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ENVIRONMENTAL and EFFLUENT MONITORING at LUCAS HEIGHTS SCIENCE and TECHNOLOGY CENTRE, 1997

by

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REPORT E

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AUSTRALIAN NUCLEAR SCIENCE
AND TECHNOLOGY ORGANISATION

LUCAS HEIGHTS SCIENCE and TECHNOLOGY CENTRE

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ABSTRACT

Results are presented of environmental and effluent monitoring conducted in the vicinity of the Lucas Heights Science and Technology Centre (LHSTC) during 1997. All low-level liquid and gaseous effluent discharges complied with existing discharge authorisations and relevant environmental regulations. Potential effective doses to the general public from controlled airborne discharges from HIFAR were estimated utilising the PC-Cream atmospheric dispersion and dosimetry code. The potential effective dose to the public was estimated to be less than 0.010 mSv/year for all receptor locations on the 1.6 km buffer zone boundary around the HIFAR research reactor. This value represents 1% of the 1 mSv/year dose limit for long term exposure that is recommended by the National Health and Medical Research Council and 10% of the HIFAR dose constraint of 0.1 mSv/year.

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ENVIRONMENTAL AND EFFLUENT MONITORING AT LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE, 1997

SUMMARY

The environmental and effluent monitoring results for 1997 show that the Australian Nuclear Science and Technology Organisation (ANSTO) complied with effluent discharge authorisations and relevant environmental regulations.

ANSTO's Trade Wastewater Agreement with Sydney Water Corporation requires ANSTO discharges to comply with:

a) The former *NSW Radioactive Substances Regulations* (1959);
b) The World Health Organisation (WHO) 1993 *Guidelines for Drinking-Water Quality,* at the Cronulla Sewage Treatment Plant (CSTP); and
c) Concentration limits for non-radiological components of the effluent.

Radionuclide concentrations in liquid effluent discharged to the sewer were below the limits specified for the most restrictive alpha and beta emitters and tritium prescribed in the former *NSW Radioactive Substances Regulations (1959).* During 1997, the monthly radionuclide concentration quotients ranged from 0.24 to 0.76. The average quotient for the year was 0.50, representing 50% of the limit.

The mean radionuclide concentration quotient based upon the WHO 1993 *Guidelines for Drinking-Water Quality* in liquid effluent for 1997 was 0.46. This represents 46% of the limit. Individual monthly quotients ranged from 0.22 to 0.72.

Concentrations of the non-radioactive components of liquid effluent discharged to the Sydney Water sewer met the standards for acceptance specified in the Trade Wastewater Agreement.

Potential effective doses to local members of the public from controlled airborne discharges from HIFAR were all estimated to be less than 0.010 millisieverts per year for receptor locations on the 1.6 kilometre radius buffer zone boundary around the HIFAR research reactor. This value represents 1.0 % 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 10% of the HIFAR dose constraint of 0.1 mSv per year approved by the Nuclear Safety Bureau.

Stormwater drainage from the Lucas Heights Science and Technology Centre (LHSTC) 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. Water samples collected from the Woronora River and Forbes Creek did not contain any detectable levels of tritium.

Groundwater monitoring at the Little Forest Burial Ground (LFBG) indicated that tritium levels were similar to past years. The gross alpha and gross beta activities in borewater were lower than pre-1996 levels, and are generally at levels considered safe for Australian drinking water. Traces of cobalt-60 were detected in bore MB16 which is in the centre of the burial trenches, however these have no health significance to humans and are well below the WHO drinking water guideline value.

Monitoring for airborne particulates at LFBG was resumed in October 1997 following vandalism and theft of the solar-powered air sampling station in 1996. The opportunity was taken to upgrade the equipment to a mobile USEPA-approved high-volume air sampler. It is

capable of sampling greater quantities of air than the previous system and is therefore more accurate. Airborne particulates at LFBG were accumulated on a filter by sampling approximately every two weeks from October to December 1997. No beryllium or plutonium was detectable on this sample.

Wind speeds recorded at LHSTC during particulate sampling at the LFBG averaged 4.4 metres per second (range 1.8 to 8.6 metres per second). Over the last seven years, analysis of all wind speed data from the 10 metre high meteorological tower at Lucas Heights showed only 4% of cases where the wind speeds were sufficient to generate particulates from an exposed surface. The LFBG site has had an established vegetation cover for many years, which further reduces the potential for off-site transport of airborne particulates. The stable conditions at LFBG did not alter during the period that air sampling was not performed, and radiological exposures to members of the public from the LFBG continue to be assessed as negligible.

During the year, thermoluminescent dosimeters measured ambient gamma radiation at various locations around the LHSTC perimeter fence and at three private residences in the nearby suburbs of Barden Ridge, Engadine and Woronora. Measurements at the three local residences showed an average external dose of about 0.9 mSv/year. The local absorbed doses in air were consistent with levels recorded in Australian capital cities (using similar dosimeters) in surveys carried out by the Australian Radiation Laboratory and reported by UNSCEAR (1993).

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

An absorbed dose level of 3.3 mSv/year was registered at location 2 in the southern sector of the LHSTC perimeter fence. This area was affected by the re-drumming and subsequent movement of temporarily-stored nuclear material to the new storage facility in Bld 59. This part of the site is not readily accessed by the general public and is approximately 1.8 kilometres away from any residential areas. On the other hand, doses at locations 4 & 5 decreased from 1996 levels, due to these operations. A comprehensive dose rate survey will be performed along the outside of the perimeter fence when the re-drumming operation is complete. Any requirement for further shielding of the storage facility in building 59 will also be addressed at this time. Other locations exhibited normal background dose rates.

Biological and seawater monitoring continued at Potter Point ocean outfall during 1997. Treated sewage effluent for the Sutherland Shire, including low-level effluent from the LHSTC, passes through the Cronulla Sewage Treatment Plant and is discharged at Potter Point. The seawater and biological sampling programs are aimed at assessing potential doses to members of the public who may recreate in the ocean off Potter Point and/or ingest fish caught in the vicinity of the outfall.

The biological monitoring program at Potter Point was designed to maximise the chances of detecting radionuclides in the marine environment. Three types of sample were collected: fish, algae (seaweed) and barnacles. Similar samples were also collected from a reference site, approximately 6.5 km south of Potter Point, at The Royal National Park. No activity which could be directly attributed to ANSTO was found in any biological samples taken from Potter Point in 1997, apart from low levels of iodine-131 which is used in nuclear medicine.

The tritium levels offshore in the immediate vicinity of Potter Point were investigated in May and November 1997. Only two samples taken near the outfall on 27 May showed detectable levels of tritium. Due to the calm conditions, the effluent plume could be sampled at the cliff outfall. The maximum tritium level observed was 15 Bq/L which is 0.2% of the WHO reference value for tritium in drinking water. The transit time for wastewater flow from Lucas

Heights to the Cronulla Sewage Treatment Plant was 11.75 hours and the minimum in-line dilution factor 50. These results are consistent with results obtained from 1993 to 1996.

The monitoring results from Potter Point 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. The potential dose is at least a factor of 1000 below the NH&MRC recommended dose limits for members of the public.

ENVIRONMENTAL AND EFFLUENT MONITORING AT LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE, 1997

1. INTRODUCTION

Radioactivity levels in authorised effluent discharges and environmental samples collected in the vicinity of the Lucas Heights Science and Technology Centre (LHSTC), formerly known as the Lucas Heights Research Laboratories, are routinely measured by the Australian Nuclear Science and Technology Organisation (ANSTO). The objective of the monitoring program is to determine whether the operations at LHSTC have complied with the applicable environmental standards, effluent discharge limits and radiation protection standards.

The environmental and effluent monitoring programs are aimed at detecting and quantifying any radioactive contaminants released from LHSTC either routinely as authorised discharges or as a result of accidental release. The programs also aim 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 (ICRP60) and adopted by the National Health and Medical Research Council of Australia (NH&MRC) and the NSW Environment Protection Authority (NSW EPA).

ANSTO has recently promulgated the "Health, Safety and Environment Policy" which commits the Organisation to undertaking its activities in a manner which the protects human health and the environment and is consistent with national and international standards. The Policy further mandates that all procedures are in accordance with Commonwealth legislation and take account of relevant NSW regulations and Australian and International Standards on environmental management and Quality Systems.

ANSTO is committed to providing verifiable evidence of the fulfilment of the policy through a program of monitoring and audit. The Organisation is also committed to an on-going community dialogue on this policy and its implementation.

This report summarises the results from the environmental and effluent surveys during 1997 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.**

Figure 1 shows the location of the LHSTC in relation to local roads, waterways and residential areas.

2. ENVIRONMENTAL PATHWAYS

The main environmental pathways by which radionuclides from LHSTC may enter the environment and 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 (hereafter referred to as Sydney Water) sewer system, to the ocean at the Potter Point outfall;
- radionuclide transport by surface/ground water and/or contaminated airborne particulate dispersion from the low-level radioactive waste burial ground at Little Forest; and
- accidental airborne releases, or liquid spills which enter the stormwater system.

In addition, there is potential for a small external dose from gamma radiation emitted by stored wastes on site.

2.1 Atmospheric Discharges

Atmospheric discharges from LHSTC have been regulated from 1968 onwards when expansion of radioisotope production made it necessary to consider possible releases of radionuclides, and in particular iodine-131. Iodine-131 has the potential to concentrate in milk after deposition onto grazing land.

The registered dairy herd closest to LHSTC is at Glenfield, approximately 13 km away (NSW Dairy Corporation, 1998). ANSTO has not been aware of any milk suppliers closer than this since 1993. This pathway is therefore not significant and is not considered further.

Since the hypothetical critical groups for inhalation of airborne activity are people living close to the LHSTC perimeter at Stevens Hall Motel, continuous air samplers are positioned near the site perimeter fence at locations nearest to suburban residences and the motel. See **Figure 2** for the location of Stevens Hall Motel.

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 significant sources of exposure since there is little or no commercial food production or processing in the neighbourhood of LHSTC and small creeks receiving run-off from the site are not used as sources of drinking water.

Levels of integrated external radiation at the LHSTC and in nearby suburban locations were also measured during 1997 using dosimeters issued by the Australian Radiation Laboratory.

2.2 The Discharge of Low-level Liquid Effluent

Since June 1980 the low-level liquid effluent generated from various operations at the LHSTC has been chemically treated and analysed to verify compliance with authorised discharge limits before discharge to the Sydney Water Corporation (Sydney Water) sewer. In accordance with the Trade Wastewater Agreement **(Section 3.1)** 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 negligible and of no radiological consequence for members of the public or employees of Sydney Water.

Monitoring of the level of radionuclides from the LHSTC near the Potter Point outfall has been undertaken since 1993 and published in ANSTO's *Environmental and Effluent Monitoring at LHSTC* reports (listed in **Appendix A**). The 1997 results for tritium in seawater a short distance from the Potter Point ocean outfall are discussed in **Section 7.0** of this report. A biological monitoring program at Potter Point has been operating since 1995. The results for the current year are presented in **Section 5.3** of this report.

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 (see **Figure 1**) for the disposal by burial of solid

waste with low levels of radioactivity and beryllium oxide that originated predominantly from LHSTC.

The disposal site was selected and wastes disposed of using international guidelines relevant at the time. Near-surface disposal was widely accepted internationally as a safe and practical way to dispose of low level solid radioactive waste, provided that the possible return of radionuclides via the human food chain, water or inhaled air, as well as possible exposure due to external radiation were strictly controlled.

Potential exposure pathways to members of the general public from the wastes buried at LFBG would be associated with the off-site transport of radionuclides by surface or ground waters or by windborne movement of contaminated particulates from the surface of the burial area. Possible exposure scenarios would include the use of contaminated surface/ground waters for drinking purposes and irrigation of vegetable gardens; eating contaminated fish or shellfish from the Georges River, 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.

Ground water and surface water associated with the LFBG and surrounding area is not utilised as a potable water supply, and the ephemeral nature of the streams excludes their use for 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 or 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.

The radiation levels over the disposal trench area are at background levels, except for a localised area near the MB16 bore (see **Section 5.7**). 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 if dissolved radionuclides were transported to the surface by ground water.

3. DISCHARGE AUTHORISATIONS

Since the 1960's the AAEC and ANSTO have discharged radioactive effluents from LHSTC 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.

The Commonwealth Government plans to form a new regulatory body, the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) which will be an amalgamation of the Australian Radiation Laboratory (ARL) and the Nuclear Safety Bureau (NSB) and have regulatory and licensing powers in respect of nuclear and radiation related activities of the Commonwealth. This new body is expected to be responsible for authorising, licensing and regulating ANSTO's radioactive discharges once it is established.

In 1993, the NSW Environment Protection Authority (EPA) withdrew from its role of regulating ANSTO's compliance with NSW legislation. Until ARPANSA is established, the Australian Radiation Laboratory will undertake independent audit and verification of ANSTO's effluent and environmental monitoring programs.

ANSTO will continue to comply with:

- any new requirements or discharge limits prescribed by the NSB;
- any provisions of relevant NSW regulations;
- authorisations issued by the NSW RAC;
- discharge limits prescribed in the former NSW Radioactive Substances Regulations (1959);
- the provisions of the Sydney Water Trade Wastewater Agreement (1995).

Summaries of annual levels of radioactivity in authorised discharges from LHSTC are presented in this and previous environmental survey reports (see **Appendix A**).

3.1 Low-Level Liquid Effluent

During 1997 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), pending the establishment of the ARPANSA. In September 1993 the NSW Radiation Control Regulation came into force. However, this regulation does not specify generic radioactivity concentration limits for liquid discharges to the sewer.

In 1995 a revised Trade Wastewater Agreement *Consent to Discharge Trade Wastewater* was negotiated with Sydney Water under the *Water Board Corporatisation Act 1994*. Under the terms of this Agreement ANSTO will comply with:

a) the former *NSW Radioactive Substances Regulations (1959);*
b) the World Health Organisation (WHO) *Guidelines for Drinking-Water Quality* 1993 reference concentrations for radionuclides in drinking water, at the Cronulla Sewage Treatment Plant (CSTP); and
c) concentration limits for non-radiological components of the effluent.

3.1.1 Radioactivity Concentration Limits - Based on the NSW Radioactive Substances Regulations

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) defined for that radionuclide. 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: *ie*

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

Within the terms of the Trade Wastewater Agreement, it is assumed that all alpha and beta radiation come from the most restrictive nuclide of each type as defined in the above-mentioned 1959 regulations. Therefore unspecified (gross) alpha and beta emitting isotopes are reported in terms of activity concentration equivalents of radium-226 and strontium-90 respectively.

When monitoring the discharge to the sewer of a mixture of unspecified alpha and beta radionuclides and tritium, the discharge authorisation then becomes:

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

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

The following table shows the activity concentration limits for the presumed most restrictive alpha or beta emitting radionuclides and tritium.

Concentration Limits under the former NSW Radioactive Substances Regulations (1959)

Maximum Permissible Activity Concentration Limits (Bq/m^3)	
radium-226	1×10^4
strontium-90	1×10^5
tritium	4×10^9

In practice, some radioactivity will arise from less restrictive isotopes than radium-226 and strontium-90, providing an additional margin of safety.

In quoting strontium-90 as the most restrictive isotope, ANSTO is complying with the 1959 Regulations under the Radioactive Substances Act. However, recent data (International Basic Safety Standards 1996) indicate that the effective dose coefficient for lead-210 (6.9×10^{-7} Sv/Bq) is greater than that for strontium-90 (2.8×10^{-8} Sv/Bq). Within the terms of the Trade Wastewater Agreement, if the presumed most restrictive alpha (or beta) emitting radionuclide can be shown to be an insignificant fraction of the overall alpha (or beta) emitting components in the effluent, then the maximum permissible concentration of the next most restrictive radionuclide may be used. To date, the level of lead-210 in all samples analysed is below the detectable limit (2 Bq/L). ANSTO is therefore continuing to report the gross beta results in terms of strontium-90.

3.1.2 Radioactivity Concentration Limits - Based on WHO Guidelines for Drinking Water, 1993

As indicated above, the Trade Wastewater Agreement requires that radionuclide concentrations at the CSTP comply with the WHO *Guidelines for Drinking-Water Quality (1993)* reference concentrations for radionuclides in drinking water, at the CSTP.

Reference values for safe levels of radionuclides in drinking water may be derived as follows, in line with the approach used in the (WHO) *Guidelines:*

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

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.

Using the latest dose conversion factors from the *International Basic Safety Standards* (1996), drinking water reference concentrations for adults were calculated for various radionuclides and are tabulated below. The International Basic Safety Standards were jointly issued by the FAO, IAEA, ILO, OECD/NEA, PAHO and WHO[1].

Radioisotope	Dose Conversion Factor(1) mSv/Bq	Drinking Water Reference Concentration Bq/L
americium-241	2.0×10^{-4}	0.69
caesium-134	1.9×10^{-5}	7.2
caesium-137	1.3×10^{-5}	10.5
chromium-51	3.8×10^{-8}	3600
cobalt-60	3.4×10^{-6}	40
iodine-131	2.2×10^{-5}	6.2
radium-226	2.8×10^{-4}	0.49
lead-210	6.9×10^{-4}	0.20
strontium-90	2.8×10^{-5}	4.9
tritium	1.8×10^{-8}	7600 (2)

1) Dose Conversion Factors are from the *International Basic Safety Standards* (1996) Table II-VI.
2) The WHO (1993) quotes a rounded up drinking water reference concentration of 7800 Bq/L, which is used throughout this report.

The WHO Guidelines are deemed to apply at the Cronulla Sewage Treatment Plant (CSTP). A conservative dilution factor of 25 is assumed between the ANSTO discharge point and the CSTP (based on previous studies conducted from 1993 to 1996, see **Appendix A**).

To obtain a concentration limit for monitoring liquid effluent at the ANSTO point of discharge, the above Drinking Water Reference Concentrations for radium-226, strontium-90 and tritium were multiplied by 1000 (converting Bq/L to Bq/m^3) and by a factor of 25 (allowing for dilution between ANSTO and the CSTP). The resulting *Activity Concentration Equivalents* are tabulated below.

[1] FAO: Food and Agriculture Organisation (UN).
IAEA: International Atomic Energy Agency (UN).
ILO: International Labor Office (UN).
OECD/NEA: Nuclear Energy Agency of the Organisation for Economic Cooperation and Development
PAHO: Pan-American Health Organisation.
WHO: World Health Organisation (UN).

Concentration Limits at ANSTO Discharge Point based on the WHO *Guidelines for Drinking-Water Quality* (1993)

Activity Concentration Equivalents (Bq/m^3)	
radium-226	1.25×10^4
strontium-90	1.25×10^5
tritium	1.95×10^8

The monthly concentration quotient is calculated using the same summation formula given in **Section 3.1.1**, but the MPC denominators are replaced by the Activity Concentration Equivalents (ACE), *ie*

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

Compliance with the Regulations
Compliance with the discharge authorisations was routinely monitored by ANSTO. Prior to the establishment of the ARPANSA, the Australian Radiation Laboratory within the Commonwealth Department of Health and Family Services independently audits and verifies ANSTO's effluent and environmental monitoring programs. During the year, Sydney Water also collected 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 until 1988, radioactive emissions from AAEC/ANSTO were subject to a discharge authorisation approved by the NSW RAC which specified the maximum amount of radioactivity that could be discharged from each of the stacks at LHSTC during a given time period.

In 1988, ANSTO proposed to the NSW RAC a revised site-wide airborne radioactive effluent discharge limit for LHSTC. The proposed revision arose out of changes to ICRP and NH&MRC recommendations occurring in the intervening 20 years, site operational changes, advances in radiation dosimetry and increased knowledge of the local meteorology at LHSTC. It was based on limiting the total amount of radioactivity discharged to the atmosphere from LHSTC, 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).

In December 1988, the NSW Radiological Advisory Council accepted the proposal subject to a number of conditions, which were subsequently complied with.

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 **Glossary** for the definition of dose constraint). This recommendation has been adopted by ANSTO.

In August 1997 the NSB issued a revised HIFAR Radioactive Airborne Discharge Authorisation specifying four weekly, quarterly and annual notification levels with a HIFAR dose constraint of 0.1 mSv. ARL concurred with this authorisation and also confirmed that a dose constraint of 0.3 mSv was appropriate for the whole site. The site dose constraint previously authorised by the NSW RAC was 0.5 mSv.

In June 1998 the NSB authorised the use of a European computer code, PC-Cream[2], to replace the ANSTO-developed ADDCOR code[3], for estimating airborne discharge doses due to HIFAR. This internationally-validated European code is considered more appropriate than the now dated ADDCOR Code, and includes the latest ICRP dose conversion factors. This PC-Cream code will be applied to the site as a whole when the pending approval is notified to ANSTO.

