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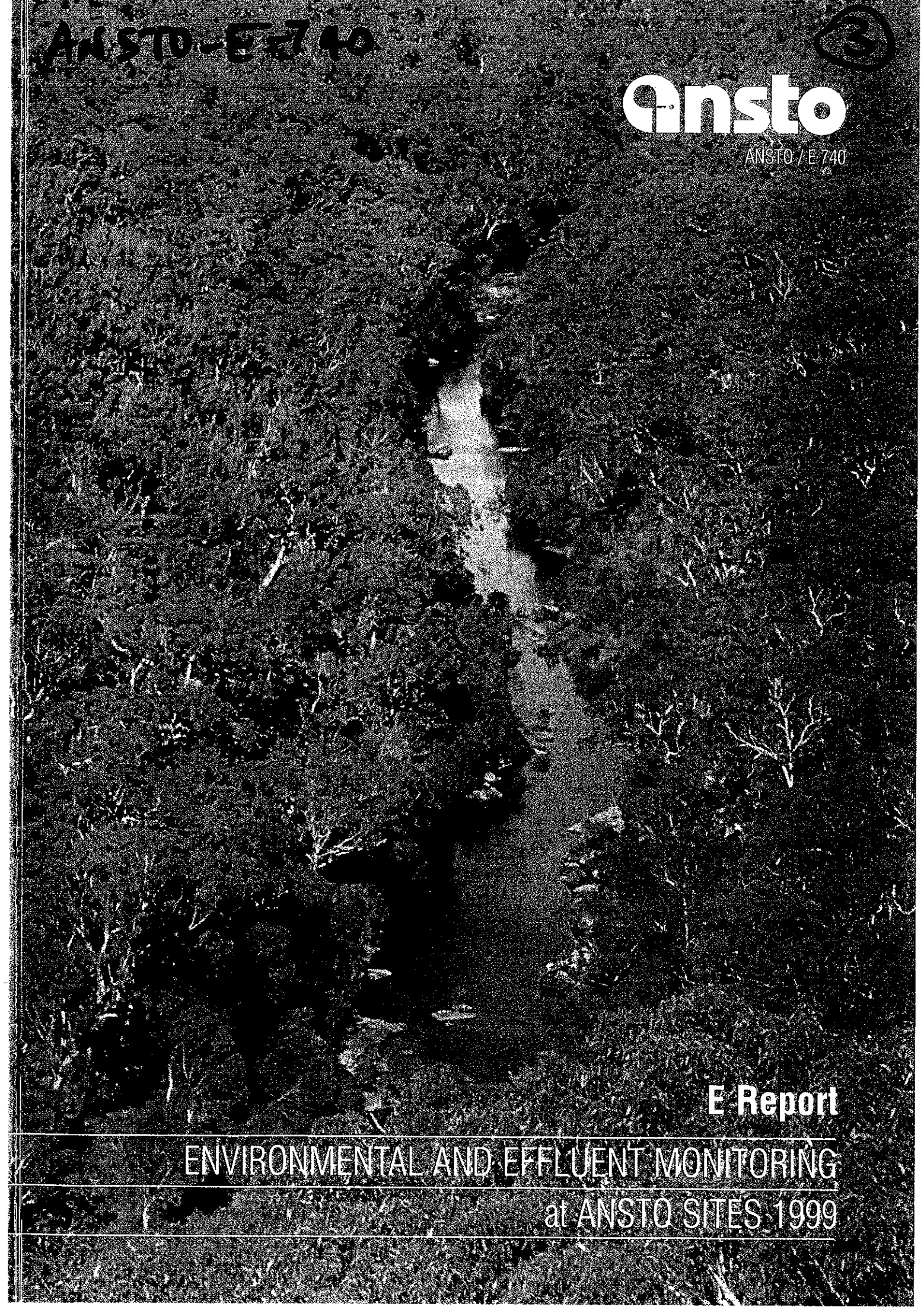

E Report

ENVIRONMENTAL AND EFFLUENT MONITORING at ANSTO SITES 1999

GENERAL CONTACT DETAILS

ANSTO	Lucas Heights Science and Technology Centre (LHSTC) New Illawarra Road, Lucas Heights NSW 2234
Postal Address:	ANSTO Private Mail Bag 1 Menai NSW 2234 Australia
Telephone:	+ 61 (2) 9717 3111
Facsimile:	+ 61 (2) 9543 5097
Email:	communications@ansto.gov.au
Internet:	ANSTO Home Page: http://www.ansto.gov.au

Guided tours of the LHSTC site and laboratories are available to individuals, groups and schools. For bookings and information telephone (02) 9717 3168.

