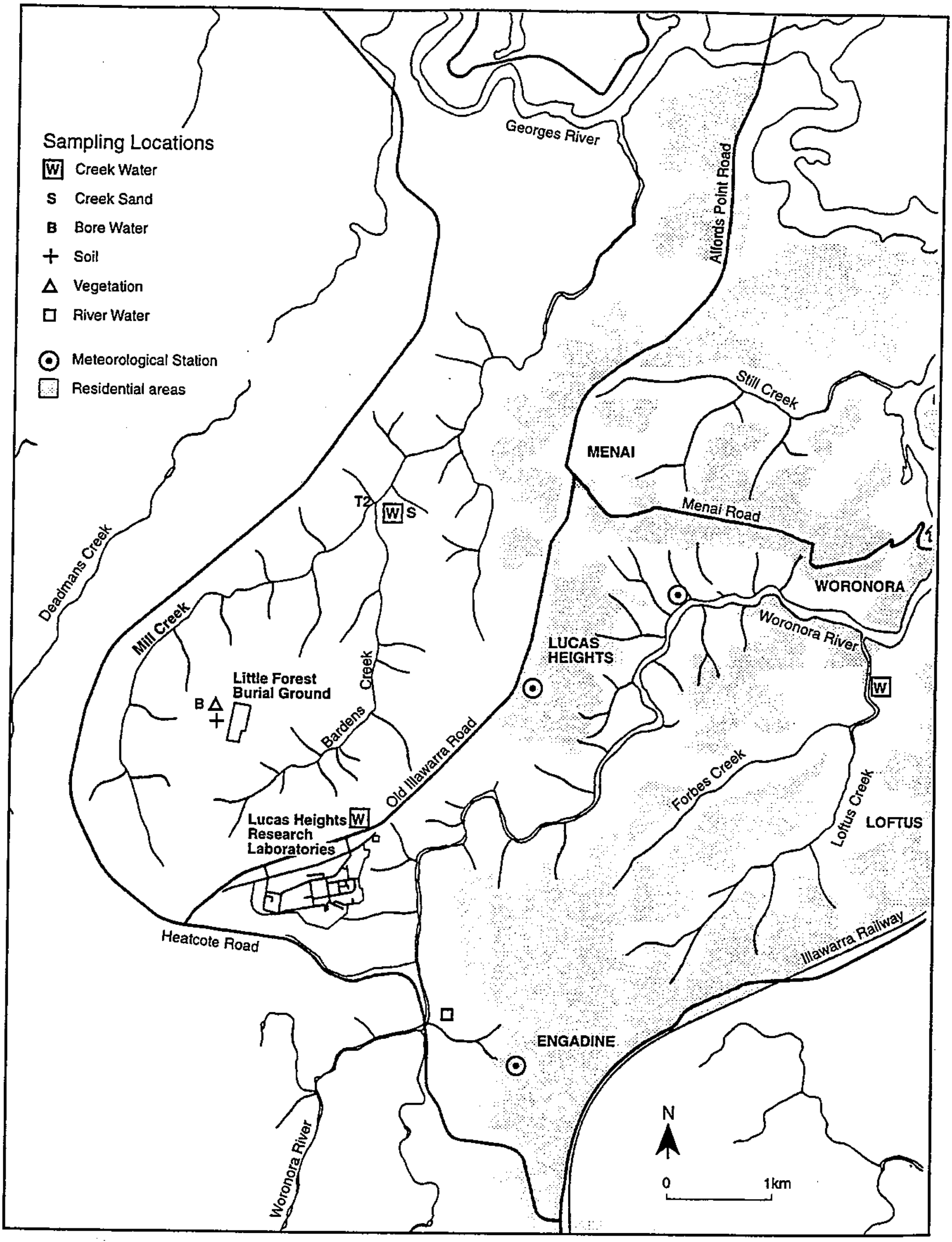

Figure 1: Location of off-site sampling points

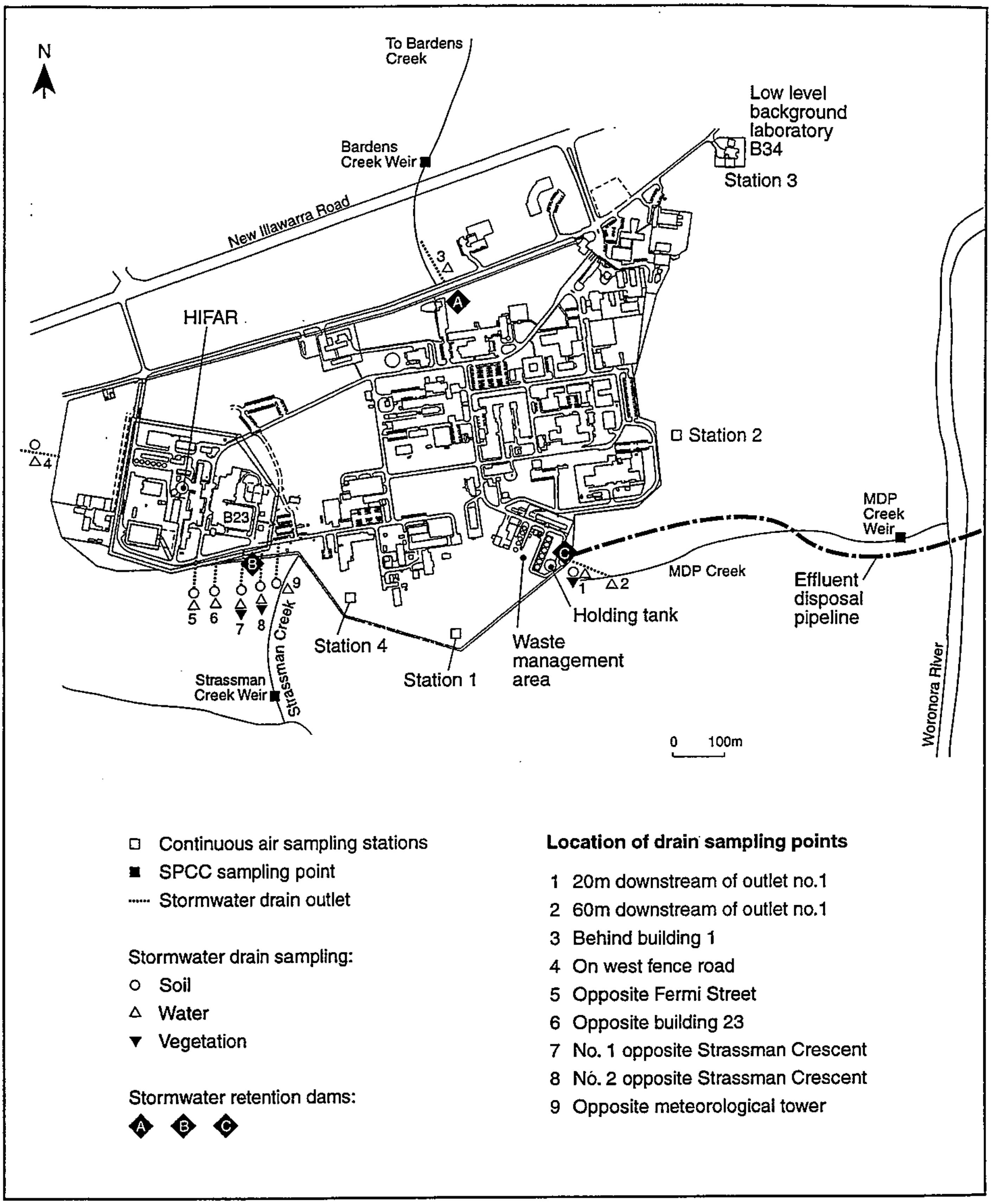