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

Appendix B lists the various types of radioactive airborne effluent releases from LHSTC 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 State Pollution Control Commission (SPCC, now the NSW EPA) at Strassman, MDP and Bardens Creeks. These creeks, shown on **Figure 2,** receive most of the stormwater running off the LHSTC area.

4. MEASUREMENT OF RADIOACTIVITY

This section presents brief descriptions of the radioactivity analyses performed, the radionuclides commonly found and information on natural radioactivity in environmental samples. The statistical analysis of data is also discussed. Definitions of terms can be found in the **Glossary**. The radioisotope symbols used in this report are listed in **Appendix C**.

4.1 Types of Radioactivity Measured

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

Gross beta activity: refers to the measurement of the total beta activity from unspecified nuclides in a sample. Tritium is not included in these assays and is reported separately.

Gamma activity: refers to the gamma rays emitted from radionuclides, which are analysed on a high purity germanium solid-state detector. A gamma spectrum for each sample is accumulated, with an energy range of 20 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 8.02 days).

Caesium-137: a fission-product that was widely dispersed around the world by atmospheric nuclear weapons testing. The isotope is deposited in precipitation or as 'dry' fallout, and adsorbs strongly onto fine sediments (like clays). Caesium-137 is widespread in foods, since its chemical behaviour is similar to that of potassium (an element essential to all living things). Caesium-137 is also formed as a by-product of the production of technetium-99m generators for medical purposes.

[2] Refer to ANSTO Safety and Reliability Report SD/SR/TN 98-7 revision 1, August 1998.
[3] Atmospheric Dispersion and Dosimetry Code for Operators and Regulators. Refer to ANSTO/DR25, 1989.

Cobalt-60 : is an activation product formed by the neutron activation of cobalt contained in the steel casings of reactor components. It has a half-life of 5.3 years and is a beta-gamma emitter. This isotope is readily concentrated by both aquatic and terrestrial organisms.

Iodine-131: a fission-product radionuclide with a half-life of 8 days. It 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 uptake by thyroid tissue. Further, inhalation of gaseous iodine-131 can also result in doses to the lung and thyroid. Iodine is more readily concentrated by marine biota than by freshwater organisms.

Tritium (^{3}H)***:*** 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 (there is no corresponding gamma emission). 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 the table of Drinking Water Reference Concentrations in **Section 3.1.2**).

Tritium is widespread in the environment. It is a cosmogenic radionuclide which was also produced as a result of atmospheric nuclear weapons testing (by far the largest contribution), and in nuclear reactors (particularly in heavy water reactors such as HIFAR) by neutron activation of deuterium.

Tritium (as tritiated water) is chemically indistinguishable from normal water and may be taken up as such by living organisms. The effective or biological half-life is relatively short, typically of the order of days. When present, tritium is found more or less uniformly distributed throughout living things, not accumulated in any particular organ. Thus the concentration factor is ordinarily assumed to be equal to one. Tritium is therefore not considered to accumulate in aquatic organisms above the concentration found in the surrounding water.

As the mass of the tritium atom is three times greater than ordinary hydrogen, chemical reaction rates and diffusion may be significantly slower, which may result in a concentration factor of less than one in some organisms at the bottom of the food chain (*ie* plants). Organically bound tritium may produce concentration factors slightly greater than one in some biota.

Tritiated water does not undergo geochemical processes such as ion exchange, adsorption or precipitation during transport through geologic media.

4.2 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 LHSTC 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 (UNSCEAR 1993: Table 5, p 65).

Potassium-40
Potassium-40 (half-life 1.28 x 10^9 years) is a primordial radioisotope of potassium, and since potassium is an essential element, 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/gamma 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 2 g 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/L.

4.3 Counting Statistics

Most of the results from the environmental monitoring program were reported using the principles of counting decision levels endorsed by Gilmore & Hemingway in *Practical Gamma-ray Spectrometry* (1995), Chapter 5, Section 5.6, pages 119-124, for determining the statistical significance of a sample count based on the uncertainties of the background.

After a sample has been "counted" or measured for radioactivity, it is important to determine whether or not the level of activity is statistically significant. Since a sample count (or peak area in the case of gamma spectrometry) becomes non-significant by being 'lost' in the background, the uncertainties in the background counts must be taken into account.

Gilmore & Hemingway have established the definitions of statistically determined decision levels in terms of the following questions:

- **Critical limit** (L_C) - 'Is the net count significantly above the background?'
- **Upper Limit** (L_U) - 'Given that this count is not significant, what is the maximum statistically reasonable count which could be attributed to the radionuclide of interest?'
- **Minimum Detectable Activity** (MDA) - 'What is the least amount of activity measurable?'

In practice, these decision limits are applied as follows:

i) The sample (C) and background (B) counts (or peak areas in gamma spectrometry) were examined, and the net counts (N) calculated: $N = C - B$.

ii) The critical limit, L_C, is defined as that count at which there is only a 5% chance that a radionuclide would be judged to be present in a sample when in reality it was not. L_C is calculated from the formula $2.33(B)^{1/2}$ (equation 5.54, page 120 of Gilmore and Hemingway), and compared with the net sample count or peak area. If the sample's net count (or peak area) is greater than L_C we can say with 95% certainty that the activity has been detected, and a result with an associated uncertainty is quoted.

iii) If the sample's net count (or peak area) is less than L_C, the sample is judged to be inactive and an upper count limit, L_U, is calculated (Gilmore and Hemingway, Section 5.6.2, page 121). The L_U value is passed through the normal activity calculation to produce an upper activity limit that is equated with the minimum detectable activity.

4.4 Laboratory Quality Management

ANSTO Quality Policy requires activities to be undertaken in a manner that promotes a quality culture for planning and undertaking research and development, the provision of items and services and reporting of these activities. To achieve this, the Environmental Monitoring laboratory is continuing to develop and improve its quality manual, procedures and instructions.

Analyses
Blanks and standards are included with each batch of samples counted. Instruments and detectors are regularly calibrated against certified standard materials. During tritium, gross alpha and gross beta analyses, samples are counted repeatedly up to five times. Long counting times (23 hours) are used for low-level gamma spectrometry samples.

Methods
Australian or International Standard methods for radiological analyses are used, where they are available. Gamma spectrometry, gross alpha, gross beta and tritium analyses of waters were performed using the same techniques as those employed at the Australian Radiation Laboratory. See **Appendix D** for details of sample analysis techniques.

Calculations
Results have been reported with the appropriate number of significant figures. All data entries are double-checked before results are released.

5. ENVIRONMENTAL MONITORING

The monitoring programs at LHSTC involve measurements of the radioactivity in local environmental samples as well as the liquid and airborne effluents discharged from the site. In **Sections 5, 6 & 7** of this report, the monitoring programs carried out at Lucas Heights and Potter Point are defined and the results are discussed.

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

Samples of sediment, groundwater, air and surface water were collected during 1997 at the sites shown in **Figures 1 to 6** and analysed for radioactivity. Sampling locations included the Woronora River, Mill Creek, Bardens Creek, Forbes Creek, Potter Point ocean outfall, LHSTC stormwater outlets, creeks draining LHSTC and the Little Forest Burial Ground. The on-site meteorological station collects data all year round and external gamma radiation levels at the perimeter of LHSTC have been measured since 1994.

The sample collection and preparation schedule is shown in **Table 1**. New methods for gross alpha, gross beta and gamma determinations, trialled in 1996, were adopted in 1997. The purpose of this change was to bring the procedures into line with the relevant Australian Standard (AS) or International Standards Organisation (ISO) methods and to enable direct comparison between ANSTO and ARL results. More detailed information on the collection, preparation and analysis of environmental samples is available in **Appendix D**. Environmental survey results for 1997 are presented in **Tables 2 to 17**.

5.1 Woronora River

Routine water samples were collected monthly from the Woronora River at the boat ramp in Jannali Reserve and analysed for tritium. No tritium was detected in these samples during 1997 and none has been detected since July 1980, when discharges of treated liquid effluent from LHSTC to the Woronora River ceased. The data are listed in **Table 2.**

5.2 Forbes Creek

Water from Forbes Creek, a tributary of the Woronora River, is sampled monthly (after rain, if possible) and analysed for tritium. The sample is taken at the point where the Sydney Water supply pipeline crosses the creek, 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 LHSTC origin. Tritium is the radionuclide most likely to be detectable under such circumstances.

Tritium was not detected in any of the samples collected during 1997, nor has any been found since sampling at Forbes Creek began in 1994 (see **Table 3**).

5.3 Potter Point Biological Monitoring

The biological monitoring program at Potter Point which commenced in 1995 and has been designed to maximise the chances of detecting radionuclides in the marine environment across a range of trophic levels in the food chain. Specimens of fish, algae and barnacles are collected. A similar coastal sampling site was selected for comparison purposes at The Royal National Park, approximately 6½ km south of Potter Point.

The species collected at Potter Point and The Royal National Park are listed below:

Common Name	Scientific Name
blackfish	*Girella sp.*
green algae (cabbage weed)	*Enteromorpha sp.* and *Cladophora sp.*
surf barnacles	*Tesseropera rosea*

The approximate quantities of biological material collected in 1997 were:

Location	Total Mass of Material Collected (kg FW)		
	Fish	Green Algae	Barnacles
Potter Point	1.2	1.9	1.2
The Royal National Park	1.2	0.8	1.2

Blackfish were caught using a fishing line baited with seaweed, while the green algae and barnacles were scraped off the rocks. Fish were filleted, the algae and barnacle samples were left whole. Samples were dried, ground and analysed for gamma-emitting radioisotopes.

The sampling locations at Potter Point and the Royal National Park are shown on **Figure 5**, and the results for fish, algae and barnacles are presented in **Tables 4, 5 & 6**. For details of the offshore monitoring at Potter Point, see **Section 7**.

Biological Monitoring Results

Gamma spectrometry of the samples collected from Potter Point did not reveal any fission product activity, apart from low levels of iodine-131 in algae.

The short-lived isotope iodine-131 was detected in algal samples from Potter Point at concentrations of 28 to 360 Bq/kg fresh weight (corrected for decay from sampling date). Seaweeds are extremely good environmental indicators, responding rapidly to small changes in pollutant concentrations. It is therefore not surprising that low levels of radionuclides may be detected in algal samples. Samples of wastewater at LHSTC were collected at about the

time that iodine-131 was measured in seaweed at the Potter Point outfall. These samples, along with effluent from the Cronulla STP, were analysed for iodine-131. None was detected.

Other gamma-emitters detected at significant levels in the biological samples were naturally-occurring radioisotopes which are commonly found in marine specimens. They include beryllium-7, potassium-40 (ubiquitous in biological samples) and daughter products of the uranium-238 and thorium-232 decay series, such as lead-210, thorium-224 and thallium-208.

The levels of iodine-131 found in macroalgae from Potter Point are of no health significance to humans. The potential radiation dose to members of the general public as a result of ANSTO's discharges to the sewer is very low. It should be noted that ANSTO is not the only source of radionuclides entering the sewer system in the Sutherland Shire.

5.4 Stormwater Outlets

Stormwater retention bunds

During 1994, small capacity concrete stormwater retention dams (bunds) were constructed on the three main stormwater outlet points for the LHSTC site. The bunds are designed to retain stormwater/groundwater seepage temporarily before its release off site. They enable the on-site containment and treatment of any small accidental spills or releases of contaminated liquid that could otherwise enter the site stormwater system. They are also used as environmental monitoring points.

The locations of the bunds are shown on **Figure 2**. Briefly, they are:

Bund A	-	Opposite building 1;
Bund B	-	Opposite the meteorological tower;
Bund C	-	On Stormwater Outlet No.1 (drains into MDP creek).

The bunds are inspected and discharged daily in order to leave capacity for any spills that may occur.

Tritium in Stormwater

In 1997 bunds A & B were sampled monthly, while bund C samples were collected weekly. All samples were analysed for tritium and the results are shown in **Tables 7a** and **7b.**

Tritium was detected in the stormwater bunds at levels well below the WHO drinking water reference concentration of 7800 Bq/L (**Section 3.1.2**). The range of tritium values for bunds A, B & C were <10 to 200, <10 to 360 and <10 to 630 Bq/L respectively.

The detection of small but measurable quantities of tritium in stormwater and creeks draining the site is not unexpected at LHSTC, since tritiated water vapour released to air from HIFAR operation, will exchange with rain water and other free water surfaces. For further information about tritium, see **Section 4.1**.

Radioactivity in MDP Bund Monthly Composite

Each week, some of the MDP Bund sample was combined to make a monthly composite, which was analysed for gross alpha, gross beta and gamma radioactivity. The results are given in **Table 7c**.

The average activities of the monthly MDP Bund composite samples (including less-than values) were as follows:

gross alpha <0.04 Bq/L;
gross beta 1.0 Bq/L.

These were well below the NSW Clean Waters Regulations limits for class C waters, which are 1.1 Bq/L for gross alpha and 11.1 Bq/L for gross beta activity.

Gamma spectrometry performed on the monthly composite samples revealed traces of caesium-137 in June and November, with no other significant gamma-emitters detected. Similar levels of caesium-137 have been detected in the past.

Sediment from Stormwater Bunds
Results for sediment collected from the three stormwater bunds are given in **Table 8**. Measurable amounts of radioactivity were detected in the sediment samples. The low-level activities found do not have any health consequences for humans.

Stormwater Outlet No.1 (MDP+60m)
Stormwater Outlet No.1 drains the south-east corner of the site into MDP creek (**Figure 2**), and has experienced some low-level radioactivity contamination of sediment and vegetation in the past. Historically, it has been sampled in a small pool about 60 metres below the actual stormwater outlet itself, known as MDP+60m.

In April 1997, sampling at the MDP+60m point was discontinued in favour of the upstream MDP bund. However, in July it was decided to reinstate the MDP+60m sampling point, in order to maintain the long history of sampling at this point.

Some of the weekly MDP+60m sample was combined each month to make a composite sample for gross alpha, gross beta and gamma spectrometry analyses. Each weekly sample was analysed for tritium.

Tritium
Tritium results for the weekly MDP+60m water samples are shown in **Table 9a** and varied from <10 to 410 Bq/L. The average tritium concentration was 180 Bq/L, which is less than 3% of the WHO drinking water reference concentration and lower than in previous years.

Radioactivity in MDP+60m Monthly Composite
Monthly gross alpha and gross beta radioactivity results for MDP+60m water samples were at background levels throughout the year, see **Table 9b**.

Caesium-137 at low levels was identified by gamma spectrometry of monthly composite water samples from MDP+60m. The average caesium-137 concentration for 1997 was 0.02 Bq/L, which represents less than 0.2% of the WHO drinking water reference concentration.

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

5.5 Creeks Draining LHSTC

SPCC Weir Sampling Points
Stormwater from the LHSTC 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**) were sampled and analysed for gross alpha and gross beta activity.

In 1997, gross alpha and gross beta analyses were performed using ISO methods 9696 & 9697. The data are presented in **Table 10**. The gross beta results include the contribution of

natural potassium-40 activity. All results were well below the NSW Clean Waters Regulations limits for gross alpha and gross beta activity, and were at or below Australian Drinking Water Guideline levels (0.1 Bq/L for gross alpha and 0.5 Bq/L for gross beta activity).

Samples of water were also collected from the SPCC sampling weir on Bardens Creek at weekly intervals during 1997, for tritium analysis. The results are shown in **Table 11**. The highest value recorded during the year was 220 Bq/L, which is less than 3% of the WHO reference concentration for tritium in drinking water (**Section 3.1.2**). The average weekly concentration at this location was less than 55 Bq/L, or 1% of the reference concentration. It should be noted that water from Bardens Creek is not part of any known drinking water supply.

5.6 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 1997, and the results are summarised in **Table 12**. These surveys were performed as part of the regular program of inspection and maintenance of the pipeline.

The dose rates recorded along the pipeline with an Eberline PRM-7 field dose-rate meter, were less than 0.10 μSv/hour and are principally due to natural background radiation.

5.7 Little Forest Burial Ground (LFBG)

Results of sampling at the LFBG are given in **Tables 13, 14, 15,** and **16**. 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 13**). Dose rates over the trenches ranged from 0.05 to 0.10 μSv/hour, consistent with normal background readings. 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 in the same range as those previously measured at these locations.

Soil
The 1997 gamma radiation survey did not indicate any areas that were greater than three times the background, therefore no soil samples were collected.

Groundwater Monitoring
Groundwater from monitoring bores located both inside and outside the fenced LFBG area were collected in June and November 1997 and analysed for tritium, gross alpha, gross beta and gamma activities. Results are listed in **Table 14.**

As reported in ANSTO/E-730 (1996), the former AAEC/ANSTO sampling and analysis methods for gross alpha/beta and gamma analysis of groundwater were replaced with those used by the Australian Radiation Laboratory. The procedures used in 1997 are outlined in **Appendix D.** Tritium analysis of all samples remained unaffected (ISO method 9698:1989).

Gamma-emitters in Groundwater
No artificial radionuclides were detected in any bores other than MB16, which contained traces of cobalt-60. The cobalt-60 concentrations were less than 1% of the adult drinking water reference concentrations tabulated in **Section 3.1.2**.

In contrast to tritium, 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. Although some sediment from bores inside the fenced area have contained fission products in the past, now that the sediments are largely excluded from the water samples, little or no activity has been detected.

Gross alpha/beta activity in Groundwater
The levels of gross alpha and gross beta activity in groundwater from LFBG not only comply with the Clean Waters Act requirements for class C waters, they are also very close to the levels considered safe for drinking water in Australia. The results generally show a reduction in gross alpha and gross beta activities when compared to pre-1996 values.

Tritium in Groundwater
For bores inside the fenced area, tritium concentrations in 1997 were similar to previous measurements, with BHF, BH10, OS2, OS3, MB13, MB16 and MB17 showing significant tritium levels. Bore MB16, being in the centre of the trenches, had the highest tritium concentration at 10560 Bq/L, 135% of the WHO recommended level for drinking water.

Tritium concentrations in the remaining bores and outside the fenced LFBG area remain at background levels, even with the considerable improvements made in detection sensitivity over the past two years.

Stream Sediment and Surface Water Sampling
Samples of surface water and sediment were collected from Mill Creek and Bardens Creek (**Figure 1**) to monitor possible off-site movement of contaminants from the LFBG. The results of gross alpha, gross beta, tritium and gamma analyses on these samples are given in **Table 15**.

No radioactivity above background levels was found. The small amount of caesium-137 in sediment from Mill Creek was associated with atmospheric nuclear weapons test fallout deposited on the banks of the stream. Previous samples from Mill Creek were collected from the sandy stream bed, however the 1997 sample was collected from the bank due to high water levels. The amount of caesium-137 found was similar to background concentrations of fallout in Hunter Valley soils (Elliott *et al*, 1990).

Monitoring Airborne Particulates
An *Ecotech* high-volume air sampler, built to USEPA specifications, was commissioned in October 1997 to replace the previous solar-powered monitoring station (which was vandalised and stolen in 1996). The *Ecotech* sampler is capable of collecting greater quantities of air than the previous system and is therefore more accurate.

The sampler is mounted on a trailer with a petrol generator for power. It is deployed away from high vegetation and operated once every two weeks for about 4 hours during normal working hours. Sampling is not performed during wet weather when airborne dust levels are negligible.

The air sampling flow rate is set at 60 m^3 per hour and airborne particulates are progressively accumulated over a period of three months on a cellulose fibre filter paper. When operated as above, the high-volume sampler will collect approximately 1440 cubic metres of air per quarter, and 5760 m^3 per annum. This is about twelve times greater than the average annual volume recorded using the previous system (since 1985: range = 330 to 762 m^3; average = 456 m^3).

The particulate sampling method described above is conservative, since a size-selective inlet is not used and larger particles in excess of respirable size may also be collected. The particles collected at LFBG would be up to about 50 microns equivalent aerodynamic diameter (EAD). Particles below 10 microns EAD are respirable and hence considered a potential health hazard. Such particulate matter is generated by industrial processes, combustion of fuels, burning of vegetation and incineration. These particles are also present in motor vehicle emissions, wind blown dust and salt air (AS 3580.96-1990).

The wind speed threshold for increased resuspension of dust particles from the ground, in temperate Australian conditions is normally considered to be about 5 to 6 metres per second (Clark, 1998 personal communication). However this will depend on local conditions such as soil moisture, the age of the particles and their bonding to the ground surface, vegetation cover and local turbulence amongst other factors. In 1991, Nigel Holmes and Associates reported that 5.6 metres per second was the critical wind speed threshold for dust generation from an exposed surface, such as the Lucas Heights Waste Management Centre.