Cover:	The Woronora River, photographed from a walking trail within the LHSTC buffer zone.
Title page:	Aerial view of the LHSTC, looking west.
Photography:	Tim Tapsell, ANSTO

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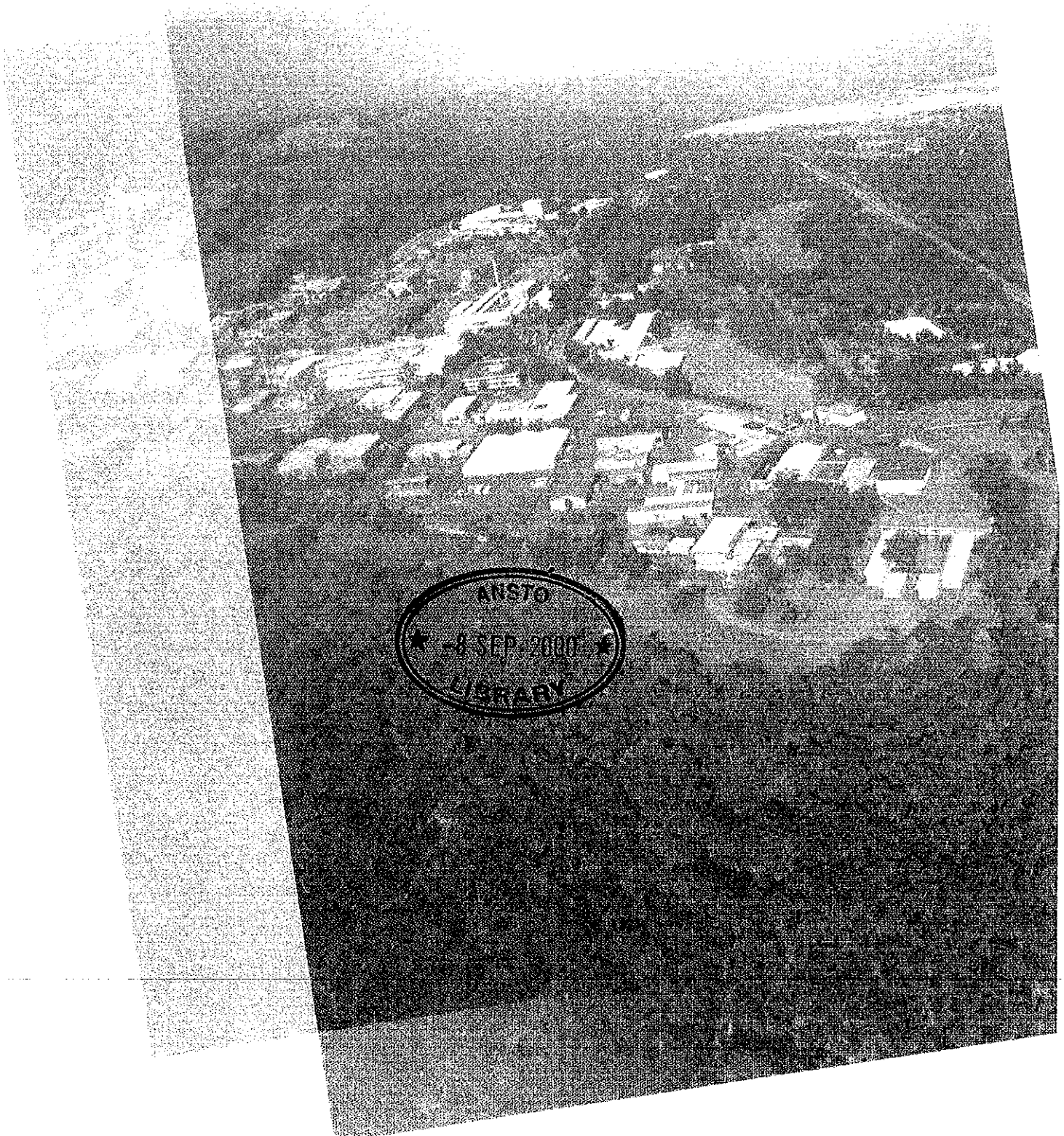

E Report

ENVIRONMENTAL AND EFFLUENT MONITORING at ANSTO SITES 1999

ENVIRONMENTAL AND EFFLUENT MONITORING AT ANSTO SITES, 1999

LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE AND THE NATIONAL MEDICAL CYCLOTRON

E.L. HOFFMANN, T. LOOSZ, L. MOKHBER-SHAHIN

ABSTRACT

Results are presented of environmental and effluent monitoring conducted in 1999 at the two sites owned and operated by ANSTO, at the Lucas Heights Science and Technology Centre (LHSTC) and the National Medical Cyclotron (NMC). 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 LHSTC controlled airborne discharges were estimated for 1999 using the PC-Cream atmospheric dispersion and dosimetry code. The potential effective doses to the public in 1999 were estimated to be less than 0.010 mSv/year for all receptor locations on the LHSTC 1.6 km buffer zone boundary or beyond. This value represents 1% of the 1 millisievert (mSv) per year dose limit for long term exposure that is recommended by the National Health and Medical Research Council and 3.3% of the LHSTC site dose constraint of 0.3 mSv/year. It is concluded that there is no impact on the health of the community, staff or the environment as a consequence of operations at the Lucas Heights Science and Technology Centre or the National Medical Cyclotron.