Figure 2: Location of stormwater and air sampling points

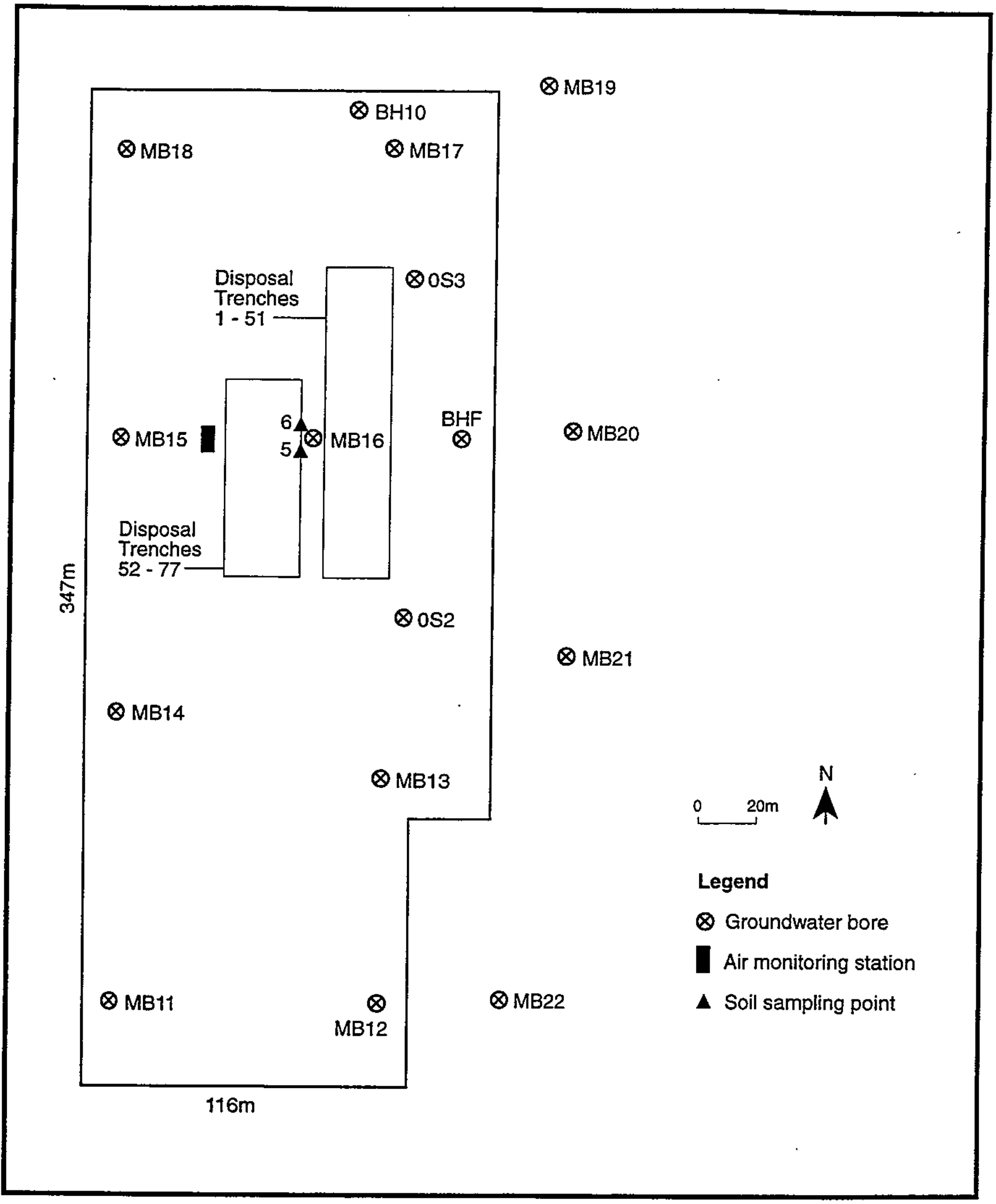

Figure 3: Little Forest Burial Ground - Location of trenches, groundwater bores, and soil sampling points