During periods of air sampling at the LFBG, wind speeds recorded at the 10 metre high ANSTO meteorological tower ranged from 1.8 to 8.4 metres per second. The average wind speed was 4.4 metres per second (from 15-minute averages). Data recorded at the 10 metre high meteorological tower at Lucas Heights for the period April 5, 1991 to June 1998 were analysed. Wind speeds greater than or equal to 5.6 metres per second occur infrequently, less than four percent of the time (Clark, 1998 personal communication).

Activities at the nearby clay/shale quarries and Lucas Heights Waste Management Centre may occasionally generate airborne dust which could impact on the sampling of particulates at LFBG. However, the LFBG is a stable and well-grassed area, which rarely experiences winds capable of significant dust generation. This further reduces the possibility that contaminated airborne particulates could be transported off-site. The stable conditions at LFBG did not alter during the period that air sampling was not performed, and radiological exposures to members of the public from the LFBG continue to be assessed as negligible.

The results for airborne particulate monitoring in the last quarter of 1997 are given in **Table 16**. At the end of each quarter, the exposed filter is divided into four equal portions. Two of these are used for beryllium and plutonium analyses; the remaining two portions are stored. No beryllium or plutonium concentrations were detected on the air filters in 1997.

5.8 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) 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. Calculations of iodine-131 activity give maximum levels of activity using a conservative set of assumptions. Analysis is via gamma spectrometry of the Maypacks (see **Appendix D** for further details).

Forty-six out of fifty-two weekly measurements of ambient iodine-131 in air at the site boundary during 1997 were below the detectable level of 0.0025 Bq/m^3 (**Table 17**). The detectable level would correspond to an annual dose of less than 0.01 mSv per year to a member of a hypothetical critical group, living at Stevens Hall Motel and receiving continuous exposure to iodine-131 at a concentration of 0.0025 Bq/m^3. Since forty-six of the

fifty-two measurements showed no detectable iodine-131, the average annual dose to the public is clearly far less than 0.01 mSv[4].

5.9 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 PC-Cream[5] which can be used to compute the effective dose to an individual due to the routine airborne or accidental release of radionuclides from the LHSTC.

In 1993, three additional meteorological stations were installed to investigate the influence of local complex terrain on wind flow, dispersion patterns and temperatures (Clark, 1997). The stations are located at the Lucas Heights Community School; Boys Town School (Engadine) and at the "Shackels Estate" in the Woronora River valley (**Figure 1**). The on-site meteorological tower and associated laboratory are shown on **Figure 4**.

Wind Direction
Annual average wind speeds recorded at Lucas Heights from 1991 to 1996 were approximately 2.5 metres per second (Clark, 1997). The winds that 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 - ENE sectors
	Night / early morning	SSE to SSW
WINTER	Daytime	from W - NW and S - SE sectors
	Night / early morning	S - WSW

Winds during autumn and spring represent a transition between the summer and winter seasons, with sea breezes observed later in the afternoon.

The influence of local topography on wind speeds and directions is very marked in the Lucas Heights area. Low wind speeds at the Woronora River valley floor are associated with the drainage of cool air into the valley at night (Clark, 1997). Winds on the plateau and ridges are stronger and steadier.

Rainfall
The annual rainfall at Lucas Heights in 1997 was 732 mm, recorded on 108 rainy days. The wettest month was February, with 127.7 mm of rainfall. Annual rainfall recorded since 1958 varies from a minimum of 556 mm to a maximum of 1658 mm.

Temperature
There are only small differences in temperatures between the three stations on the ridges and plateau above the Woronora River valley. The valley generally has higher daytime temperatures, which indicates some trapping of warm air in the valley.

[4] Based on the Committed Effective Dose per Unit Activity given in the *International Basic Safety Standards* (1996), Safety Series No.115.
[5] Refer to ANSTO Safety and Reliability Report SD/SR/TN 98-7 revision 1, August 1998.

The coldest month overall was July with an average midday temperature of 14.8 ^{0}C while the warmest month was December, when the average midday temperature was 26.2 ^{0}C.

The temperature extremes recorded were: Minimum: 4.3 ^{0}C (June & August 1997);
Maximum: 40.9 ^{0}C (December).

5.10 External Gamma Radiation

Levels of ambient external gamma radiation at and in the vicinity of the Lucas Heights Research Laboratories were measured during 1997 using two different types of thermoluminescent dosimeters (TLD) as used by the Australian Radiation Laboratory (ARL) and ANSTO.

The dosimeters issued by ARL are the same as those used for personal monitoring and consist of calcium sulphate thermoluminescent material with three filtered areas and an open window.

The environmental dosimeters used by ANSTO contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters. They were analysed at ANSTO using a Harshaw 6600 TLD reader (manufactured by BICRON).

Figure 6 shows the locations of dosimeters 1 to 15.

Table 18 shows the integrated annual absorbed dose to air, in millisieverts, as monitored by the ARL dosimeters for the calendar year 1997, and compares these figures with results for 1994 through to 1996. Measurements were made over quarterly monitoring periods, the dosimeters were returned to ARL for measurement, and the readings were reported to ANSTO as annual absorbed dose to air in terms of milligray. The absorbed dose was then converted to effective dose (in millisieverts) using the conservative conversion factor of one[6].

The 1997 annual doses measured at or within the LHSTC perimeter fence, had a minimum of 0.7 mSv and a maximum of 3.3 mSv. The 1997 annual absorbed dose to air due to environmental radiation measured outside several homes in the vicinity of the LHSTC was around 0.9 mSv. When converted to an hourly rate, this figure corresponds with the average hourly absorbed dose rate to air from terrestrial gamma radiation, recorded in Australian capital cities in surveys carried out by the ARL and reported by UNSCEAR (1993). This means that the external gamma dose rates at residences near the LHSTC are at normal background levels. The annual doses measured at these locations have remained constant (within measurement tolerances) since the introduction of TLD monitoring in 1994.

Data obtained from the ARL and ANSTO dosimeters, placed at the same locations, are compared in **Table 18a**. The results from the two types of TLD show no significant difference.

The process of re-drumming and movement of radioactive materials affected the pattern of doses in the HIFAR fenced area during 1996. There is still some re-drumming occurring in this area, and when it is completed a comprehensive dose rate survey of the perimeter fence will be undertaken for comparison with pre-1996 surveys. As a result of the relocation of the material, the 1997 dose at location 2 on the inner perimeter fence (closest to the building 59 extension) has increased when compared with the pre-1996 measurements. Building 59 is a storage facility for low level radioactive wastes. This location is about 1.8 kilometres away from any residential areas and there is no public occupancy of the area. The results of the

[6] UNSCEAR (1993) use conversion factors of 0.72 Sv per Gy for adults, 0.80 for children and 0.93 for infants.

planned dose rate survey, together with a consideration of occupancy factors, will indicate whether there is a requirement for further shielding of the building 59 extension.

6. EFFLUENT MONITORING

ANSTO's Safety Division performs the routine monitoring of the airborne effluent released from LHSTC stacks.

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

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

6.1 Airborne Effluent Stack Discharges

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

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

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

Stack Sampling

During 1997, 12 to 13 discharge stacks were monitored on a weekly basis. For most gases, vapours and particulate emissions, filter cartridges called Maypacks are connected to 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 4 weeks when some of the particulate filters are measured again for gross alpha and gross beta activity. This is to confirm whether 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 activity in the sample.

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

Results

Table 19 presents the 1997 quarterly airborne emissions for the individual stack release points.

The most significant airborne radionuclide discharged from site was argon-41 from HIFAR. Argon-41 is a short-lived radioactive gas produced by the neutron activation of air inside the reactor irradiation facilities. The level of argon-41 discharged in the year was 81.5 % of the NSB annual notification level for HIFAR (200 TBq) and 8.2% of the correction level (revised

to 2000 TBq in October 1998). Four weekly, quarterly and annual notification and correction levels were not exceeded throughout the year.

The airborne effluent stack discharge data were used to estimate possible doses to members of the public due to airborne releases from HIFAR (see **Section 8.1**), by utilisation of the PC-Cream atmospheric dispersion and dosimetry computer model. Airborne dose estimates for the remaining stacks will be published in the 1998 *Environmental and Effluent Monitoring at LHSTC* report, after ANSTO receives authorisation (from the NSB and ARL, or ARPANSA) to apply the PC-Cream code to all the stack discharges.

It should be noted that the public doses due to the discharges are very low (well below the 0.3 mSv dose constraint adopted by ANSTO) and much smaller than natural background.

6.2 Low-Level Liquid Effluent Discharges

The Waste Management Section at ANSTO is responsible for the handling, treatment, routine monitoring and authorised discharge of liquid effluent arising from operations at LHSTC.

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:

i) the liquid effluent from radioactive laboratories, which has a low level of radioactivity;
ii) the trade effluent from laboratories and workshops in which radioactive and toxic materials are not handled; and
iii) sewage.

The sewage waste is passed through an on-site sewage treatment plant before temporary storage in holding tanks. The active liquid effluent goes through an alum-based chemical treatment process for removal of radionuclides. The trade waste is tested and chemically treated if necessary. Finally, water seeping into the sump in the vicinity of Building 27 (the intermediate waste and spent fuel storage facility) is pumped into the holding tanks. The levels of gamma emitting isotopes and tritium in the groundwater seepage are monitored monthly .

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, and are analysed for gross alpha and gross beta radioactivity, pH, ammonia and total chromium. A volume weighted monthly composite sample is produced from all discharge samples for the month. This monthly composite sample is analysed for gross alpha/beta, tritium and gamma activity and assessed for compliance with the Sydney Water Trade Waste Agreement (as are the individual pipeline samples which make up the monthly composite).

Liquid Effluent Results
Groundwater seepage from the area below Building 27, analysed monthly (**Table 20**), showed no significant gamma activity, and tritium levels were well below the WHO drinking water guideline value given in **Section 3.1.2**.

Radioactivity levels in authorised liquid effluent discharges to the Sydney Water sewer are summarised in **Table 21**. The Maximum Permissible Concentrations under the former NSW Radioactive Substances Regulations and the WHO *Guidelines for Drinking-Water Quality* Activity Concentration Equivalents are also shown.

Former NSW Radioactive Substances Regulations (1959)
The average concentration quotient for monthly effluent composite samples in 1997 was 0.50, and all of the monthly radionuclide concentration quotients were less than unity, demonstrating compliance with the former NSW Radioactive Substances Regulations (1959).

World Health Organisation Guidelines for Drinking-Water Quality
The average monthly quotient term (based on the WHO Activity Concentration Equivalents at the ANSTO discharge point) for 1997 was 0.46. All of the individual monthly quotient terms were also less than unity, demonstrating compliance with the WHO *Guidelines for Drinking-Water Quality* at the CSTP.

All discharges for the year were analysed for the following non-radioactive components: suspended solids; pH; ammonia; biological oxygen demand; grease and chromium. All discharges complied with the relevant standards for acceptance of trade wastes to the sewer, as required by Sydney Water. The data are listed in **Table 22**.

7. POTTER POINT OFFSHORE MONITORING

Advanced primary treated effluent from the Cronulla Sewage Treatment Plant is discharged from a submerged cliff face outfall at Potter Point, located at the northern end of Bate Bay on the Southern Sydney coastline, NSW (**Figure 5**).

Public interest groups such as the Sutherland Shire Council and the Surfriders Association have in the past expressed concern that liquid effluent discharged to the sewer by ANSTO may be a radiation hazard to swimmers and surfers in the vicinity of the Potter Point ocean outfall.

Since 1995, ANSTO has carried out biannual investigations at Potter Point with the following objectives:

i) to measure the transit times and dilution factors between Lucas Heights and the Cronulla Sewage Treatment Plant (CSTP);
ii) to study the dispersion of tritium in the vicinity of the outfall; and
iii) to continue a program of biological monitoring.

To satisfy objectives i) and ii) above, two routine effluent releases were monitored during 1997. As in previous investigations, tritium was used to monitor the sewage plume since it is usually present in the ANSTO discharges. Tritium is widely used in environmental tracer studies. In addition, ANSTO commissioned Unisearch Water Research Laboratory to model the plume dispersion using the conditions prevailing during the second effluent release in November 1997.

Sampling of biota at Potter Point was also performed twice during the year (see **Section 5.3**).

7.1 May 1997 Effluent Monitoring

The contents of a holding tank at Lucas Heights were released between 18:36 hours on 26 May 1997 and 01:50 hours on the following morning. Hourly samples were taken from the pipeline during the release and the tritium concentration determined. The total volume released over 7.23 hours was 529 kilolitres, with an average tritium concentration of 15520 Bq/L. The discharge rate throughout the release was steady, averaging 1.22 kilolitres per minute.

Effluent Transit Time to Cronulla STP
An automatic sampler was used to collect hourly samples of effluent near the outflow of the Cronulla STP. The tritium concentration of the effluent varies as it passes through the treatment plant. The interval between the mid-point of the effluent release from Lucas

Heights and the time at which the maximum tritium concentration was observed at the STP, was approximately 11.8 hours. This is consistent with effluent transit times obtained in previous studies, which were in the range of 9.6 to 11.8 hours.

Offshore sampling
On exit from the Cronulla STP the treated sewage travels via a pipeline to the Potter Point outfall where it enters the ocean (this takes approximately one hour).

As in previous offshore monitoring of effluent releases, the Environment Division research vessel *Imara* conducted an hourly sampling program throughout the daylight hours of 27th May. Two-litre samples of water were taken from the visible effluent plume moving away to the south of the outfall, at depths of 0.5, 1.0 and 2 metres.

These samples were taken at five stations that were marked by buoys placed in position before sampling commenced and accurately fixed using the differential global positioning system available on board the vessel. The first sampling station was located directly above the ocean outfall (close to the shore) due to the calm conditions prevailing on this occasion. The remaining five stations were positioned within the sewage plume up to 200 metres from the outfall.

Results
The water samples were analysed for tritium concentration by liquid scintillation counting. Tritium was detected in only two samples taken from station 1 over the outfall pipe, at 0.5 and 1 metre depths. The maximum tritium concentration at the outfall was 15 Bq/L which occurred about 17.5 hours after the release began. All other samples were less than the limit of detection (5 Bq/L), therefore the *offshore dilution ratio* could not be determined on this occasion.

The average tritium concentration in the effluent released from LHSTC on 26 may 1997 was 15 520 Bq/L and the highest concentration in samples taken the next day at the outflow of the Cronulla STP was 310 Bq/L. The minimum *in-line dilution ratio* was 50. This is higher than previously observed values for overnight releases, *ie* outside normal business hours, which were 26.9, 21.5, and 31.7. On weekdays, the flow rate of effluent through the Cronulla STP during business hours is generally greater than at night, when industrial premises are closed.

7.2 November 1997 Effluent Monitoring

On the evening of 19 November 1997, two holding tanks containing 210 kilolitres each of liquid effluent were discharged to the Sydney Water Sewer. Samples of the effluent were taken from the holding tanks at LHSTC prior to the release. Unfortunately the automatic sampler set up at the Cronulla STP malfunctioned and no samples were taken.

Offshore Sampling
Three sampling stations were set up offshore from Potter Point in the visible sewage plume. The distance from the outfall to sampling station 1 was 50 metres, while station 3 was 200 metres away.

Samples were collected at depths of 0.5, 1 and 2 metres every hour from 09:00 to 15:00 hours on 19 November. No detectable tritium was found in samples from stations 1, 2 or 3, all were below the limit of detection (5 Bq/L).

Since no samples were taken at the STP and no tritium was found in the offshore samples, the *dilution factor* and *effluent transit time* between LHSTC and the Cronulla STP could not be determined on this occasion.

7.3 Modelling of the Potter Point Outfall by Unisearch WRL

At the request of ANSTO, the dispersion of tritium from the Potter Point ocean outfall was modelled under the prevailing conditions on 27 May 1997. The work was undertaken by the commercial consulting service of the University of NSW, Unisearch Water Research Laboratory (WRL Technical Report 97/17, June 1997).

The transport and dilution of the plume within Bate Bay are numerically modelled using hydrodynamic and water quality models for sea conditions, as well as prevailing wind, temperature and current data collected from the Ocean Reference Station (ORS) off Bondi. The effluent transit times from the LHSTC to the Cronulla STP and from the STP to the outfall have been measured with reasonable precision in previous studies. Using this information, it is possible to calculate the concentration of tritium in the vicinity of Potter Point at any nominated time or location since 1995, when the Potter Point sampling program began.

The Potter Point plume was modelled at hourly intervals between 09:00 and 15:00 hours on the day of sampling, 27 May 1997.

The general findings of the model were as follows:

- initially there were weak northward flowing currents, which turned south and strengthened during the day;
- there was slow initial dilution of the plume, which remained offshore spreading in both northerly and south-south westerly directions, but tending more towards the south during the day as the offshore current speed increased;
- the plume dilution factors varied from about 20 at the outfall, to 2000 and greater within about 2 km of the outfall ; and
- the plume was transported close to the surface.

The model output at 11:00 hours is shown in **Figure 7,** corresponding to the time at which the maximum tritium concentration occurred at the ocean outfall.

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

The principal sources of potential radiation exposure to members of the public from routine operations at LHSTC are from airborne emissions and low level liquid effluent discharges to the sewer. These sources comply with discharge authorisations given previously by the NSW Radiological Advisory Council or concentration limits specified in the Trade Waste Agreement with Sydney Water. 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 site dose constraint adopted by ANSTO.

8.1 Airborne Emissions

As indicated in **Section 3.2**, the PC-Cream 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. **Table 23** gives a summary of the estimated effective doses due to airborne discharges from HIFAR, at specified locations and distances from the 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 less than 0.010 mSv per year. That is, 1% of the NH&MRC recommended annual dose limit of 1 mSv and less than 10% of the HIFAR dose constraint of 0.1 mSv authorised by the NSB. For members of the

general public residing at the 1.6 km radius ANSTO buffer zone boundary and beyond, the most exposed individual was also estimated to receive less than 0.010 mSv/year.

Iodine-131 emissions from the LHSTC were also monitored at the perimeter fence. Assuming continuous exposure to the iodine-131 minimum detectable concentration of 0.0025 Bq/m^3, the potential effective dose to members of the critical group would be about 0.01 mSv per year. Since forty-six of the fifty-two weekly iodine-131 measurements were below the detectable limit, the average potential dose to the public is clearly less than 0.01 mSv per year. This figure represents 1% of the NH&MRC recommended annual dose limit of 1 mSv and about 3% of the site dose constraint adopted by ANSTO, and was calculated in an extremely conservative manner. This is consistent with the results obtained from the PC-Cream model.

Table 24, 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 and is generally accepted to range from 1.8 to 2.2 mSv per year in Australia.

It can be readily shown that the potential dose estimates to members of the general public from airborne discharges at LHSTC are only a very small fraction, less than 0.5%, of the radiation dose received by everyone each year from naturally occurring sources of radiation.

8.2 Low-Level Liquid Effluent

Low-level liquid effluent is chemically treated and analysed before controlled discharge to the Sydney Water 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 studies conducted by ANSTO at the CSTP and the Potter Point ocean outfall area in 1995 and 1996 determined the dilution effects on radionuclides contained in the treated effluent discharged by ANSTO to the sewer. Due to the low tritium concentrations in the offshore plume during the 1997 studies, the offshore dilution factors could not be determined, however modelling of the plume by Unisearch WRL confirmed previous measurements.

The levels of iodine-131 found in algae collected near the outfall, as well as tritium measured in the ocean a short distance from the outfall, are negligible. They do not pose any health risk to members of the public recreating in the ocean in the vicinity of the outfall or ingesting seafood from the area.

8.3 External Radiation

The levels of external gamma radiation were measured by thermoluminescent dosimeters located at private residences in Barden Ridge, Engadine and Woronora (see **Tables 18 & 18a**). The local absorbed doses in air were consistent with levels recorded in Australian capital cities (using similar dosimeters) in surveys carried out by the Australian Radiation Laboratory and reported by UNSCEAR (1993).

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

The highest levels of external gamma radiation at LHSTC were registered in the western sector of the perimeter fence. These locations are not readily accessible to the general public and, due to the lack of occupancy, any incremental dose resulting from proximity to the fence will be negligible. However, as indicated in **Section 5.10**, ANSTO has relocated the nuclear

material to a shielded storage facility to reduce the doses at these locations, and will undertake a comprehensive dose-rate survey of the area.

8.4 Little Forest Burial Ground

The environmental survey results for the LFBG show similar trends to past years.