INIS DESCRIPTORS

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

Airborne Particulates, Algae, Alpha Decay Radioisotopes, Alpha Particles, Americium-241, ANSTO, Argon-41, Australia, Beryllium-7, Beta Decay Radioisotopes, Cesium-134, Cesium-137, Chemical Effluents, Cobalt-57, Cobalt-60, Contamination, Cyclotrons, Dose Equivalents, Dose-Constraint, Dose Limits, Drinking Water, Environmental Exposure Pathway, Environmental Impacts, Evaluated Data, Fishes, Fission Product Release, Gallium-67, Gamma Radiation, Gaseous Wastes, Ground Water, Iodine-123, Iodine-131, Iodine-132, Iodine-133, Liquid Wastes, Low Level Counting, Measuring Methods, Noble Gases, Plutonium-239, Potassium-40, Public Health, Radiation Doses, Radiation Monitoring, Radioactive Effluents, Natural Radioactivity, Rivers, Sampling, Seawater, Sediments, Soils, Stack Disposal, Standards, Statistics, Strontium-90, Surface Waters, Thallium-201, Thorium-232, Thermoluminescent Dosimetry, Tritium, Uranium-238, Water Quality, Wind, Zinc-65.

CONTENTS

TABLES CONT.

ENVIRONMENTAL AND EFFLUENT MONITORING AT ANSTO SITES, 1999

SUMMARY

The Australian Nuclear Science and Technology Organisation (ANSTO) is an agency of the Australian Commonwealth Government, providing services to government, industry, the research and development community and the wider community. ANSTO owns and operates two sites incorporating several national facilities, including the HIFAR research reactor, the Australian National Tandem Accelerator for Applied Research (ANTARES) and the National Medical Cyclotron (NMC). The ANSTO sites are both located in Sydney, New South Wales:

- the main site at Lucas Heights, known as the Lucas Heights Science and Technology Centre (LHSTC); and
- The National Medical Cyclotron, adjacent to the Royal Prince Alfred Hospital in inner city Sydney.

ANSTO operations which involve radiation or radioactive material are regulated under the Australian Radiation Protection and Nuclear Safety Act 1998, the object of which is to protect the health and safety of people and to protect the environment from the harmful effects of radiation. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has been established within the Health and Aged Care portfolio to implement the provisions of the Act and the associated regulations. Under the Act ARPANSA has the authority to undertake independent audit of the effluent and environmental monitoring programs at ANSTO sites.

ANSTO has a Health, Safety and Environment Policy that commits the Organisation to undertaking its activities in a manner that 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 environmental and effluent monitoring results for 1999 show that ANSTO operations complied with effluent discharge authorisations and relevant environmental regulations for both the LHSTC and the NMC sites.

The National Medical Cyclotron

The radiopharmaceutical products made at the National Medical Cyclotron are relatively short-lived with half-lives ranging from minutes to hours. As a consequence the small amounts of liquid and airborne emissions from the NMC have limited impact on the environment or humans. All emissions met the prescribed discharge limits in 1999.

Liquid Effluent from LHSTC

ANSTO has an Agreement (No.4423) with Sydney Water Corporation which allows ANSTO to discharge treated liquid effluent from LHSTC to the sewer as long as the discharges comply with:

- the World Health Organisation (WHO) 1993 Guidelines for Drinking-Water Quality, at the Cronulla Sewage Treatment Plant (CSTP); and
- concentration limits for non-radiological components of the effluent.

During 1999, radionuclide concentrations in liquid effluent discharged to the sewer were below the limits specified in the Sydney Water Trade Wastewater Agreement. The average monthly concentration quotient for radioactivity in liquid effluent was less than 16% of the above WHO limit. Concentrations of the non-radioactive components of liquid effluent discharged to the Sydney Water sewer also met the standards for acceptance specified in the Trade Wastewater Agreement.