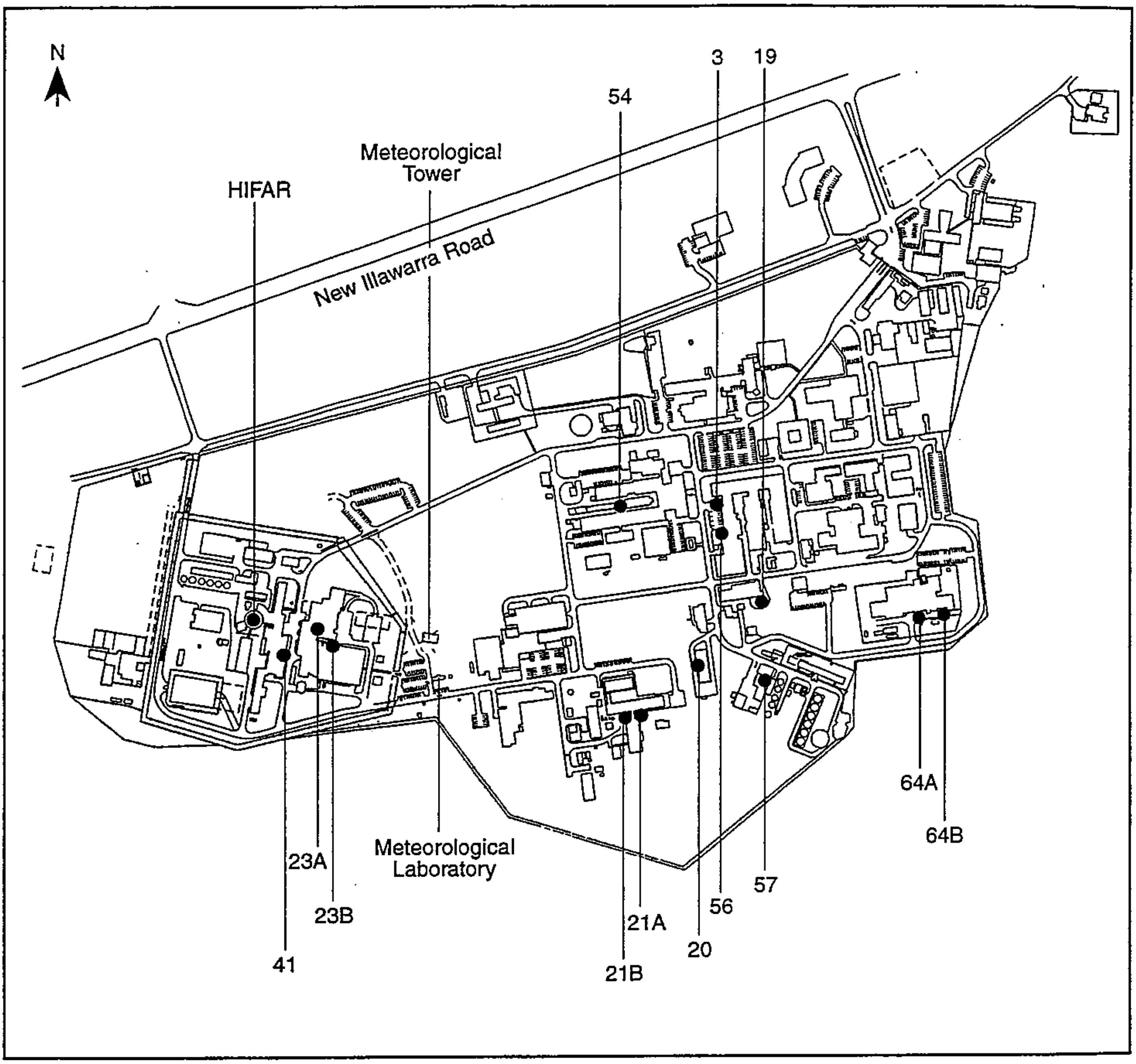

Figure 4: Location of airborne effluent release stacks and meteorological facilities