Tritium was detected at higher concentrations in groundwater near the burial trenches, with low levels occurring in several monitoring bores inside the fenced area. All bores were below drinking water guideline levels for tritium, except MB16, which had a maximum of 10560 Bq/L.

Very low levels of cobalt-60 were detected in MB16, which is in the centre of the trenches. No other borewater contained fission-product radioactivity.

Gross alpha and gross beta activity in the bores were generally around the Australian Drinking Water guideline levels of 0.1 Bq/L for alpha, and 0.5 Bq/L for beta (following subtraction of naturally occurring potassium-40 as required by the protocol).

All of the groundwater monitoring bores outside the LFBG fenced area show background levels of radioactivity. Surface water sampled from Mill and Bardens Creeks also show only naturally-occurring radionuclides. The small amount of caesium-137 found in sediment from Mill Creek was associated with atmospheric nuclear weapons test fallout on the banks of the stream, and is comparable to background concentrations of fallout caesium-137 found in soils from Sydney and the Hunter Valley regions (Elliott et al, 1990).

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 non-radioactive wastes (disposed of by other agencies) in the areas adjacent to LFBG, makes the groundwater unsuitable for human consumption.

Sampling of airborne particulates at LFBG was resumed during the last quarter of the year, following the theft of equipment in 1996. The replacement equipment was a high-volume air sampler built to US-EPA specifications. No beryllium or plutonium was detected.

Based on these and previous surveys, it is concluded 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 near MB16 in the middle of the trenches. Radiation readings around the LFBG site boundary fence are all at background levels, confirming that possible doses to members of the public from external radiation can also be regarded as negligible.

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The Environmental Chemistry group (Environment Division) used ICPAES techniques to determine beryllium levels on the LFBG air filters.

Safety Division determined iodine-131 levels in air samples.

Safety Division supplied details of airborne effluent sampling and analysis procedures.

Dosimeter readings for external gamma radiation at LHSTC (**Tables 18 & 18a**) and airborne effluent release data (**Tables 19 & 23**) were supplied by Safety Division.

Liquid effluent release data (**Tables 21 & 22**) were supplied by Waste Management Section (Nuclear Technology Division).

10. REFERENCES/ BIBLIOGRAPHY

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

ANSTO Safety and Reliability Report. *Estimates of Doses from Routine Emissions of Radionuclides to Atmosphere from HIFAR during the Financial Years 1996/97 and 1997/98.* SD/SR/TN 98-7 Revision 1, August 1998.

Australian Radiation Laboratory (ARL), April 1990. *A Nation-Wide Survey of Radon and Gamma Radiation Levels in Australian Homes*. M.K. Langroo, K.N. Wise, J.C. Duggleby, L.H. Kotler. ARL/TR090, ISSN 0157-1400.

Clark, G.H. (June 1997) *An Updated Analysis of the Lucas Heights Climatology – 1975 to 1996.* ANSTO/E-731. Environment Division, Australian Nuclear Science & Technology Organisation.

Clark, G.H. (1998), Environment Division, Australian Nuclear Science & Technology Organisation. Personal communication.

Elliott, G.L, Campbell, B.L, Loughran, R.J. *Correlation of Erosion Measurements and Soil Caesium-137 Content.* Appl. Radiat. Isotopes, Vol.41(8), pp 713-17, 1990. Int. J. Radiat. Appl. Instrum. Part A. Pergamon Press. Great Britain.

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

Gordon Gilmore, John Hemingway, 1995. *Practical Gamma-Ray Spectrometry.* John Wiley & Sons, West Sussex, England.

Harries, J.R. and Calf, G.E. (1980). *Tritium Measurements in the Tasman Sea and the Southern Ocean.* Australian Journal of Marine and Freshwater Research. Vol 31, No.6, pp737-45.

Hoffmann, E.L., Loosz, T., (1994). *Environmental Survey at Lucas Heights Research Laboratories, 1992.* ANSTO/E-709. Australian Nuclear Science and Technology Organisation.

International Atomic Energy Agency, 1985. *Sediment K_ds and Concentration Factors for Radionuclides in the Marine Environment*, Technical Reports Series No.247, IAEA, Vienna.

International Atomic Energy Agency (IAEA), 1981. *Shallow Ground Disposal of Radioactive Wastes - A Guidebook.* Safety Series No. 53, Vienna.

International Basic Safety Standards (BSS) for Protection against Ionising Radiation and for the Safety of Radiation Sources (1996), jointly sponsored by the FAO, IAEA, ILO, OECD/NEA, PAHO and WHO. Safety Series No.115, Vienna.

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

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

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

International Organisation for Standardisation, (ISO). *Water Quality - Determination of tritium activity concentration - Liquid scintillation counting method.* ISO 9698:1989 (E). Geneva, Switzerland.

International Organisation for Standardisation, (ISO). *Water Quality - Measurement of gross alpha activity in non-saline water - Thick source method.* ISO 9696:1992 (E). Geneva, Switzerland.

International Organisation for Standardisation, (ISO). *Water Quality - Measurement of gross beta activity in non-saline water - Thick source method.* ISO 9697:1992 (E). Geneva, Switzerland.

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

National Health and Medical Research Council (NH&MRC), 1989. *Recommended Radiation Protection Standards for Individuals Exposed to Ionising Radiation*. Radiation Health Series No.27.

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

National Health and Medical Research Council Report 39. *Recommendations for Limiting Exposure to Ionising Radiation* and *National Standard for Limiting Occupational Exposure to Ionising Radiation*, 1995. Australian Government Publishing Service, Canberra, ACT.

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

National Radiological Protection Board (NRPB), 1991. *Committed Equivalent Organ Doses and Committed Effective Doses from Intakes of Radionuclides.* Part I, Chapter 4.3.3, Table 4.1. Report NRPB-R245, Chilton, UK.

Nigel Holmes and Associates (1991), *Air Quality Assessment, Lucas Heights Regional Depot.* Prepared for NSW Waste Services.

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

NSW Dairy Corporation. Registered dairies in Sydney, relative to LHSTC. Personal communication, John Carr, October 1998.

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

Radiation Control Regulation, 1993 under the *Radiation Control Act, 1990.* Government Gazette No.94, 27 August 1993. NSW Government Printery, Australia.

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

Standards Association of Australia (SAA), 1990. *Methods For Sampling And Analysis Of Ambient Air. Method 9.6: Determination Of Total Suspended Particulates (TSP) – High Volume Sampler Gravimetric Method.* AS 3580.9.3-1990, Sydney.

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

Sydney Water Corporation Pty Ltd. *Sydney Water Trade Waste Policy & Management Plan, August 1995.* Standards for Acceptance of Liquid Trade Wastes to Sewers.

Unisearch Ltd. Water Research Laboratory, University of NSW. *Potter Point Outfall Modelling, 27 May, 1997.* WRL Technical Report 97/17. Author: D.R. Cox.

United Nations Scientific Committee on the Effects of Atomic Radiation. *Sources and Effects of Ionising Radiation.* UNSCEAR 1993 Report to the General Assembly, with scientific annexes. United Nations, New York.

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

Wilson, A.R.W., 1959. *Safe Levels for the Discharge of Radioactive Effluent into the Woronora Estuary.* AAEC/K260. Australian Atomic Energy Commission.

World Health Organisation (WHO) 1993. *Guidelines for Drinking-Water Quality.* Volume 1 Recommendations, 2nd Edition, Geneva.

TABLE 1

ENVIRONMENTAL MONITORING SCHEDULE, 1997

SAMPLE	STATION	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Stormwater	**MDP+60m:** 60m down-stream of MDP BUND.	Weekly, plus monthly composite.	2 x 5 L sampled with polyethylene bottle.	250mL aliquot of the weekly sample distilled for tritium analysis. Weekly samples bulked into two monthly composites: 4 -5L for α,β analysis; 8 - 10L for γ. Remainder acidified & stored.
	Bund C: MDP	Weekly, plus monthly composite.	5 L sampled with polyethylene bottle.	250 mL of weekly sample distilled for tritium analysis. 1L from each weekly sample bulked into a 4-5 L monthly composite: 1L used for α,β analysis; 2L for γ. Remainder acidified & stored.
	Bunds: A & B	Monthly.	1 L sampled with polyethylene bottle.	Distilled for tritium analysis. Remainder acidified & stored.
Estuary water	**Woronora River**: station E5.9 at Jannali Park.	Monthly.	250 mL, sampled by polyethylene bottle at surface.	Distilled for tritium analysis.
Creek water	**Bardens Creek Weir.**	Weekly.	250 mL sampled from weir overflow.	Distilled for tritium analysis.
	SPCC points: Bardens Ck Weir; MDP Ck Weir; Strassman Ck.	Monthly.	3L sampled after rain.	Gross α,β analysis on 2L (ISO method). Remaining 1L acidified & stored.
	Forbes Creek.	Monthly.	1 L sampled after rain.	Distilled for tritium analysis. Remainder acidified & stored.
	Bardens and Mill Creeks: station T2 near confluence.	Yearly.	5 L water from each creek (above the junction of the two creeks).	Evaporated and counted for α,β,γ. 250 mL distilled for tritium analysis. Remainder acidified & stored.

Continued next page...

TABLE 1 Continued...

SAMPLE	STATION	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Ground water	**Little Forest Burial Ground.**	Twice yearly.	Bores are pumped dry & allowed to refill. 10L Sampled from the centre of the bore, avoiding the sediment.	Evaporated and counted for α,β,γ. 250 mL distilled for tritium analysis. Remainder acidified & stored.
	Sump near Bld 27	Monthly.	1 L ground water seepage collected with clean sponge.	Distilled for tritium analysis. Direct gamma spectrometry on 500mL in Marinelli beaker. Remainder acidified & stored.
Airborne particulates	**Little Forest Burial Ground** trench area.	Quarterly: particulates are accumulated for ~ 4 hours every 2 weeks over three months.	Airborne particulates collected on a filter paper using mobile *Ecotech* high-volume air sampler.	Each quarterly sample divided into four equal parts: one analysed for beryllium by ICPMS, another put aside for a yearly composite, analysed for $^{239/240}$Pu. The remaining two pieces are stored.
Ambient iodine-131 in air	**Stations 1,2,3,4** along the eastern boundary of site.	Continuous samples, changed weekly.	Collected on activated charcoal filters (Maypacks).	Gamma spectrometry of Maypacks.
Soil / sediment	**Stormwater bunds A, B & C.**	Yearly, or whenever bunds are emptied.	Bund is drained. ~2 kg sampled randomly from accumulated sediments.	Soils/sediments are dried, ashed and sieved, then counted for α,β,γ activity.
	Little Forest Burial Ground.	If indicated by annual dose rate survey.	1 kg, from surface.	As above.
	Effluent discharge pipeline.	If indicated by six-monthly dose rate survey.	1 kg, from surface.	As above.
	Bardens and Mill Creeks: Station T2.	Yearly.	From creek bed (above junction of the two creeks).	As above.

Continued next page...

TABLE 1 Continued...

SAMPLE	STATION	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Marine Biological Samples	**Potter Point Ocean Outfall**	Twice yearly.	Barnacles, algae & fish, near the outfall.	Gamma spectrometry of dried, homogenised samples.
	The Royal National Park.	Twice yearly.	Barnacles, algae & fish .	As above.
Gamma Dose Rate Survey	**Effluent discharge pipeline.**	Twice yearly.	Pipe joints and ground surveyed using Eberline PRM-7 dose-rate meter. Soil sampled if >3 times the background dose.	If collected, soils are sieved and ashed, then counted for α,β,γ activity.
	Little Forest Burial Ground.	Yearly.	Burial trenches are surveyed using a field dose-rate monitor. Soil is sampled if >3 times background.	As above.
External Gamma Radiation	**LHSTC perimeter:** 15 sites; **Local suburbs:** 3 sites.	Quarterly.	Two types of Thermoluminescent Dosimeter (TLD) badges, exposed to ambient gamma radiation.	Personal-type TLD's sent to ARL for analysis. Environmental TLD's analysed at ANSTO. Results reported as effective dose in mSv/year.

Note:
1. Sampling locations are shown on **Figure 1** through 7.

TABLE 2

TRITIUM IN WORONORA ESTUARY WATER
STATION E5.9, 1997

Date	Tritium Bq/L
7.1.97	< 70
4.2.97	< 100
4.3.97	< 100
1.4.97	< 20
6.5.97	< 20
3.6.97	< 10
1.7.97	< 10
5.8.97	< 10
2.9.97	< 10
7.10.97	< 10
5.11.97	< 10
9.12.97	< 20

Notes:

1. The Reference Activity Concentration for tritium in drinking water is 7800 Bq/L (WHO, 1993).
2. Values which are quoted as "less than" figures were below the stated minimum detectable activity (calculated with 95 % confidence).

TABLE 3

TRITIUM IN FORBES CREEK WATER SAMPLES, 1997

Date	Tritium (Bq/L)
21.1.97	< 60
18.2.97	< 100
19.3.97	< 20
8.4.97	< 20
6.5.97	< 20
3.6.97	< 10
1.7.97	< 10
5.8.97	< 10
9.9.97	< 10
5.11.97	< 10
9.12.97	< 20

Notes:

1. A "less than" value indicates that the result was below the minimum detectable activity (stated at the 95 % confidence level).

TABLE 4

RADIOACTIVITY IN **BLACKFISH** FROM POTTER POINT OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1997

Location	Date Sampled	Gamma Emitters in FISH [1] Bq/kg FW [2]			
		U&Th Series [3]	^{40}K	^{60}Co	^{137}Cs
POTTER POINT Ocean Outfall	6.6.97	-	150 ± 20	-	-
	"	-	160 ± 20	-	-
	28.10.97	-	150 ± 20	-	-
	"	-	150 ± 20	-	-
The Royal National Park Reference site	28.4.97	-	100 ± 10	-	-
	"	-	100 ± 10	-	-
	31.10.97	-	140 ± 20	-	-
	"	-	130 ± 10	-	-

Notes:

1. Fish were unwashed and filleted (de-boned) with scales & skin intact.
2. Refers to the radioactivity per kilogram of fresh (wet) sample.
3. Refers to the unquantified presence of decay products from either of the natural uranium-238 or thorium-232 decay series. Potassium-40 is also of natural origin.

TABLE 5

RADIOACTIVITY IN ALGAE FROM POTTER POINT
OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1997

Sampling Location	Date Sampled	Gamma Emitters in ALGAE [1] Bq/kg FW [2]					
		U&Th Series [3]	^{7}Be	^{40}K	^{60}Co	^{137}Cs	^{131}I
POTTER POINT Ocean Outfall	6.6.97	✓	8 ± 2	110 ± 10	-	-	360 ± 40
	"	✓	4 ± 2	140 ± 10	-	-	90 ± 10
	28.10.97	✓	21 ± 3	160 ± 20	-	-	28 ± 5
	"	✓	15 ± 2	160 ± 20	-	-	33 ± 5
The Royal National Park Reference site	22.4.97	✓	-	180 ± 20	-	-	-
	"	✓	-	180 ± 20	-	-	-

TABLE 6

RADIOACTIVITY IN BARNACLES FROM POTTER POINT
OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1997

Sampling Location	Date Sampled	Gamma Emitters in BARNACLES [1] Bq/kg FW [2]				
		U&Th Series [3]	^{7}Be	^{40}K	^{60}Co	^{137}Cs
POTTER POINT Ocean Outfall	6.6.97	✓	-	30 ± 10	-	-
	"	✓	-	30 ± 10	-	-
	28.10.97	-	-	35 ± 5	-	-
	"	✓	-	20 ± 5	-	-
The Royal National Park Reference site	22.4.97	-	-	30 ± 5	-	-
	"	-	-	20 ± 7	-	-
	31.10.97	-	-	30 ± 5	-	-
	"	-	-	20 ± 5	-	-

Notes for Tables 5 & 6:

1. Algae (*Enteromorpha sp., Cladophora sp.*) and barnacles (*Tesseropera rosea*) were analysed whole and unwashed.
2. Refers to the radioactivity per kilogram of fresh (wet) sample.
3. Refers to the unquantified presence of daughter products from either of the natural uranium-238 or thorium-232 decay series.
4. **U&Th series, ^{7}Be and ^{40}K** are all of natural origin.

TABLE 7a

TRITIUM IN MONTHLY WATER SAMPLES FROM STORMWATER BUNDS, 1997

Date	Tritium Bq/L	
	BUND A: Behind Building 1	BUND B: Opposite Meteorological Tower
28.1.97	< 100	360 ± 80
21.2.97	150 ± 40	270 ± 70
25.3.97	50 ± 10	190 ± 10
15.4.97	< 70	< 30
13.5.97	< 10	< 10
18.6.97	< 30	< 30
28.7.97	< 20	140 ± 20
19.8.97	< 10	60 ± 20
16.9.97	70 ± 20	180 ± 20
14.10.97	110 ± 10	110 ± 20
5.11.97	200 ± 20	70 ± 20
9.12.97	< 40	< 10

Notes:

1. Refer to **Figure 2** for the sampling point locations.
2. The WHO reference concentration for tritium in drinking water is 7800 Bq/L.
3. A "less-than" value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level).

TABLE 7b

TRITIUM IN WEEKLY WATER SAMPLES FROM MDP BUND C, 1997

Date	Tritium Bq/L	Date	Tritium Bq/L
1.4.97	150 ± 20	19.8.97	130 ± 10
8.4.97	130 ± 30	26.8.97	180 ± 20
15.4.97	110 ± 10	3.9.97	< 10
21.4.97	40 ± 10	9.9.97	330 ± 20
29.4.97	110 ± 20	16.9.97	160 ± 20
6.5.97	110 ± 20	23.9.97	160 ± 20
13.5.97	150 ± 10	30.9.97	150 ± 10
20.5.97	110 ± 20	7.10.97	< 40
27.5.97	190 ± 10	14.10.97	160 ± 20
3.6.97	130 ± 50	21.10.97	< 50
10.6.97	290 ± 10	29.10.97	110 ± 10
17.6.97	110 ± 10	4.11.97	50 ± 10
24.6.97	100 ± 10	11.11.97	460 ± 40
2.7.97	120 ± 20	18.11.97	140 ± 20
8.7.97	190 ± 10	25.11.97	110 ± 10
15.7.97	120 ± 10	2.12.97	630 ± 10
22.7.97	180 ± 20	9.12.97	60 ± 20
28.7.97	90 ± 10	16.12.97	160 ± 10
5.8.97	150 ± 20	23.12.97	140 ± 20
12.8.97	300 ± 40	30.12.97	< 30

Notes:

1. Refer to **Figure 2** for the location of this sampling point.
2. The average tritium level during 1997 was below 155 Bq/L, which is less than 2% of the WHO reference activity (7800 Bq/L).
3. The weekly water samples from MDP Bund C were combined into monthly composite samples and analysed for gross alpha/beta and gamma activity. See **Table 7c** for these results.
4. A "less-than" value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level).

TABLE 7c

RADIOACTIVITY IN MONTHLY COMPOSITE
WATER SAMPLES FROM MDP BUND C, 1997

Monthly Composite	RADIOACTIVITY (Bq/L)			
	Gross α	Gross β	Gamma emitters	
			^{137}Cs	^{40}K
April	< 0.03	1.26 ± 0.02	-	< 0.40
May	< 0.03	1.54 ± 0.03	-	< 0.40
June	0.04 ± 0.01	1.23 ± 0.03	0.06 ± 0.02	< 0.40
July	0.06 ± 0.02	0.86 ± 0.02	-	< 0.40
August	0.04 ± 0.01	1.04 ± 0.02	-	< 0.40
September	0.04 ± 0.01	1.11 ± 0.02	-	< 0.30
October	0.03 ± 0.01	0.65 ± 0.01	-	< 0.50
November	0.04 ± 0.01	0.72 ± 0.02	0.03 ± 0.01	< 0.50
December	0.03 ± 0.01	0.74 ± 0.02	-	< 0.50

Notes:

1. From April 1997, the MDP Bund C was sampled weekly for tritium (see **Table 7b**) and the remainder of the weekly samples combined to make a monthly composite water sample for gross alpha, beta and gamma analysis.
2. The gross beta results include the contribution from potassium-40 (a natural beta-gamma emitter).
3. A "less than" value indicates that the result was below the minimum detectable activity (stated at the 95 % confidence level).
4. The average concentration of ^{137}Cs in 1997 was 0.01 Bq/L, which is 0.1 % of the WHO reference value for ^{137}Cs in drinking water (10.5 Bq/L), see **Section 3.1.2.**
5. The NSW Clean Water Regulations (1972) specify limits for radioactivity in class C waters as follows: gross α 1.1 Bq/L ; gross β 11.1 Bq/L.