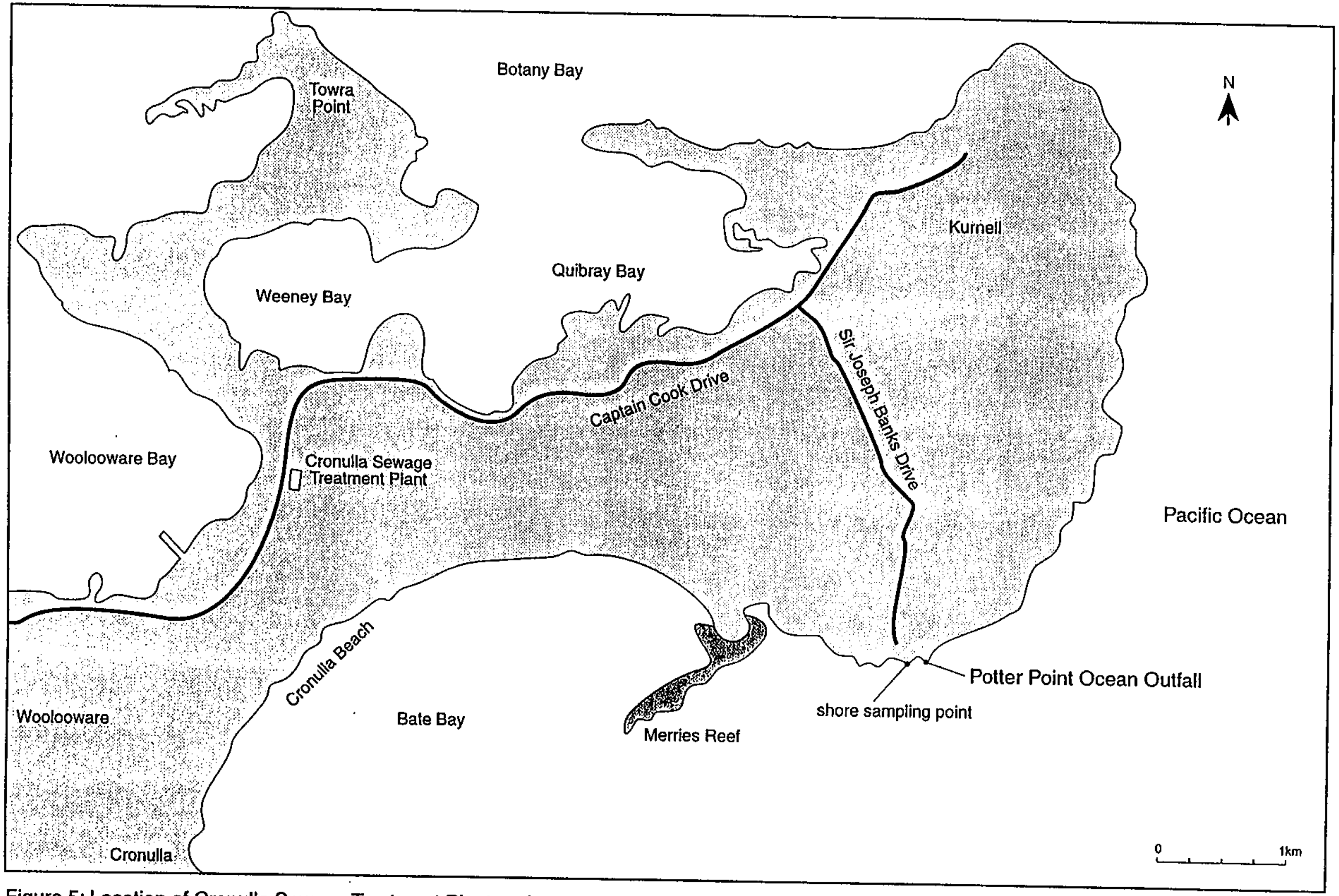

Figure 5: Location of Cronulla Sewage Treatment Plant and ocean outfall at Potter Point