TABLE 8

RADIOACTIVITY IN SEDIMENT FROM STORMWATER BUNDS, 1997

Bund Location	Date	RADIOACTIVITY in SEDIMENT (Bq/g DW) [1]	
		Gamma emitters	^{40}K
BUND A: Behind Building 1	30.5.97	U & Th Series ^{7}Be 0.081 ± 0.008 ^{137}Cs 0.005 ± 0.001	0.23 ± 0.02
BUND B: Opposite Meteorological Tower	30.5.97	U & Th Series ^{7}Be 0.051 ± 0.005 ^{60}Co 0.005 ± 0.001	0.10 ± 0.01
BUND C: MDP Stormwater Outlet No.1	30.5.97	U & Th Series ^{7}Be 0.040 ± 0.010 ^{137}Cs 0.130 ± 0.010 ^{134}Cs 0.006 ± 0.001 ^{60}Co 0.007 ± 0.001 ^{144}Ce 0.060 ± 0.010 ^{241}Am 0.006 ± 0.001	0.25 ± 0.03

Notes:
1. Refers to the radioactivity per gram of dry weight.
2. See **Figure 2** for the location of the stormwater bunds.

TABLE 9a

TRITIUM IN WEEKLY WATER SAMPLES FROM
MDP + 60m, 1997

Date	Tritium Bq/L	Date	Tritium Bq/L
7.1.97	400 ± 40	26.8.97	190 ± 20
15.1.97	200 ± 40	2.9.97	< 10
21.1.97	400 ± 40	9.9.97	210 ± 20
28.1.97	240 ± 40	16.9.97	160 ± 10
4.2.97	330 ± 70	23.9.97	170 ± 30
11.2.97	< 100	30.9.97	160 ± 20
18.2.97	160 ± 40	7.10.97	< 60
25.2.97	410 ± 50	14.10.97	170 ± 30
4.3.97	180 ± 30	21.10.97	100 ± 20
12.3.97	190 ± 30	29.10.97	120 ± 10
18.3.97	220 ± 10	4.11.97	140 ± 10
25.3.97	180 ± 20	11.11.97	240 ± 10
2.7.97	70 ± 20	18.11.97	190 ± 20
8.7.97	190 ± 20	25.11.97	160 ± 20
15.7.97	120 ± 20	2.12.97	160 ± 10
22.7.97	180 ± 20	9.12.97	40 ± 10
28.7.97	160 ± 10	16.12.97	170 ± 20
5.8.97	70 ± 20	23.12.97	110 ± 20
12.8.97	200 ± 20	30.12.97	120 ± 20
19.8.97	190 ± 20		

Notes:

1. Refer to **Figure 2** for the location of this sampling point, 60m downstream of Stormwater Outlet No.1 on MDP Creek.
2. Sampling at MDP+60m ceased from April-June in favour of the upstream MDP Bund sampling point, but was reinstated in July due to the long history of continuous sampling at this location.
3. A "less-than" value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level).
4. The average tritium level during 1997 was 180 Bq/L, representing 2 % of the WHO reference concentration for tritium in drinking water (7800 Bq/L).
5. The weekly water samples above are also combined into monthly composite samples and analysed for gross alpha/beta and gamma activity. See **Table 9b** for these results.

TABLE 9b

RADIOACTIVITY IN MONTHLY COMPOSITE
WATER SAMPLES FROM MDP+60m, 1997

Monthly Composite[1]	RADIOACTIVITY (Bq/L)			
	Gross α	Gross β [2]	Gamma emitters	
			^{137}Cs [3]	^{40}K
January	< 0.02	0.66 ± 0.01	-	< 0.50
February	0.03 ± 0.01	0.50 ± 0.01	-	< 0.40
March	< 0.02	0.71 ± 0.02	0.050 ± 0.010	< 0.70
April [4]	-	-	-	-
May	-	-	-	-
June	-	-	-	-
July	< 0.03	0.72 ± 0.02	0.020 ± 0.004	0.22 ± 0.04
August	0.03 ± 0.01	0.49 ± 0.01	0.016 ± 0.003	< 0.10
September	0.04 ± 0.01	0.51 ± 0.01	0.007 ± 0.003	< 0.10
October	0.03 ± 0.01	0.57 ± 0.01	0.034 ± 0.004	0.13 ± 0.04
November	< 0.03	0.46 ± 0.02	0.023 ± 0.004	< 0.10
December	0.04 ± 0.01	0.58 ± 0.01	0.033 ± 0.004	^{40}K 0.09 ± 0.04 ^{7}Be 0.25 ± 0.03

Notes:

1. This location was sampled weekly for tritium (see **Table 9a**). The remainding weekly samples were bulked into the monthly composite water sample for gross alpha, beta and gamma analyses.
2. The gross beta results include the contribution from potassium-40 (a natural beta-gamma emitter).
3. A "less than" value indicates that the result was below the minimum detectable activity (stated with 95 % confidence).
4. The average ^{137}Cs level in 1997 was below 0.02 Bq/L, which is less than 0.2% of the WHO reference value for ^{137}Cs in drinking water (10.5 Bq/L), see **Section 3.1.2**.
5. Sampling at MDP+60m ceased from April-June in favour of the upstream MDP Bund sampling point, but was reinstated in July due to the long history of continuous sampling at this location.
6. The NSW Clean Water 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 10

RADIOACTIVITY IN WATER FROM SPCC SAMPLING POINTS, 1997

Date	RADIOACTIVITY (Bq/L)					
	Strassman Creek		**Bardens Creek Weir**		**MDP Creek Weir**	
	Gross α	Gross β	Gross α	Gross β	Gross α	Gross β
31.1.97	< 0.03	0.07 ± 0.01	< 0.02	0.06 ± 0.01	< 0.02	0.43 ± 0.01
21.2.97	< 0.03	0.06 ± 0.01	< 0.03	0.08 ± 0.01	< 0.02	0.44 ± 0.01
25.3.97	< 0.03	0.06 ± 0.01	< 0.03	0.07 ± 0.01	< 0.03	0.39 ± 0.01
21.4.97	< 0.03	0.06 ± 0.01	< 0.02	0.08 ± 0.01	< 0.02	0.54 ± 0.01
27.5.97	< 0.03	0.05 ± 0.01	< 0.03	0.07 ± 0.01	< 0.02	0.42 ± 0.01
30.6.97	0.04 ± 0.02	0.07 ± 0.01	< 0.02	0.06 ± 0.01	0.04 ± 0.02	0.46 ± 0.01
30.7.97	< 0.02	0.04 ± 0.01	< 0.03	0.05 ± 0.01	< 0.02	0.45 ± 0.01
27.8.97	0.04 ± 0.01	0.07 ± 0.01	< 0.03	0.07 ± 0.01	0.04 ± 0.01	0.47 ± 0.01
16.9.97	0.03 ± 0.01	0.06 ± 0.01	0.04 ± 0.01	0.08 ± 0.01	< 0.03	0.50 ± 0.01
29.10.97	< 0.02	0.06 ± 0.01	< 0.02	0.06 ± 0.01	< 0.01	0.51 ± 0.01
5.11.97	< 0.02	0.06 ± 0.01	< 0.02	0.07 ± 0.01	< 0.03	0.52 ± 0.01
11.12.97	< 0.03	0.09 ± 0.01	< 0.03	0.07 ± 0.01	< 0.03	0.42 ± 0.01
AVERAGE	< 0.03	0.06	< 0.03	0.07	< 0.03	0.46

Notes:

1. See **Figure 2** for the location of the SPCC sampling points.
2. Values which are quoted as "less than" figures were below the stated minimum detectable activity (calculated with 95 % confidence).
3. All gross beta results include the contribution from natural potassium-40 (a beta-gamma emitter).
4. The NSW Clean Waters Regulations (1972) specify limits for radioactivity in class C waters as follows: gross alpha: 1.1 Bq/L gross beta: 11.1 Bq/L.
5. Samples were analysed using the international standard methods for gross alpha and gross beta determinations in waters: ISO 9696 & 9697.

TABLE 11

TRITIUM IN WATER FROM BARDENS CREEK WEIR
(at SPCC sampling point), 1997

Date	Tritium Bq/L	Date	Tritium Bq/L
7.1.97	< 70	8.7.97	40 ± 10
15.1.97	< 60	15.7.97	80 ± 10
21.1.97	< 60	22.7.97	< 40
28.1.97	< 100	28.7.97	30 ± 10
4.2.97	< 100	5.8.97	50 ± 20
11.2.97	< 100	12.8.97	< 30
18.2.97	< 100	19.8.97	50 ± 20
25.2.97	220 ± 30	26.8.97	< 30
4.3.97	< 100	3.9.97	< 50
12.3.97	40 ± 10	9.9.97	100 ± 10
18.3.97	< 60	16.9.97	< 30
25.3.97	50 ± 20	23.9.97	30 ± 10
1.4.97	40 ± 10	30.9.97	40 ± 10
8.4.97	< 30	7.10.97	30 ± 10
15.4.97	< 50	14.10.97	40 ± 10
21.4.97	30 ± 10	21.10.97	< 30
29.4.97	< 30	29.10.97	< 30
6.5.97	30 ± 10	5.11.97	100 ± 20
13.5.97	100 ± 20	11.11.97	60 ± 20
20.5.97	< 50	18.11.97	30 ± 10
27.5.97	60 ± 10	25.11.97	< 20
3.6.97	40 ± 10	2.12.97	< 20
10.6.97	40 ± 10	9.12.97	60 ± 20
17.6.97	40 ± 10	16.12.97	80 ± 20
24.6.97	30 ± 10	23.12.97	30 ± 10
2.7.97	50 ± 10	30.12.97	30 ± 10

Notes:

1. The average weekly tritium concentration at Bardens creek weir during 1997 was less than 55 Bq/L, which is <1% of the WHO drinking water reference activity concentration.
2. Values which are quoted as "less than" figures were below the stated minimum detectable activity (calculated with 95 % confidence).

TABLE 12

GAMMA SURVEY - EFFLUENT DISCHARGE PIPELINE, 1997

Date	Location [1]	Dose Rate (μSv/hour) [2]		Background Dose Range (μSv/hour)
		Ground Below Joint	Pipe Joint	
30.4.97	Joints #1-22	0.05 - 0.07	0.05 - 0.09	0.04 - 0.09
30.9.97	Joints #1-22	0.05 – 0.07	0.05 - 0.09	0.05 – 0.07

Notes:
1. Excluding joints #18 & 19 which are inaccessible.
2. Survey of exposed portions of pipeline between LHSTC and the Sydney Water sewer connection, using a calibrated Eberline PRM-7 dose-rate meter.

TABLE 13

GAMMA SURVEY - BURIAL TRENCHES
LITTLE FOREST BURIAL GROUND, 1997

Date	Location	Dose Range (μSv/hour)
2 October 1997	Background reading (outside LFBG fence)	0.08 – 0.10
	Readings over all trenches	0.05 – 0.10
	Point #5	0.05 – 0.10
	Point #6	0.15 – 0.20

Notes:
1. See **Figure 3** for the location of the waste burial trenches and sampling points at LFBG.
2. The survey was performed using a calibrated Eberline PRM-7 dose rate meter.

TABLE 14

RADIOACTIVITY IN GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1997

Bore	Date Sampled	RADIOACTIVITY Bq /L				
		^{3}H	Gross α	Gross β	Gamma Emitters	
					^{60}Co	^{40}K
BHF	12.6.97	380 ± 10	0.06 ± 0.04	0.16 ± 0.02		< 0.45
BH10	5.6.97	4240 ± 40	0.17 ± 0.11	0.26 ± 0.06		< 0.48
OS2	5.6.97	1110 ± 40	0.09 ± 0.02	0.12 ± 0.01		< 0.74
OS3	5.6.97	3260 ± 20	0.10 ± 0.03	0.55 ± 0.02		< 0.56
MB11	5.6.97	< 30	< 0.10	0.10 ± 0.03		< 0.80
MB12	5.6.97	30 ± 10	< 0.10	0.05 ± 0.02		0.75 ± 0.30
MB13	5.6.97	3460 ± 70	< 0.05	0.08 ± 0.02		< 0.60
MB14	5.6.97	50 ± 10	< 0.13	0.17 ± 0.03		0.68 ± 0.32
MB15	5.6.97	< 40	< 0.09	0.11 ± 0.02		< 0.80
MB16	5.6.97	9930 ± 100	0.16 ± 0.03	0.37 ± 0.02	0.20 ± 0.02	< 0.43
MB17	5.6.97	1650 ± 20	0.07 ± 0.03	0.08 ± 0.02		< 0.45
MB18	5.6.97	90 ± 10	< 0.07	0.14 ± 0.02		< 0.45
MB19	12.6.97	80 ± 10	< 0.42	0.67 ± 0.13		1.34 ± 0.37
MB20	12.6.97	< 30	0.17 ± 0.06	0.31 ± 0.03		< 0.46
MB21	12.6.97	80 ± 10	< 0.28	0.14 ± 0.05		< 0.44
BHF	4.11.97	250 ± 20	0.07 ± 0.02	0.16 ± 0.02		< 0.23
BH10	4.11.97	870 ± 10	0.09 ± 0.03	0.09 ± 0.02		< 0.15
OS2	4.11.97	1300 ± 40	0.07 ± 0.01	0.13 ± 0.01		< 0.22
OS3	4.11.97	3380 ± 20	0.10 ± 0.02	0.36 ± 0.02		< 0.23
MB11	4.11.97	< 10	< 0.05	0.04 ± 0.01		< 0.22
MB12	4.11.97	< 20	< 0.04	< 0.02		< 0.25
MB13	4.11.97	2200 ± 40	< 0.03	0.11 ± 0.01		< 0.20
MB14	4.11.97	< 40	< 0.08	0.09 ± 0.03		< 0.19
MB15	4.11.97	< 20	< 0.04	0.05 ± 0.01		< 0.23
MB16	4.11.97	10560 ± 50	0.13 ± 0.02	0.37 ± 0.01	0.25 ± 0.03	< 0.17
MB17	4.11.97	1110 ± 30	< 0.06	0.06 ± 0.01		< 0.24
MB18	4.11.97	70 ± 10	< 0.13	0.16 ± 0.04		< 0.22
MB19	4.11.97	40 ± 10	< 0.24	0.33 ± 0.10		0.27 ± 0.10
MB20	4.11.97	< 20	0.08 ± 0.03	0.19 ± 0.03		0.23 ± 0.09
MB21	4.11.97	30 ± 10	< 0.13	< 0.23		0.33 ± 0.09

Notes:

1. See **Figure 3** for the location of the sampling bores.
2. A "less than" value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level).
3. The WHO guideline value for tritium in drinking water is 7800 Bq/L.
4. Gross beta results include the contribution from natural potassium-40.
5. Australian Drinking Water Guideline levels for radioactivity are: gross alpha < 0.1 Bq/L
   gross beta < 0.5 Bq/L.
6. ^{60}Co in MB16 was <1 % of the WHO reference concentration for ^{60}Co in drinking water.
7. Shading indicates those bores which are outside the fenced area of the LFBG.

TABLE 15

RADIOACTIVITY IN CREEKS RECEIVING RUNOFF FROM THE LITTLE FOREST BURIAL GROUND AREA, 1997

Sample Location	Date	RADIOACTIVITY in SEDIMENT (Bq/g DW)			
		Gross α	Gross β	γ-emitters	
Mill Creek	20.10.97	1.30	0.66	^{40}K 0.30 ± 0.03 ^{137}Cs 0.019 ± 0.002	
Bardens Creek	20.10.97	0.92	0.09	^{40}K 0.04 ± 0.01	
		RADIOACTIVITY in WATER (Bq/L)			
		Gross α	Gross β	γ-emitters	Tritium
Mill Creek	20.10.97	0.05 ± 0.01	0.14 ± 0.01	^{40}K 0.27 ± 0.17	< 10
Bardens Creek	20.10.97	0.03 ± 0.01	0.11 ± 0.01	^{40}K 0.55 ± 0.13	< 10

Notes:

1. See **Figure 1** for the location of these sampling points.
2. The creeks were each sampled approximately 20m upstream from their confluence.

TABLE 16

PARTICULATES IN AIR AT LITTLE FOREST BURIAL GROUND, 1997

Sampling Period [1]	Average Windspeed m s^{-1}	Equivalent Volume m^3	Beryllium		$^{239/240}$ Plutonium	
			μg (total)	μg m^{-3}	Bq	Bq m^{-3}
Oct – Dec	4.4	358.8	< 0.060	< 1.7 x 10^{-4}	< 0.0001	< 2.8 x 10^{-7}

Notes:

1. The average windspeed was averaged from readings taken at the LHSTC meteorological tower, 10m above ground.
2. Samples were collected using a mobile Ecotech high-volume air sampler (USEPA approved).
3. Airborne particulate samples were periodically accumulated on a large filter over a period of 3 months. The sampling duration and frequency was approximately 4 hours, every 2 weeks. The filter was divided into four equal parts: one used per Be & Pu analysis, two are retained as duplicates.
4. The Equivalent Volume is 25% of the total volume of air sampled, since one-quarter of the filter is used for each analysis.

TABLE 17

AMBIENT IODINE-131 IN AIR, 1997

Sampled during the week ending :	Iodine-131 Air Concentration Bq / m^3	Sampled during the week ending :	Iodine-131 Air Concentration Bq / m^3
7.1.97	< 0.0025	15.7.97	0.004
15.1.97	< 0.0025	22.7.97	< 0.0025
21.1.97	< 0.0025	28.7.97	< 0.0025
28.1.97	< 0.0025	5.8.97	< 0.0025
4.2.97	< 0.0025	12.9.97	< 0.0025
11.2.97	< 0.0025	19.8.97	< 0.0025
18.2.97	< 0.0025	26.8.97	< 0.0025
25.2.97	< 0.0025	2.9.97	< 0.0025
4.3.97	0.005	9.9.97	0.003
11.3.97	< 0.0025	16.9.97	< 0.0025
18.3.97	< 0.0025	23.9.97	< 0.0025
25.3.97	< 0.0025	30.9.97	< 0.0025
1.4.97	< 0.0025	7.10.97	< 0.0025
8.4.97	< 0.0025	14.10.97	0.007
15.4.97	< 0.0025	21.10.97	< 0.0025
21.4.97	< 0.0025	29.10.97	< 0.0025
29.4.97	< 0.0025	4.11.97	< 0.0025
6.5.97	< 0.0025	11.11.97	< 0.0025
13.5.97	< 0.0025	18.11.97	< 0.0025
20.5.97	< 0.0025	25.11.97	< 0.0025
27.5.97	< 0.0025	2.12.97	< 0.0025
3.6.97	< 0.0025	9.12.97	< 0.0025
10.6.97	0.007	16.12.97	< 0.0025
17.6.97	< 0.0025	23.12.97	0.005
24.6.97	< 0.0025	30.12.97	< 0.0025
1.7.97	< 0.0025		
8.7.97	< 0.0025		

Notes:

1. 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:
   (a) all iodine-131 activity was released during the first day of the 7 day sampling period;
   (b) all the activity was concentrated at one sampling point.
2. A person with continuous exposure to iodine-131 at the detectable concentration of 0.0025 Bq/m^3 would receive an effective dose of less than 0.01 mSv per year (IAEA, 1994).

TABLE 18

EXTERNAL GAMMA RADIATION AT LHSTC,
(ARL Dosimeter Results), 1994 to 1997

	Dosimeter Location: on-site	Effective Dose (mSv / year)[1]			
		1994	1995	1996	1997
1	Hifar fence - south east	1.0 ± 0.1	1.2 ± 0.3	0.8 ± 0.3	0.9 ± 0.4
2	Hifar fence - south	2.2 ± 0.4	2.4 ± 0.5	2.2 ± 0.3	3.3 ± 0.5
3	Perimeter fence - west	1.2 ± 0.2	1.4 ± 0.3	1.0 ± 0.4	1.2 ± 0.5
4	Hifar fence - west	1.5 ± 0.7	1.5 ± 0.5	2.1 ± 0.3	1.5 ± 0.6
5	Hifar fence - north west	1.4 ± 0.7	1.2 ± 0.4	3.0 ± 0.5	1.2 ± 0.5
6	Perimeter fence - north A	0.9 ± 0.3	1.0 ± 0.4	0.8 ± 0.3	0.9 ± 0.4
7	Internal fence - north	0.9 ± 0.3	1.1 ± 0.5	0.8 ± 0.3	1.1 ± 0.4
8	Perimeter fence - north B	0.9 ± 0.2	1.2 ± 0.7	0.7 ± 0.3	1.0 ± 0.4
9	Perimeter fence - north east	0.9 ± 0.2	1.0 ± 0.4	0.7 ± 0.3	0.8 ± 0.3
10	Perimeter fence - east	1.0 ± 0.3	1.2 ± 0.3	0.7 ± 0.3	0.9 ± 0.4
11	Perimeter fence - south east	1.0 ± 0.3	1.0 ± 0.3	0.5 ± 0.2	0.9 ± 0.3
12	Corner of Curie and Roentgen St	1.2 ± 0.4	1.2 ± 0.5	0.8 ± 0.3	1.2 ± 0.5
13	Perimeter fence - south	0.8 ± 0.2	0.9 ± 0.4	0.6 ± 0.2	0.7 ± 0.3
14	Hifar fence - east	1.0 ± 0.2	1.1 ± 0.4	0.8 ± 0.3	1.0 ± 0.4
15	Hifar fence - north east	1.1 ± 0.3	1.2 ± 0.4	0.9 ± 0.4	1.1 ± 0.5
	Dosimeter Location: off-site				
16	Private house - Lucas Heights	0.9 ± 0.2	0.9 ± 0.3	0.7 ± 0.3	0.8 ± 0.3
17	Private house - Engadine	0.8 ± 0.1	1.0 ± 0.4	0.8 ± 0.3	1.1 ± 0.4
18	Private house - Woronora	0.9 ± 0.2	1.1 ± 0.5	0.7 ± 0.3	0.9 ± 0.4

Notes:

1. The data were reported as absorbed dose to air (mGy) and converted to effective dose for adults (mSv) using a conservative conversion factor of 1. UNSCEAR (1993) uses a factor of 0.72 Sv per Gy for adults, 0.80 for children and 0.93 for infants.
2. Refer to **Figure 6** for the location of dosimeters 1 to 15.
3. The ARL dosimeters are the same as those usually used for personal monitoring, consisting of calcium sulphate thermoluminescent material with three filtered areas and an open window. The ANSTO environmental dosimeters contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters.
4. The uncertainties (at the 95% confidence level) have been estimated from the standard deviation of the results for several dosimeters placed at the same location

TABLE 18a

EXTERNAL GAMMA RADIATION AT LHSTC,
Comparison of ARL and ANSTO Dosimeter Results, 1997

	Dosimeter Location: on-site	1997 Effective Dose (mSv / year)[1]	
		ARL TLD'S	ANSTO TLD'S
1	Hifar fence - south east	0.9 ± 0.4	1.1 ± 0.1
2	Hifar fence - south	3.3 ± 0.5	3.4 ± 0.2
3	Perimeter fence - west	1.2 ± 0.5	1.2 ± 0.1
4	Hifar fence - west	1.5 ± 0.6	1.5 ± 0.1
5	Hifar fence - north west	1.2 ± 0.5	1.2 ± 0.1
6	Perimeter fence - north A	0.9 ± 0.4	1.0 ± 0.1
7	Internal fence - north	1.1 ± 0.4	1.0 ± 0.1
8	Perimeter fence - north B	1.0 ± 0.4	1.0 ± 0.1
9	Perimeter fence - north east	0.8 ± 0.3	0.9 ± 0.1
10	Perimeter fence - east	0.9 ± 0.4	1.0 ± 0.1
11	Perimeter fence - south east	0.9 ± 0.3	0.9 ± 0.1
12	Corner of Curie and Roentgen St	1.2 ± 0.5	1.1 ± 0.1
13	Perimeter fence - south	0.7 ± 0.3	0.8 ± 0.1
14	Hifar fence - east	1.0 ± 0.4	1.1 ± 0.1
15	Hifar fence - north east	1.1 ± 0.5	1.2 ± 0.1
	Dosimeter Location: off-site		
16	Private house - Lucas Heights	0.8 ± 0.3	0.8 ± 0.1
17	Private house - Engadine	1.1 ± 0.4	1.3 ± 0.1
18	Private house - Woronora	0.9 ± 0.4	0.9 ± 0.1

Notes:

1. The data were reported as absorbed dose to air (mGy) and converted to effective dose for adults (mSv) using a conservative conversion factor of 1. UNSCEAR (1993) uses a factor of 0.72 Sv per Gy for adults, 0.80 for children and 0.93 for infants.
2. Refer to **Figure 6** for the location of thermoluminsecent dosimeters (TLD's) 1 to 15.
3. The ARL dosimeters are the same as those usually used for personal monitoring, consisting of calcium sulphate thermoluminescent material with three filtered areas and an open window. The ANSTO environmental dosimeters contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters.
4. The uncertainties (at the 95% confidence level) have been estimated from the standard deviation of the results for several dosimeters placed at the same location

TABLE 19

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS, 1997

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) 1997						
Bld 54 (hotcells)	4	4212	0.14	-	155	31 196
15A (HIFAR)	1	3	0.33	855	42	101
19	1	ND	0.02	-	-	ND
23A	6	4442	0.87	-	-	-
23B	1.2	1.2	0.02	-	-	-
41	21	14	0.14	-	-	-
3	7	1	0.08	-	-	-
56	7	4	0.25	-	-	-
57	1	1	0.04	160	-	-
20	10	2	0.44	8	-	-
21A	1	0	0.03	-	-	-
21B	0.14	0.09	ND	-	-	-
2nd Quarter (Apr - Jun) 1997						
Bld 54 (hotcells)	5	4 455	0.16	-	209	25 491
15A (HIFAR)	1	3	0.55	903	39	66
19	1	ND	0.02	-	-	ND
23A	7	6 919	0.73	-	-	-
23B	1	4	0.03	-	-	-
41	2	58	0.15	-	-	-
3	5	2	0.08	-	-	-
56	8	6	0.28	-	-	-
57	1	1	0.05	22	-	-
20	7	8	0.01	9	-	-
21A	1	0.55	0.03	-	-	-
21B	0.17	0.12	0.01	-	-	-

Continued next page...

TABLE 19 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) 1997						
Bld 54 (hotcells)	ND	3 272	ND	-	145	15 831
15A (HIFAR)	ND	4	0.18	1 144	47	65
19	-	-	-	-	-	-
23A	ND	6 697	0.43	-	-	-
23B	ND	2	ND	-	-	-
41	ND	17	ND	-	-	-
3	3	1.89	ND	-	-	-
56	ND	8	ND	-	-	-
57	ND	1.26	ND	3	-	-
20	3	6	0.13	6	-	-
21A	ND	0.77	ND	-	-	-
21B	ND	0.10	ND	-	-	-
4th Quarter (Oct - Dec) 1997						
Bld 54 (hotcells)	ND	2 942	ND	-	141	17 568
15A (HIFAR)	ND	3	0.48	985	35	78
19	-	ND	-	-	-	-
23A	ND	8 230	8.24	-	-	-
23B	ND	4.42	ND	-	-	-
41	ND	10	ND	-	-	-
3	2	2	ND	-	-	-
56	ND	6	ND	-	-	-
57	ND	1	ND	223	-	-
20	0.40	162	0.10	26	-	-
21A	ND	1	ND	-	-	-
21B	ND	0.12	ND	-	-	-

Notes:

1. See **Figure 4** for the location of the discharge stacks.
2. See **Appendix B** for a list of the different types of airborne discharges and their origins.
3. "Noble Gases" emitted from Bld 54 stack are short-lived radioactive isotopes of Xenon and Krypton from Tc-99 production. HIFAR emits mainly Argon-41 produced by the neutron activation of air inside the reactor irradiation facilities.
4. "ND" indicates that the radioactivity was not detected.

TABLE 20

RADIOACTIVITY IN GROUNDWATER
FROM THE VICINITY OF BUILDING 27, 1997

Date Sampled	RADIOACTIVITY (Bq/L)	
	Gamma-emitters	Tritium
21.1.97	^{40}K < 1.4	530 ± 80
19.2.97	^{40}K < 2.5	300 ± 100
18.3.97	^{40}K < 2.4	280 ± 30
15.4.97	^{40}K 2.2 ± 0.7	390 ± 20
13.5.97	^{40}K 2.1 ± 0.7	360 ± 30
18.6.97	^{40}K < 2.4	450 ± 10
15.7.97	^{40}K < 2.0	290 ± 20
26.8.97	^{40}K < 1.6	390 ± 20
30.9.97	^{40}K < 2.0	290 ± 20
22.10.97	^{40}K < 2.0	300 ± 20
12.11.97	^{40}K < 2.4	370 ± 20
15.12.97	^{40}K < 2.4	450 ± 30

Notes:

1. Building 27 is the intermediate waste and spent fuel storage facility.
2. Gamma spectrometry was performed on 500 mL acidified groundwater in a Marinelli beaker.
3. The average tritium levels in groundwater near building 27 in 1997 were below 370 Bq/L, less than 5% of the WHO reference concentration for tritium in drinking water (7800 Bq/L).
4. Results quoted as "less than" figures were below the minimum detectable activity (stated with 95 % confidence).

TABLE 21

RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED TO THE SYDNEY WATER SEWER, 1997

MONTH	TOTAL VOLUME Discharged m^3	AVERAGE CONCENTRATION IN DISCHARGES			Average MONTHLY Concentration QUOTIENT [3]	
		ALPHA [1] Bq/m^3	BETA [2] Bq/m^3	TRITIUM Bq/m^3	Former 1959 Radioactive Substances Regulations	WHO Guidelines for Drinking Water
January	6835	4.31×10^2	2.79×10^4	6.10×10^6	0.32	0.30
February	7938	5.18×10^2	4.11×10^4	2.38×10^6	0.46	0.39
March	5498	5.05×10^2	4.12×10^4	4.73×10^6	0.46	0.40
April	5150	3.37×10^2	3.45×10^4	1.90×10^6	0.68	0.62
May	5198	1.12×10^2	3.14×10^4	3.86×10^6	0.43	0.38
June	8254	1.14×10^3	1.83×10^4	3.85×10^6	0.30	0.28
July	9239	5.97×10^3	1.09×10^4	1.33×10^6	0.71	0.69
August	6581	4.03×10^3	2.42×10^4	2.35×10^6	0.65	0.61
September	9397	1.26×10^3	3.39×10^4	1.56×10^6	0.47	0.41
October	9305	6.15×10^2	1.77×10^4	2.52×10^6	0.24	0.22
November	4346	9.83×10^2	3.97×10^4	2.80×10^6	0.47	0.43
December	5438	1.99×10^3	4.98×10^4	2.33×10^7	0.76	0.72
Average	6932	1.49×10^3	3.09×10^4	4.72×10^6	0.50	0.46
Maximum Permissible Concentration (Former 1959 Radioactive Substances Regulations)	-	1.0×10^4 (as ^{226}Ra)	1.0×10^5 (as ^{90}Sr)	4.0×10^9	1.00	-
Activity Concentration Equivalent at ANSTO (WHO Guidelines for Drinking Water)	-	1.25×10^4 (as ^{226}Ra)	1.25×10^5 (as ^{90}Sr)	1.95×10^8	-	1.00

Notes:

1. A mixture of unidentified alpha-emitting nuclides, assumed to be all radium-226 (ie. the worst possible case) when calculating the concentration quotient.
2. A mixture of unidentified beta-emitting nuclides, assumed to be all strontium-90 (ie. the worst possible case) when calculating the concentration quotient.
3. Concentration Quotient: the sum of the average monthly concentrations of a, b and tritium radioactivity in the liquid effluent divided by the Maximum Permissible Concentration (MPC) or Activity Concentration Equivalent for that radionuclide. The relevant quotient term must be no greater than one (unity) to comply with the requirements of the former NSW Radioactive Substances Regulations (1959) or the WHO Guidelines for Drinking-Water Quality (1993).
4. All discharges for 1997 were below the former NSW Radioactive Substances Regulations MPC concentration limits and the Activity Concentration Equivalents at ANSTO (based on the WHO Guidelines for Drinking-Water Quality).
5. Results were compiled from the monthly Liquid Effluent Discharge Reports as issued by Waste Management section.

TABLE 22

NON-RADIOACTIVE COMPONENT OF LIQUID EFFLUENT
DISCHARGED TO THE SYDNEY WATER SEWER,
February 1995 – December 1997

Component mg/L	Minimum	Maximum	YEARLY AVERAGE [1]			AVERAGE 1995 to 1997	Standard for Acceptance[2] mg/L
			1995	1996	1997		
Suspended Solids	5	64	30.5	23	22	25	200
pH	6.8	7.9	7.4	7.2	7.3	7.3	7 – 10
Ammonia	< 0.05	52.2	20.8	17.8	16.0	18.2	50
BOD	< 2	110	< 25	36	23	< 28	85 [3]
Grease	< 5	59	< 20	14	13	< 16	50
Chromium	< 0.05	4.40	0.62	1.34	1.36	1.1	3

Notes:

1. When calculating averages, "<" values were included, therefore the yearly averages above are slightly overestimated.
2. Each month, four geometric mean samples (collected at 2 hour intervals over a single production day) plus the monthly pipeline composite sample (representative of all discharges for the month), were analysed for their non-radioactive components.
3. 95% of all samples analysed must be less than or equal to the Standards for Acceptance of Liquid Trade Wastes to Sewers, specified in the Sydney Water Trade Waste Policy & Management Plan, 1995.
4. The Standards for Acceptance do not stipulate a specific limit for BOD acceptance to all sewers, therefore the Agreed limit is applicable in this case

TABLE 23

ESTIMATED EFFECTIVE DOSES FROM HIFAR AIRBORNE DISCHARGES, 1997

Receptor Location	Percent of HIFAR dose constraint [1]	Percent of annual dose limit [2]	Effective dose 1997 mSv/yr [3]
Nearest resident	1.68	0.17	0.0017
LHSTC Library	2.77	0.28	0.0028
LHSTC Building 9	5.36	0.54	0.0054
LHSTC Main gate	1.83	0.18	0.0018
Stevens Hall Motel	5.21	0.52	0.0052
MWDA Depot	1.20	0.12	0.0012
BMX track	0.63	0.06	0.0006
Woronora Valley	0.62	0.06	0.0006
At 1.6 kilometre radius from HIFAR			
NORTH	5.74	0.57	0.0057
NNE	3.38	0.34	0.0034
NE	3.21	0.32	0.0032
ENE	2.88	0.29	0.0029
EAST	1.83	0.18	0.0018
ESE	0.96	0.10	0.0010
SE	1.77	0.18	0.0018
SSE	1.74	0.17	0.0017
SOUTH	0.56	0.06	0.0006
SSW	0.67	0.07	0.0007
SW	2.31	0.23	0.0023
WSW	2.04	0.20	0.0020
WEST	0.79	0.08	0.0008
WNW	0.79	0.08	0.0008
NW	1.46	0.15	0.0015
NNW	2.55	0.26	0.0026
At 4.8 kilometre radius from HIFAR			
NORTH	1.28	0.13	0.0013
NNE	0.77	0.08	0.0008
NE	0.77	0.08	0.0008
ENE	0.68	0.07	0.0007
EAST	0.41	0.04	0.0004
ESE	0.21	0.02	0.0002
SE	0.38	0.04	0.0004
SSE	0.42	0.04	0.0004
SOUTH	0.14	0.01	0.0001
SSW	0.17	0.02	0.0002
SW	0.56	0.06	0.0006
WSW	0.44	0.04	0.0004
WEST	0.18	0.02	0.0002
WNW	0.17	0.02	0.0002
NW	0.31	0.03	0.0003
NNW	0.55	0.05	0.0005

1. The HIFAR dose constraint is set at 0.1 mSv/year
2. The annual dose limit for members of the public is 1 mSv/year.
3. ANSTO Safety and Reliability Report SD/SR/TN 98-7 revision 1, August 1998.

TABLE 24

ANNUAL EFFECTIVE DOSES TO ADULTS
FROM NATURAL SOURCES

Source of exposure	Annual effective dose (mSv)	
	Typical	Elevated
Cosmic rays	0.39	2.0
Terrestrial gamma rays	0.46	4.3
Radionuclides in the body (except radon)	0.23	0.6
Radon and its decay products	1.3	10
Total (rounded)	2.4	-

Notes:
1. Table taken from UNSCEAR (1993) Table 1, page 18.
2. "Typical" values are from areas of normal background.
3. "Elevated" values are from areas of higher exposure and are representative of large regions. Even higher values occur locally.

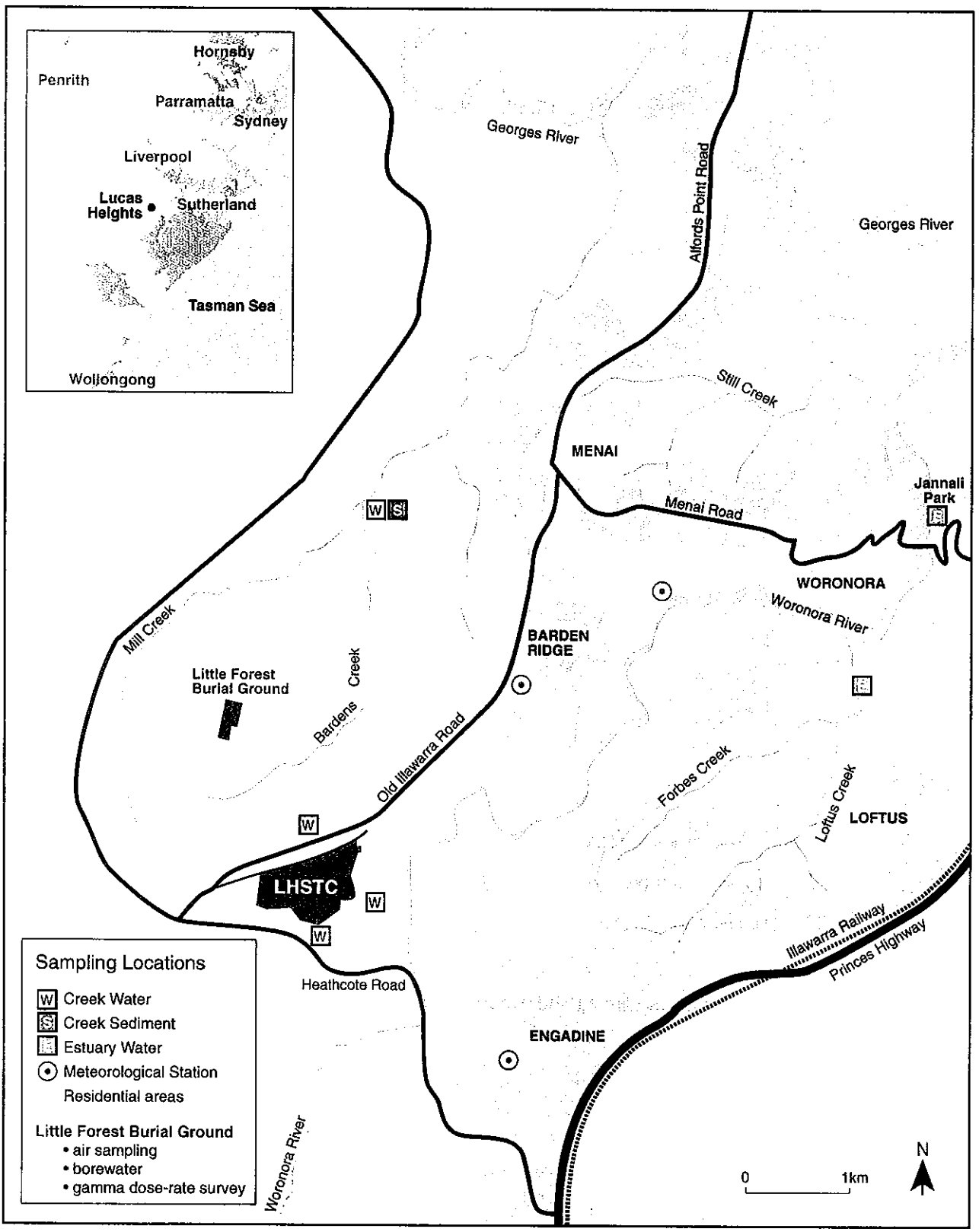

Figure 1: Location of the Lucas Heights Science and Technology Centre and Off-site Sampling Points.