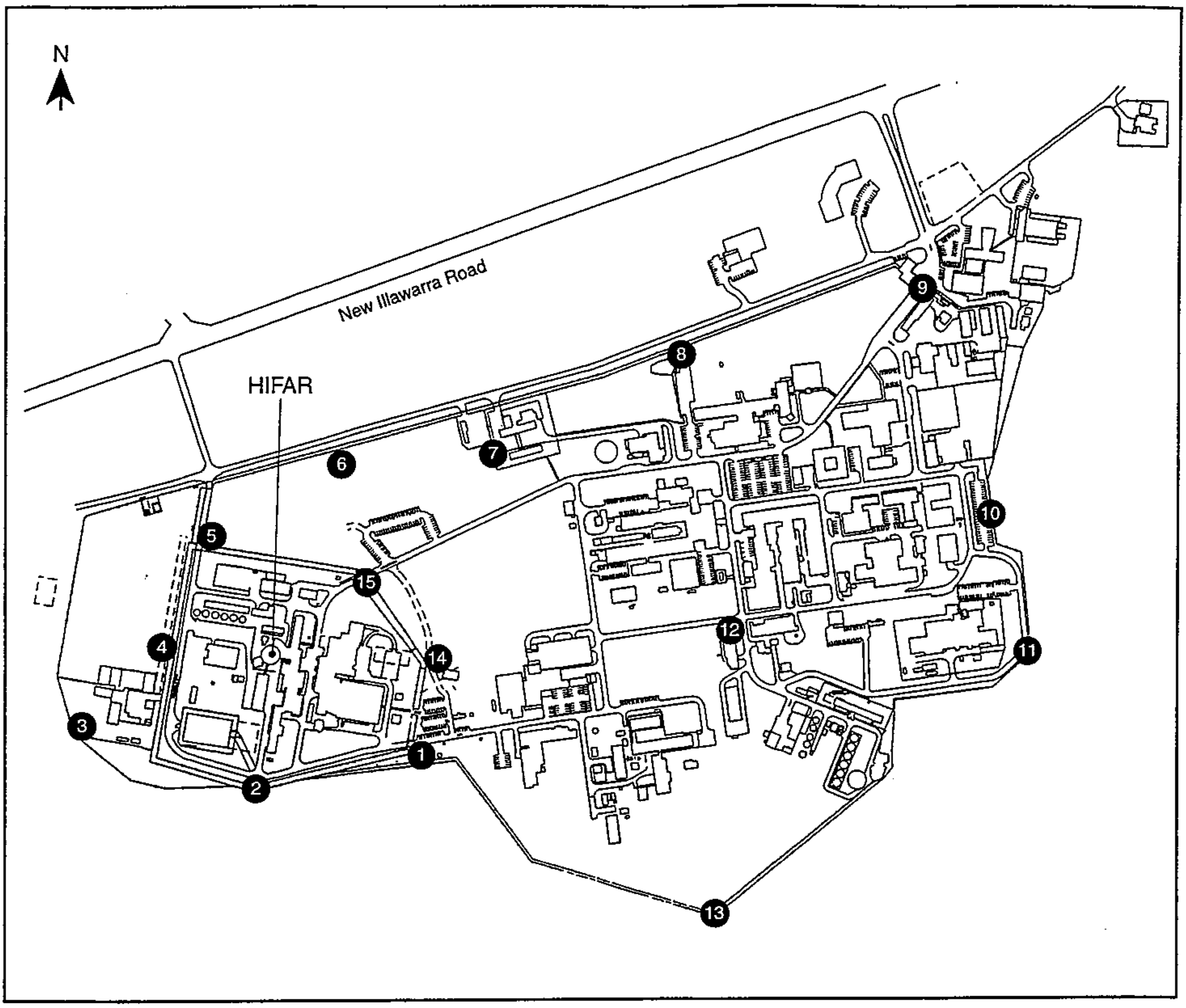

Figure 6: Location of external radiation dosimeters at Lucas Heights Research Laboratories

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 more than 20 mSv per year. Members of the public should not receive more than 1 mSv/ year (NH&MRC 1995).

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 REPO

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APPENDIX B

STACK DISCHARGES OF RADIOACTIVITY AT LUCAS HEIGHTS

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

Radioactive Nuclide	Half-life	Stack	Form of Release	Comment
Tritium	12 years	Bld 20	Water Vapour	Bld 20 is the decontamination centre and occasionally handles coolant pumps removed from the reactor for maintenance.
Tritium	12 years	Bld 57	Water Vapour	Bld 57 is where the spent resin beds, used to purify the 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. 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

SYMBOLS AND PREFIXES USED IN THIS REPORT

Symbol	Name
α	alpha
β	beta
^{241}Am	americium-241
^{7}Be	beryllium-7
^{60}Co	cobalt-60
^{144}Ce	cerium-144
^{137}Cs	caesium-137
^{134}Cs	caesium-134
^{131}I	iodine-131
K	potassium (stable)
^{40}K	potassium-40
^{239}Pu	plutonium-239
^{226}Ra	radium-226
^{90}Sr	strontium-90
^{232}Th	thorium-232
^{3}H	tritium
^{238}U	uranium-238

PREFIXES

K (Kilo) = 10^3 =1 000

M (Mega) = 10^6 = 1 000 000

G (Giga) = 10^9 = 1 000 000 000

T (Tera) = 10^{12} = 1 000 000 000 000

m (milli) = 10^{-3} = 0.001

u (micro) = 10^{-6} = 0.000001

n (nano) = 10^{-9} = 0.000000001

p (pico) = 10^{-12} = 0.000000000001

APPENDIX D

ENVIRONMENTAL SAMPLE COLLECTION, PREPARATION AND ANALYTICAL PROCEDURES

The levels of activity encountered in environmental samples are usually very low. Therefore, the samples are often concentrated so meaningful analyses can be performed. These concentrated samples can be stored for long periods, in case 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 1 kg 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.

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*). Two to three kilograms are collected, and the whole, unwashed vegetation is dried, weighed and ashed.

Ashed biological samples (vegetation, milk, oysters, etc.) are ground and homogenised in a mortar and pestle, then compacted into 2-inch diameter tablets of 8 grams, using a hydraulic press. This ensures that the samples are presented to the alpha, beta and gamma detectors in uniform dimensions.

Surface and Ground Waters

Surface waters from the SPCC sampling points are collected in 1 litre polyethylene bottles, and evaporated in small aliquots onto aluminium planchettes according to the Australian Standard Method 3550.5-1990. The water samples are not acidified, but are prepared immediately upon arrival in the laboratory.

Other surface water samples and groundwaters of 10 litres or more are evaporated at 110°C, the residue weighed, homogenised, tabletted, and counted for gross alpha, beta and gamma radioactivity. Results are in Bq/Litre for most samples, but in Bq/g sediment for the groundwaters from LFBG.

Air Samples: Ambient 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 is located adjacent to the burial trenches at the Little Forest Burial Ground, to monitor possible aerial dust dispersion of contaminants from the site. The location of the air sampler is 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 drawn at approximately 8 litres per minute through 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 beryllium and plutonium analyses required.

Environmental Radiation - ARL dosimeters
External radiation levels at the perimeter of LHRL and in some surrounding suburban areas were measured using thermoluminescent dosimeters (TLD's) issued by the Australian Radiation Laboratory (ARL). These dosimeters are the same as those issued for personal monitoring, and consisted of calcium sulphate thermoluminescent material with three filtered areas and an open window.

The TLD badges are exposed for three months at a time, then sent to the ARL where they are analysed and the results reported to ANSTO. The readings are reported as absorbed dose to air in milligrays (mGy). Measurements were made over four consecutive exposure periods and the results calculated in terms of annual dose.

During 1994 ANSTO purchased special environmental dosimeters, compatible with the ANSTO automatic TLD reader. These dosimeters have been used for monitoring since August 1994. The results will be reported following 12 months use.

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 counting on a Canberra/Packard model 300c liquid scintillation counter. Total counting time is 100 minutes per sample, comprising five 20-minute counts. The limit of detection is presently 0.045 to 0.050 Bq/mL.

Low levels of tritium in waters - by electrolysis

As the tritium isotope is a weak beta emitter, it is difficult to detect at environmental levels. This method achieves a low limit of detection through pre-concentration of the sample by electrolysis. Samples are distilled to remove any salts, then 600 mL of the distillate is subjected to electrolysis, thus concentrating the tritium in the sample. 10 mL of the concentrated sample is added to Instagel scintillant, and counted for thirty 20 minute intervals in a liquid scintillation spectrometer. The limit of detection is 0.2 Tritium Units (1 TU = 118 mBq/L), or 0.000024 Bq/mL.

Alpha and beta activity in soils

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.

Potassium-40 beta activity

In calculating the net beta activity in soils and vegetation, the activity due to natural potassium-40 is subtracted. The potassium-40 activity can be calculated in two ways : either by direct calculation from its 1460 keV peak in the gamma spectrum of the sample, or by chemical analysis of the sample's potassium content and a subsequent calculation of the potassium-40 activity. The specific activity of potassium is 31.2 Bq (due to K-40) per gram of stable potassium. In many cases, the beta activity of a sample is almost entirely due to the potassium-40 contribution.