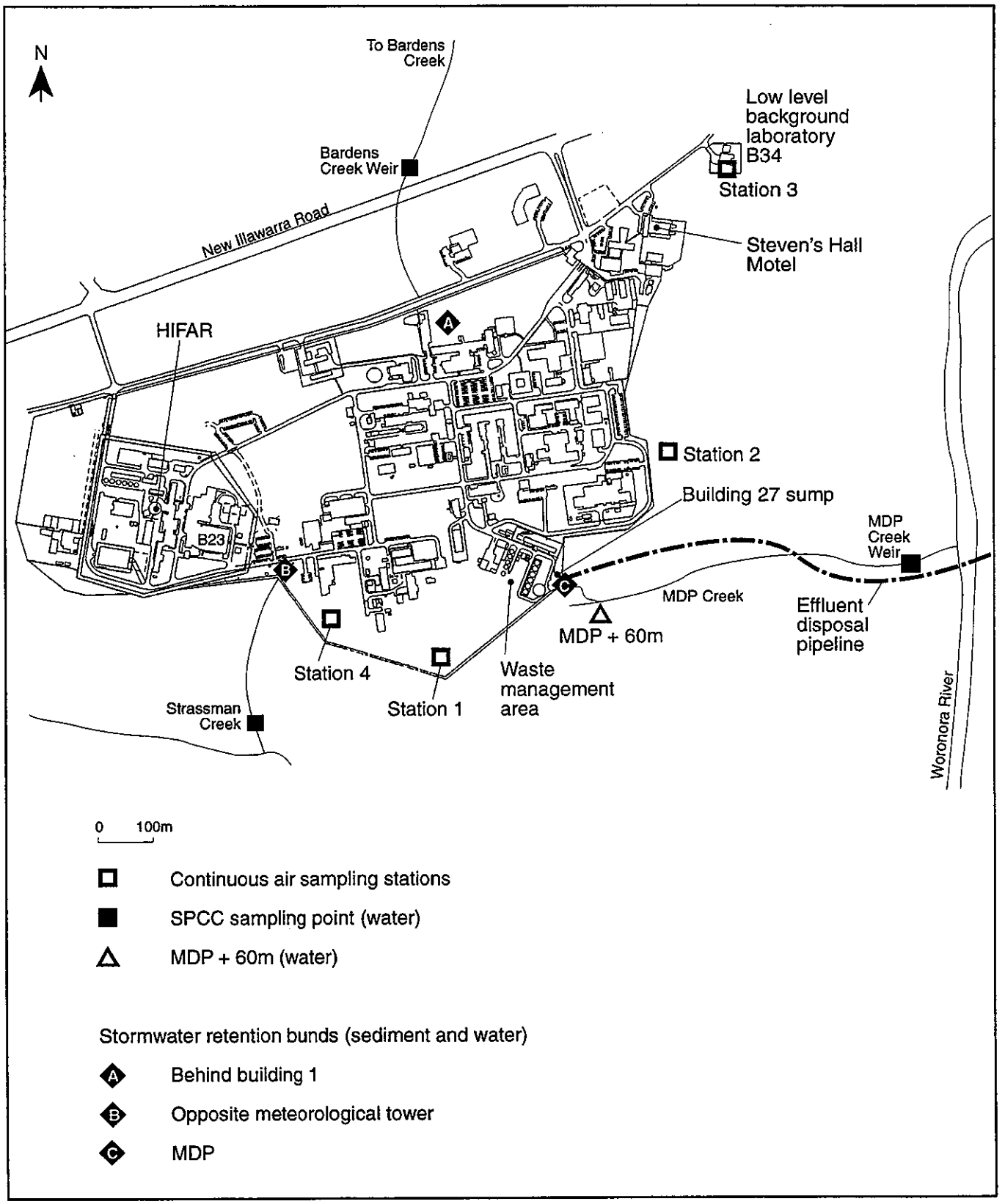

Figure 2: Location of Stormwater and Air Sampling Points at LHSTC.

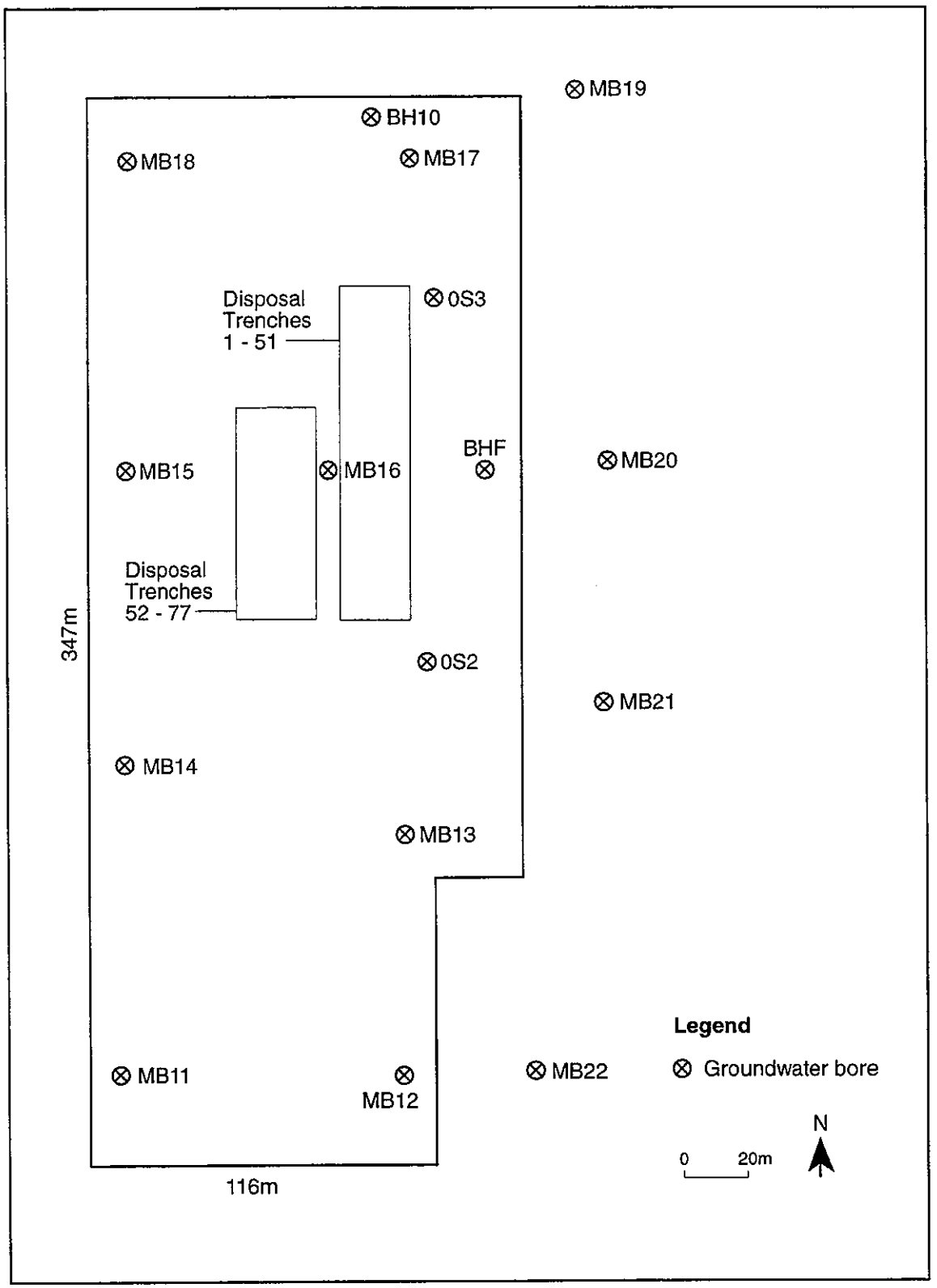

Figure 3: Little Forest Burial Ground - Location of Trenches and Groundwater Bores.

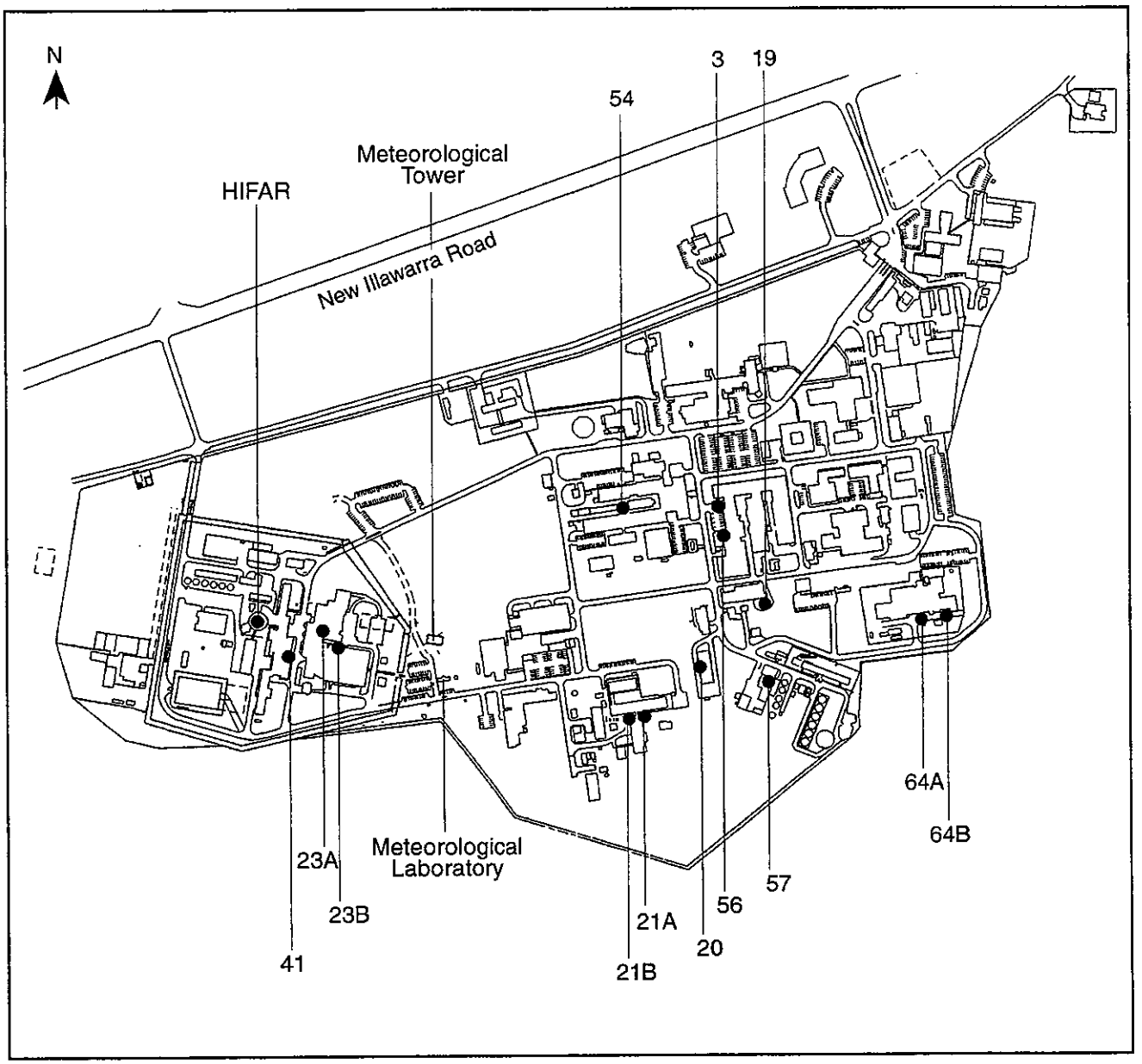

Figure 4: Location of Airborne Effluent Release Stacks and Meteorological Facilities at LHSTC.

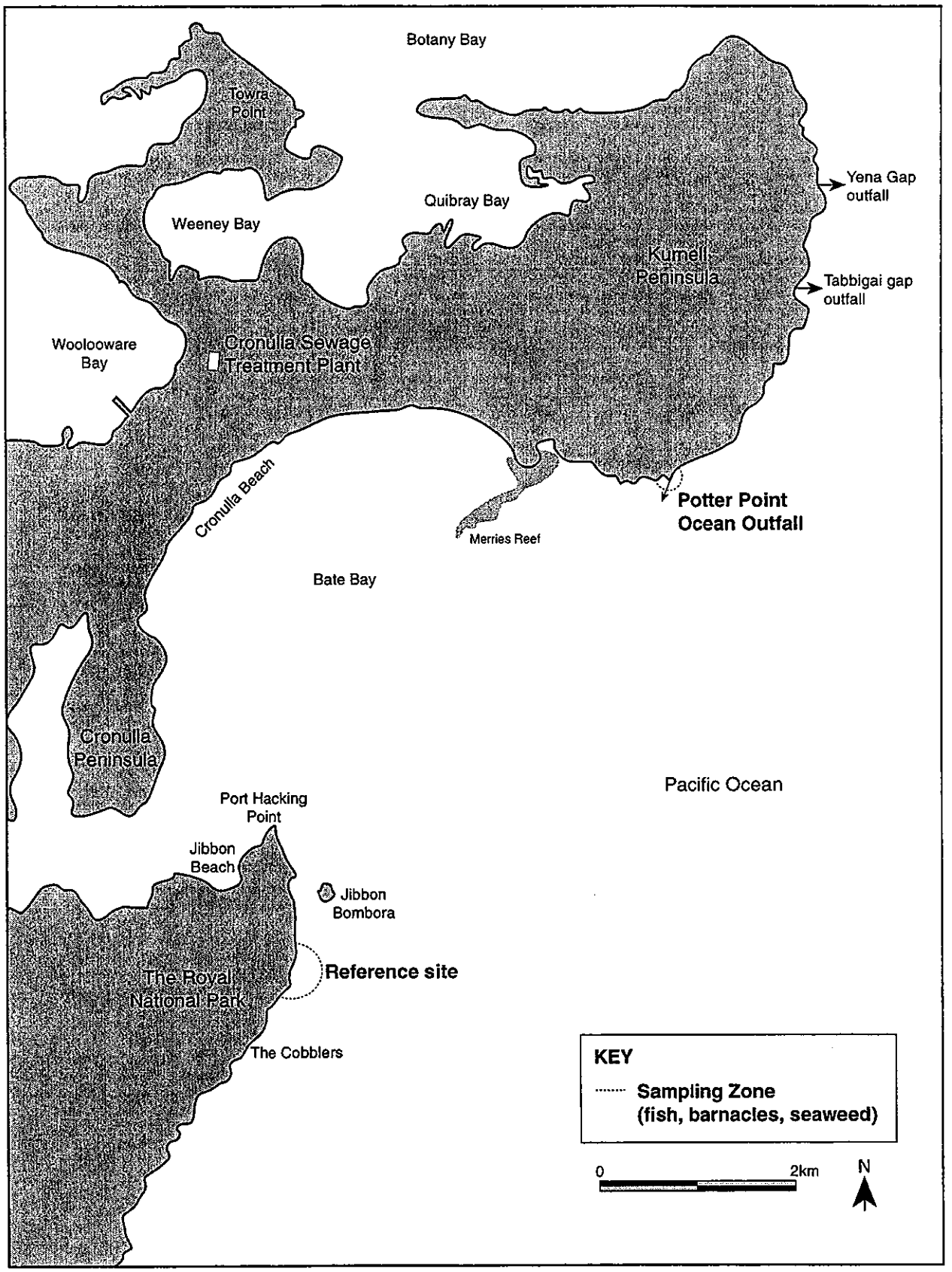

Figure 5: Location of Sampling Zones at Potter Point Ocean Outfall and The Royal National Park.

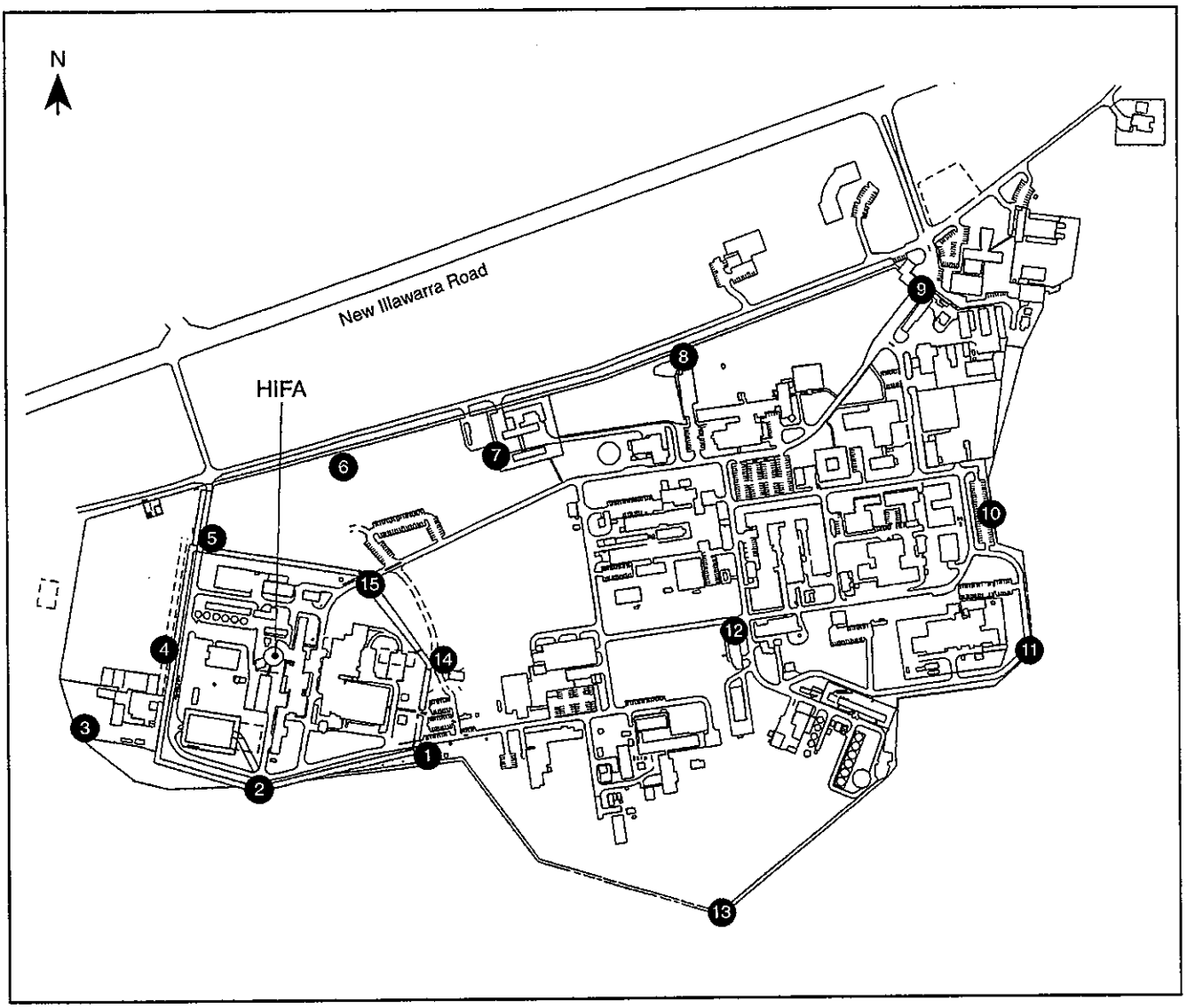

Figure 6: Location of External Radiation Dosimeters at LHSTC.