Gross alpha and beta activity - planchette samples

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.

Gross alpha and beta activity - tabletted water, vegetation and biota samples

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 natural uranium are used to standardise the counter for beta and alpha activity, respectively.

Gamma spectrometry - water residues, soils, vegetation, fresh water

Gamma spectra are obtained by placing prepared samples onto the Ortec Gamma-X high-purity germanium (HPGe) low-background detector, and acquiring counts over a 23 hour period. A multi-channel analyser sorts the spectra according to the energy of the gamma photons. Peaks in the sample spectra are identified using an Ortec software package, *Maestro 11*. Background spectra are used to deduct (strip) the background radioactivity (due to the detector components), from the sample activity. Peaks at certain energies in the stripped spectrum are used to identify the isotope and the amount present in the sample. A spectrum report is printed for each sample, showing the sample description, the peaks identified, and gross/ net areas of the peaks with errors.

The gamma energy spectrum is calibrated daily using certified point sources. The effeciency of the detector is determined periodically using a range of gamma sources, prepared from reference materials of known activity, in the same matrix and geometry as the samples. Background spectra are aquired each week, and are counted for the same length of time as the samples, but with no sample present.

Sample geometries include:

tablets (water residues, ashed vegetation, biota),
petri dishes (60mm diameter filled with soil/ sediment/ashed or dried material),
450 mL Marinelli Beakers (for large quantities of ash, or for liquid samples).

Air samples - Ambient Iodine-131

One set of Maypacks are set aside each week for random independent checking (usually every 3-6 months) by officers of the ARL. 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

The air sampler at LFBG monitors possible aerial dust dispersion of contaminants from the site. The duplicate air filters are analysed for beryllium and plutonium.

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 (performed by ANSTO's Environmental Radiochemistry Laboratory).

APPENDIX E

EFFLUENT SAMPLE COLLECTION AND ANALYSIS PROCEDURES

Airborne Effluent

The authorised airborne effluent discharges from LHRL stacks are monitored weekly by ANSTO's Occupational Health and Safety Program.

Sampling for gases, fumes and particulates

For many gases, fumes and particulate emissions, filter cartridges called Maypacks are used. The Maypacks consist of a charcoal section to trap gases and vapours and a particulate filter trap.

The sample holder which contains the Maypack, intrudes into the stack flow to be sampled. A vacuum pump is used to draw a proportion of the effluent airstream through the Maypack sampler. The flow of rate through the sample holder, and therefore the Maypack sampler, is controlled by a critical orifice in series with the sampler. The flow rate is thus limited to 10 litres per minute. The sampling flow rates are checked weekly using a calibrated flow meter, at the time when the Maypack filters are changed.

The stack flow rates are measured every three months using a 'hot wire anemometer', and whenever the ventilation system is altered in any way (*ie* new fans, change of filters, changes to ducting).

The Maypack is counted using a gamma spectrometer with a NaI detector in a shielded space. Both sides of the Maypack are counted, and the geometric mean of the two readings taken. The filter paper is cut off the Maypack and counted for alpha- and beta-emitting particulates. After initial analysis both components of the Maypacks are stored for 13 weeks when some of the particulate filters are measured again for gross alpha and beta activity. This is to confirm that any particulate activity previously measured was principally due to short-lived radioisotopes.

Sampling for Tritiated Water

Tritiated water in the airborne effluent is sampled using a tritium bubbler. A proportion of the stack airstream is drawn through a series of four Dreschel bottles filled with 250 mL of demineralised water, thus trapping the tritiated water with an efficiency of 99%. The flow rate is limited to 1 litre per minute by a critical orifice. The four samples are transferred to a one litre flask, topped-up to 1 litre, and a 1 mL subsample taken for testing. A liquid scintillation counter is then used to measure the tritium level in the sample.

Sampling for Noble Gases

Noble gases are measured in situ by a gamma spectrometer. As the effluent passes through a 250 mL sampling flask at 4 litres per minute, a gamma spectrometer with a NaI detector counts the noble gases as they pass through.