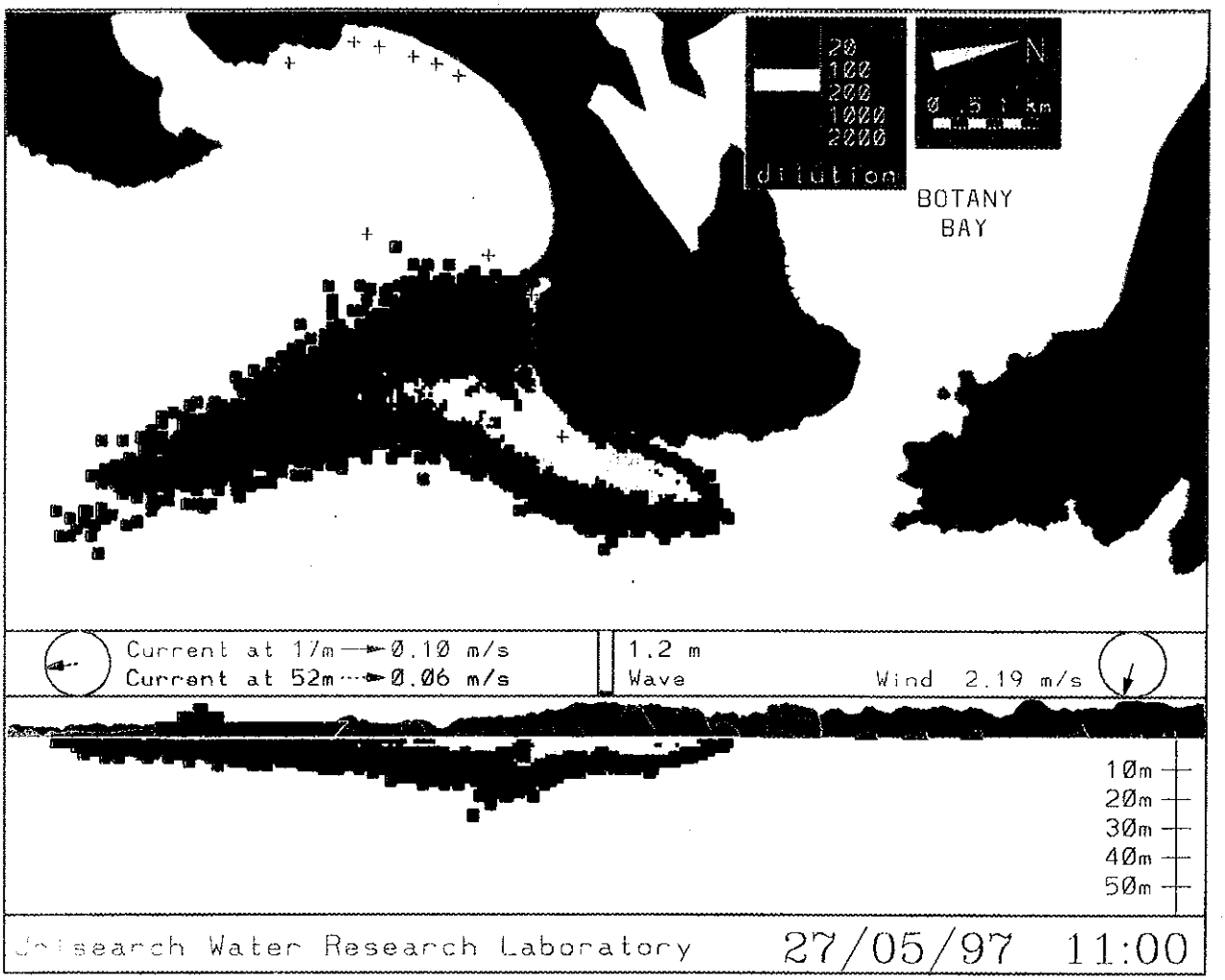

Figure 7: Numerical Modelling of the Potter Point Ocean Outfall Sewage Plume at 11:00 hours on 27 May 1997, by Unisearch Water Research Laboratory.

GLOSSARY OF TERMS

absorbed dose: 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). See radiation dose.

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 radioactivity, equal to one radioactive disintegration per second. This SI unit may be used instead of the curie (Ci): *ie*

$$1 \text{ curie} = 3.7 \times 10^{10} \text{ becquerels.}$$

beta particle (ray): A particle emitted from an atom during radioactive decay. Beta particles 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 betas 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.

biological half-life of an isotope: The time required for one-half of an absorbed radioisotope to be excreted from the body. Also called *biological turnover*.

buffer zone: A 1.6 km boundary around ANSTO (measured radially from the HIFAR reactor), within which no residential development is allowed to occur.

concentration factor: The ratio of an element in the consumer, to that of the environment or what is consumed, *ie*

$$\frac{\text{Concentration in consumer}}{\text{Concentration in environment or food.}}$$

critical orifice: A device which restricts air-flow through a sampling assembly to a constant rate, provided the required vacuum is applied.

daughter product: A nuclide formed from 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, and/or gamma radiation.

dilution ratio: The ratio of effluent concentration at release, to the maximum concentration at the destination.

dose constraint : For public exposure, the dose constraint is the maximum 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.

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: A 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 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 joules per kilogram, termed the *sievert* (Sv), or more commonly the *millisievert* (mSv) (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).

equivalent dose: A weighted radiation dose to an organ or tissue, which 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).

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 original 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 operated 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.

planchette: A small, lipped flat dish used for holding samples to be counted under a detector - water samples may also be evaporated directly onto the planchette. Usually made of stainless steel or aluminium.

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. A beta/gamma emitter.

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.

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. 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.

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 about 2.4 millisieverts. Replaces the rem: 1 Sv = 100 rem.

transit time for the passage of effluent: the time interval from the midpoint of an effluent release to the time at which the maximum concentration of the effluent is detected at the destination.

tritium: The isotope of hydrogen of mass 3. It is naturally radioactive (a weak beta-emitter), and can also be made in a number of ways, including neutron absorption in lithium, deuterium or heavy water. It has a half-life of 12.3 years.

APPENDIX A: PREVIOUS ENVIRONMENTAL SURVEY REPORTS

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

Giles, M.S., Stockdale, J.A., (1966). *Results of the Lucas Heights Biological Survey, December 1959 to December 1964*. AAEC/E-151 Supplement No.1.

Cook, J.E., Dudaitis, A., Giles, M.S., (1969). *Environmental survey at AAEC Research Lucas Heights. Results for 1965, 1966 and 1967*. AAEC/E-151, Supplement No.1.

Cook, J.E., Dudaitis, A., (1970). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1968*. AAEC/E-151, Supplement No.2.

Cook, J.E., Dudaitis, A., (1970). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1969*. AAEC/E-151, Supplement No.3.

Conway, N.F., Dudaitis, A. (1972). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for the Period January-July 1970*. AAEC/E-246.

Dudaitis, A., (1973). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for the Period August 1970 to December 1971*. AAEC/E-271.

Dudaitis, A., (1974). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1972*. AAEC/E-201.

Davy, D.R., Dudaitis, A., (1974). *Environmental Survey at the Research Establishment, Lucas Heights. Results for 1973*. AAEC/E-335.

Davy, D.R., Dudaitis, A., (1976). *Environmental Survey at the Research Establishment, Lucas Heights. Results for 1974*. AAEC/E-375.

Hespe, E.D., (1979). *Environmental Survey at the AAEC Research Establishment, Lucas Heights. Results for 1975, 1976 and 1977*. AAEC/E-467.

Hespe, E.D., (1979). *Results of the 1978 Environmental Survey at the AAEC Research Establishment, Lucas Heights*. AAEC/E-494.

Giles, M.S., Dudaitis, A., (1980). *Environmental Survey at the Research Establishment, Lucas Heights. Results for 1979*. AAEC/E-508.

Giles, M.S., Dudaitis, A., (1982). *Environmental Survey at the Research Establishment, Lucas Heights. Results for 1980*. AAEC/E-542.

Williams, A.R., Dudaitis, A., (1983). *Environmental Survey at the Research Establishment, Lucas Heights, 1981*. AAEC/E-563.

Giles, M.S., Dudaitis, A., (1984). *Environmental Survey at the Research Establishment, Lucas Heights, 1982*. AAEC/E-591.

Giles, M.S., Dudaitis, A., (1985). *Environmental Survey at the Research Establishment, Lucas Heights, 1983*. AAEC/E-622.

Giles, M.S., Dudaitis, A., (1986). *Environmental Survey at the Research Establishment, Lucas Heights, 1984*. AAEC/E-638.

Giles, M.S., Foy, J.J., Hoffmann, E.L., (1988). *Environmental Survey at the Research Establishment, Lucas Heights, 1985*. AAEC/E-677.

Giles, M.S., Foy, J.J., Hoffmann, E.L., (1989). *Environmental Survey at Lucas Heights Research Laboratories, 1986*. ANSTO/E-687.

Giles, M.S., Foy, J.J., Hoffmann, E.L., (1989). *Environmental Survey at Lucas Heights Research Laboratories, 1987.* ANSTO/E-688.

Giles, M.S., Foy, J.J., Hoffmann, E.L., (1990). *Environmental Survey at Lucas Heights Research Laboratories, 1988.* ANSTO/E-689.

Hoffmann, E.L., Arthur, A., (1990). *Environmental Survey at Lucas Heights Research Laboratories, 1989.* ANSTO/E-694.

Hoffmann, E.L., (1991). *Environmental Survey at Lucas Heights Research Laboratories, 1990.* ANSTO/E-704.

Hoffmann, E.L., Loosz, T.,(1994). *Environmental Survey at Lucas Heights Research Laboratories, 1991.* ANSTO/E-708.

Hoffmann, E.L., Loosz, T., (1994). *Environmental Survey at Lucas Heights Research Laboratories, 1992.* ANSTO/E-709.

Hoffmann, E.L., Loosz, T., (1995). *Environmental Survey at Lucas Heights Research Laboratories, 1993.* ANSTO/E-716.

Hoffmann, E.L., Camilleri, A., Loosz, T., Farrar, Y., (1995). *Environmental and Effluent Monitoring at Lucas Heights Research Laboratories, 1994.* ANSTO/E-717.

Hoffmann, E.L., Loosz, T., Farrar, Y., (May 1996). *Environmental and Effluent Monitoring at Lucas Heights Science & Technology Centre, 1995.* ANSTO/E-725.

Hoffmann, E.L., Loosz, T., Farrar, Y., (June 1997). *Environmental and Effluent Monitoring at Lucas Heights Science & Technology Centre, 1996.* ANSTO/E-730.

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 4 weeks 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 particle sizes > 0.3 microns.
Argon-41 (Nobles gas)	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 wet with 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 (Other Activity)	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 (Other Activity)	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, at most, only traces of iodine-131 in the exhaust from HIFAR under normal operation, the effluent is continuously sampled for iodine, since it would be the most important activity released in a serious accident to the reactor.
Xenon-133 Xenon-135 Xenon-135m Krypton-87 Krypton-85m Krypton-88 (Noble gases)	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 that are released during dissolution are delayed 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. 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 delayed 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 as necessary. 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

Symbol	Name
α	alpha
β	beta
γ	gamma
^{241}Am	americium-241
^{7}Be	beryllium-7
^{137}Cs	caesium-137
^{134}Cs	caesium-134
^{144}Ce	cerium-144
^{51}Cr	chromium-51
^{60}Co	cobalt-60
^{131}I	iodine-131
K	potassium (stable)
^{40}K	potassium-40
^{240}Pu	plutonium-240
^{90}Sr	strontium-90
^{208}Tl	thallium-208
^{232}Th	thorium-232
^{3}H	tritium
^{238}U	uranium-238

SI units

Quantity	SI unit and abbreviation
Absorbed dose	Gray (Gy)
Dose equivalent	Sievert (Sv)
Radioactivity	Becquerel (Bq)

Multiples and submultiples of SI units

Factor	Prefix and abbreviation	Factor	Prefix and abbreviation
10^{3}	kilo (k)	10^{-3}	milli (m)
10^{6}	mega (M)	10^{-6}	micro (μ)
10^{9}	giga (G)	10^{-9}	nano (n)
10^{12}	tera (T)	10^{-12}	pico (p)

APPENDIX D

ENVIRONMENTAL SAMPLE COLLECTION AND ANALYTICAL PROCEDURES

5.1 Sample Collection

Potter Point Biological Samples
As part of the environmental monitoring program at Potter Point ocean outfall, samples of fish (*Girella sp.*, commonly called 'Blackfish'), macrophytic algae (*Enteromorpha intestinalis* or 'green hair weed') and surf barnacles (*Tesseropera rosea*) were collected.

Fish were caught off the rocks at Potter Point using a fishing line baited with weed, while the green algae and barnacles were scraped off the rocks. Fish were filleted and scaled, the algae and barnacles were left whole. None of the samples were washed.

All samples were oven-dried at 70 ^{0}C. Dried samples were powdered using a ring grinder, then weighed into plastic petri dishes for gamma-counting.

Soils and Sediments
Soils were sampled to a depth of 4 cm until approximately 1kg was collected. Samples were oven-dried overnight at 100 ^{0}C, then passed through a coarse sieve to remove large stones and organic matter. The dry weight was recorded, then the sample ignited at 450 ^{0}C in a muffle furnace, cooled and re-weighed. The whole, ashed sample was subsampled for gamma spectrometry and gross beta counting. The remainder of the ashed sample was sieved to yield a fraction with particle sizes ranging from 125 to 250 microns for the gross alpha analysis.

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

Waters
All water samples were collected in polythene bottles. Samples were acidified to a pH less than 2 using nitric acid, except those for tritium analysis which were analysed as soon as possible after arrival in the laboratory (usually the same day).

Ground Waters
Groundwaters from bores at Little Forest Burial Ground were collected by first pumping out the contents of each bore, then allowing all the bores to recharge with fresh groundwater over a period of at least two days. The samples were then collected by pumping ten-litres from the centre of each bore into a jerrycan, using a petrol-fuelled pump. The sampling method was modified in December 1996 to reduce disturbance of sediment in the bores, consequently the sediment loading of the samples has decreased.

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.

Airborne Particulates - LFBG
An *Ecotech* portable high-volume air sampler was commissioned in October 1997 to replace the previous solar-powered monitoring station. The new sampler is mounted on a trailer and is deployed for about 4 hours approximately every two weeks.

The air sampling flow rate is set at 60 m^3 per hour and the airborne particulates are progressively accumulated over a period of three months on cellulose fibre filter papers. The amount of air sample collected in this manner is approximately 1440 m^3 per quarter. The exposed filters are divided into four equal portions: two are used for beryllium and plutonium analyses; the remaining two are stored.

For the beryllium analyses, one of the filter portions is digested using Method 3050 of the US Environment Protection Authority and analysed with an Inductively Coupled Plasma Mass Spectrometer (Method 3120B of the American Public Health Authority).

To maximise the probability of detecting plutonium, an annual composite comprising ¼ of each quarterly sample, is used for the alpha spectrometry analysis, which is performed by ANSTO's Environmental Radiochemistry Laboratory.

Environmental Radiation - ARL dosimeters
External radiation levels at the perimeter of LHSTC and in some surrounding suburban areas were measured using thermoluminescent dosimeters (TLD's) issued by the Australian Radiation Laboratory (ARL).These dosimeters consist of calcium sulphate thermoluminescent material with three filtered areas and an open window.

ANSTO also used environmental dosimeters from Bicron NE Technology, model *Harshaw 6600* which contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters. They were analysed at ANSTO using an automatic reader. Results were analagous with those of the ARL TLD's.

Measurements were made over four consecutive exposure periods of approximately three months duration, and the ARL-issued TLD badges were sent back to the ARL to be analysed. The results were normalised to exposure rates per day to allow for differences in the length of monitoring periods, and calculated in terms of annual absorbed dose to air in milligrays (mGy). For this report the readings were then converted to effective dose (mSv) using the conservative conversion factor of 1. The uncertainty for the annual dose is the 95% confidence level estimated from the standard deviation of the results for several dosimeters placed at the same locations.

5.2 Analysis Methods

Tritium in waters
Water samples to be analysed for tritium were prepared by distillation according to the International Organization for Standardization (ISO) standard method 9698:1989(E). Aliquots of five millilitres (one millilitre in previous years) were taken from the distilled samples and combined with 11 mL of *Ultima Gold* scintillant cocktail in polyethylene counting vials. The samples were counted in a Packard Tri-carb Liquid Scintillation Analyser, model 2700TR. The first set of counts are discarded in order to allow the samples several hours to equilibrate in the dark. Three tritium standards (prepared monthly using a certified Amersham tritium solution) and a distilled water blank were counted with the samples, to check the operation and background radioactivity of the counter. A series of quenched standards were counted to determine the relationship between the spectral index of the external standard and the counting efficiency. Sample activity was corrected for chemical quenching. Total counting

time was 100 minutes per vial, comprising five 20-minute counts. Results were calculated in terms of Bq/litre along with a minimum detectable activity (at 95% confidence).

Gross Alpha/Beta Activity in Soils
Soils/sediments were counted for gross beta activity in a Geiger-Müller tube with a 2-inch diameter end-window. Alpha counting of these samples was 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). Beta and alpha activities were assumed to have energies similar to potassium-40 and natural uranium respectively. Analytical grade potassium chloride was 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, was used to standardise the alpha detector.

Gross Alpha/Beta Activity in Waters – changeover to ISO methods
Most water samples were screened for gross alpha/beta activities to determine whether further tests for individual radionuclides were necessary. All of these water samples for 1997 were analysed using ISO methods 9696 & 9697(1992).

In previous years, gross alpha/beta analyses of waters were performed using either the Standards Association of Australia method AS 3550.5(1990) or the AAEC/ANSTO tablet method. These methods are described, together with their advantages and disadvantages, in Appendix D of report ANSTO/E-730(1997).

ISO 9696 & 9697 (1992) - planchette thick source methods
In this method, the water sample is acidified, evaporated almost to dryness, converted to the sulphate form by addition of excess sulphuric acid and then ignited at 350 °C. A portion of the ignited residue is transferred and fixed to a stainless steel counting planchette. As alpha particles are absorbed by matter, it is necessary to optimise the thickness of the source to enable the maximum amount of sample to be counted with a minimum of absorption. The amount of sample residue dispensed onto the planchette was standardised at 100 mg.

Standard sources of 100 mg thickness were used to calibrate the Canberra 2400 thin-window gas-flow proportional alpha/beta counting system. The 100 mg standard sources were prepared as as described in the relevant ISO method, using calcium sulphate spiked with americium-241 for alpha activity and potassium sulphate for beta (due to the natural ^{40}K content).

The ISO methods are not suitable for saline waters, but are usually applicable to samples with high levels of suspended or dissolved solids. Advantages over the AS method are: improved accuracy and repeatability of results; ability to store dry residues for future reference; unfiltered samples can be used; acidified samples can be used on stainless steel planchettes which have lower backgrounds than aluminium planchettes. Disadvantages: long preparation times and risk of losing samples through increased handling.

ARL gel method for preparation of gamma sources
All water samples which were concentrated for gamma spectrometry were prepared by the following method. Sample volumes ranging from two to twelve litres were evaporated on a hotplate to about 50 mL. The pH of the cooled solution was adjusted to 3-4 with the addition of 10 molar sodium hydroxide. The concentrated sample was reheated, quantitatively transferred to a 65 mm petri dish, mixed with about 2 grams of agar and allowed to set. The lid was sealed on with silicone glass sealant and the sample counted for gamma-emitters. This method was adapted (by permission) from a technique used at the ARL. Results are expressed in Bq/litre. The building 27 sump sample is not concentrated prior to counting which allows a faster determination for short-lived radionuclides.

Gamma spectrometry - water, soils, vegetation, fish, algae, barnacles, maypacks
Gamma spectra are obtained by placing prepared samples onto a 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. Peak areas in the sample spectra are calculated using an Ortec software package, *Maestro II.* Background spectra are acquired with no sample present to determine the radioactivity due to the environment and detector components, as distinct from the sample activity. Peaks at certain energies in the 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, gross and net areas of the peaks and associated counting errors.

The gamma detector energy spectrum is calibrated periodically using certified point sources. The counting efficiency of the detector is determined over a range of energies using several gamma sources, prepared from IAEA reference materials. These standard reference materials have a similar matrix to the types of samples usually encountered and are prepared in the same geometry. Background spectra are acquired with no sample present and are counted for the same length of time as the samples.

Prepared samples for gamma spectrometry are presented in a uniform geometry, *ie* packed into petri dishes of 65mm diameter. The types of samples counted are mainly concentrated water samples set in agar gel, ashed vegetation or biota; dried/ashed sediments or powdered material.

Marinelli beakers are also used for direct counting of unconcentrated liquid samples. They are plastic containers which fit over and around the detector and contain 500 mL of sample. Calibration of the detector efficiency is done using a Marinelli beaker filled with a certified Amersham standard solution containing several gamma-emitting radionuclides.

Potassium-40 beta activity
In many cases, the beta activity of a sample is almost entirely due to the natural potassium-40 contribution. In calculating the net beta activity of soils or waters, the activity due to natural potassium-40 may be 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 latter method is more accurate. The specific activity of potassium is 27.6 Bq of potassium-40 per gram of stable potassium (Australian Drinking Water Guidelines, 1996).

Air samples - Ambient Iodine-131
One set of Maypacks are set aside each week in case random independent checking is required by officers of the ARL. The other set is analysed at ANSTO, by placing the four cartridges simultaneously under 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 using a high-purity germanium gamma detector, 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, *ie* any iodine-131 results are corrected for decay (due to the 8 day half-life) back to the first day of the sampling period.
- that all the measured activity was released at one point (there are actually four locations being measured).

APPENDIX E : AIRBORNE EFFLUENT SAMPLE COLLECTION AND ANALYSIS

The authorised airborne effluent discharges from LHSTC stacks are monitored weekly by ANSTO's Safety Division.

Sampling for gases, vapours and particulates
For the gas, vapour and particulate emissions, filter cartridges called Maypacks are used. The Maypacks consist of an activated charcoal section to trap gases and vapours, and a particulate filter.

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-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 sodium-iodide 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 four weeks when some of the particulate filters are measured again for gross alpha and beta activity. This is to confirm whether 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 200 mL of demineralised water, thus trapping the tritiated water with an efficiency of about 99%. The flow rate is limited to 1 litre per minute by a Millipore 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 is used to count the noble gas activity.

⋖ END OF REPORT ⋗