Airborne Discharges from LHSTC

Potential effective doses to local members of the public from controlled airborne discharges in 1999 were estimated to be less than 0.010 mSv per year, for receptor locations on the 1.6 kilometre radius LHSTC buffer zone boundary. This represents less than 1% 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 3.3% of the site dose constraint of 0.3 mSv per year.

The estimated potential doses to members of the general public from airborne discharges at LHSTC are only a very small fraction, less than half a percent, of the radiation dose received by everyone each year from naturally occurring sources of radiation.

Stormwater and Surface Waters - LHSTC

Stormwater drainage from the LHSTC complied with the NSW Protection of the Environment Operations Act (1997) limits for gross alpha and gross beta activity. Sampling included the on-site stormwater bunds and off-site sampling points on the three small creeks receiving most of the run-off from the site. Levels of tritium and gamma activity found in stormwater at LHSTC (with the exception of tritium in one on-site bund sample) were very low in comparison with WHO drinking water guidelines. Surface water samples collected off-site at the confluence of Mill and Bardens Creeks, from the Woronora River and Forbes Creek, did not contain significant levels of tritium.

Since the levels of detected activity are very low and stormwater does not enter any known human drinking water supply, it is concluded that there are no environmental or health consequences to humans from the measured radioactivity in LHSTC stormwater.

Little Forest Burial Ground

Groundwater monitoring of fifteen bores at the Little Forest Burial Ground (LFBG) indicated that tritium levels were similar to past years. The gross alpha and gross beta activities in groundwater were lower than the levels prescribed

for Class C waters in the regulations associated with the Protection of the Environment Operations Act 1997. Except for the gross alpha activity in MB16, they were also below the Australian Drinking Water Guidelines levels. Traces of cobalt-60 and caesium-137 were detected in bore MB16, which is in the centre of the burial trench area, at less than 1% of the relevant WHO drinking water reference concentrations. A small amount of americium-241, below 3% of the WHO reference concentration, was found in the OS2 bore. The low levels of radioactivity found in groundwater have no health significance to humans or the environment.

A mobile high-volume air sampler (built to US Environment Protection Agency specifications) was used to monitor airborne particulates at the LFBG throughout 1999. Airborne particulates were progressively accumulated on filters by sampling approximately every two weeks over three-month periods. Dry, relatively windy sampling days were chosen to maximise the chance of particulate collection. No beryllium or plutonium was detected in LFBG airborne particulates during 1999. The LFBG has an established vegetation cover and rarely (less than 4% of the time) experiences winds capable of significant particulate generation. The radiological exposures to members of the public from the LFBG continue to be negligible.

External Gamma Radiation

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 0.8 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 the United Nations Scientific Committee on the Effects of Atomic Radiation (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 3.2 mSv/year was registered at location 2 in the southern sector of the LHSTC perimeter fence. This area was affected by stored radioactive material. This part of the site is not readily accessed by the general public and is approximately 1.8 kilometres away from any residential areas. Other locations exhibited normal background dose rates ranging from 0.7 to 1.1 mSv/year.

Potter Point Ocean Outfall

Biological and seawater monitoring continued at the Potter Point ocean outfall during 1999. 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 swim in the ocean off Potter Point and/or eat 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 kilometres south of Potter Point, at The Royal National Park. The only activity in biological samples taken from Potter Point that may potentially be attributed to ANSTO were the low levels of cobalt-60 and iodine-131 found in algae. However, iodine-131 also enters the sewage system from local hospitals using nuclear medicines. The concentrations of iodine-131 and cobalt-60 found in algae were of no radiological significance, particularly since neither isotope was found in blackfish which consume the algae.

The tritium levels offshore in the immediate vicinity of Potter Point were investigated in June and December 1999. Out of 108 seawater samples taken within 130 metres of the outfall only seven showed detectable levels of tritium. The maximum tritium level observed in the seawater was 36 Bq/L which is less than 0.5% of the WHO reference value for tritium in drinking water. The time taken for wastewater to flow from Lucas Heights to the Cronulla Sewage Treatment Plant was about 9.5 hours and the minimum in-line dilution factor was 30. These results are consistent with previous results obtained from 1993 to 1998.

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 National Health and Medical Research Council (NH&MRC) recommended dose limits for members of the public.

It is concluded that there is no impact on the health of the community, staff or the environment as a consequence of operations at the Lucas Heights Science and Technology Centre or the National Medical Cyclotron.

Under the Health, Safety and Environment Policy, ANSTO is committed to on-going dialogue with the community on the implementation of the monitoring program. As a contribution to fulfilling this commitment, ANSTO will analyse samples from the local community for environmental radioactivity levels. Contact the ANSTO Communications Manager on (02) 9717 3770 for further information.

Groundwater sampling at Little Forest Burial Ground.

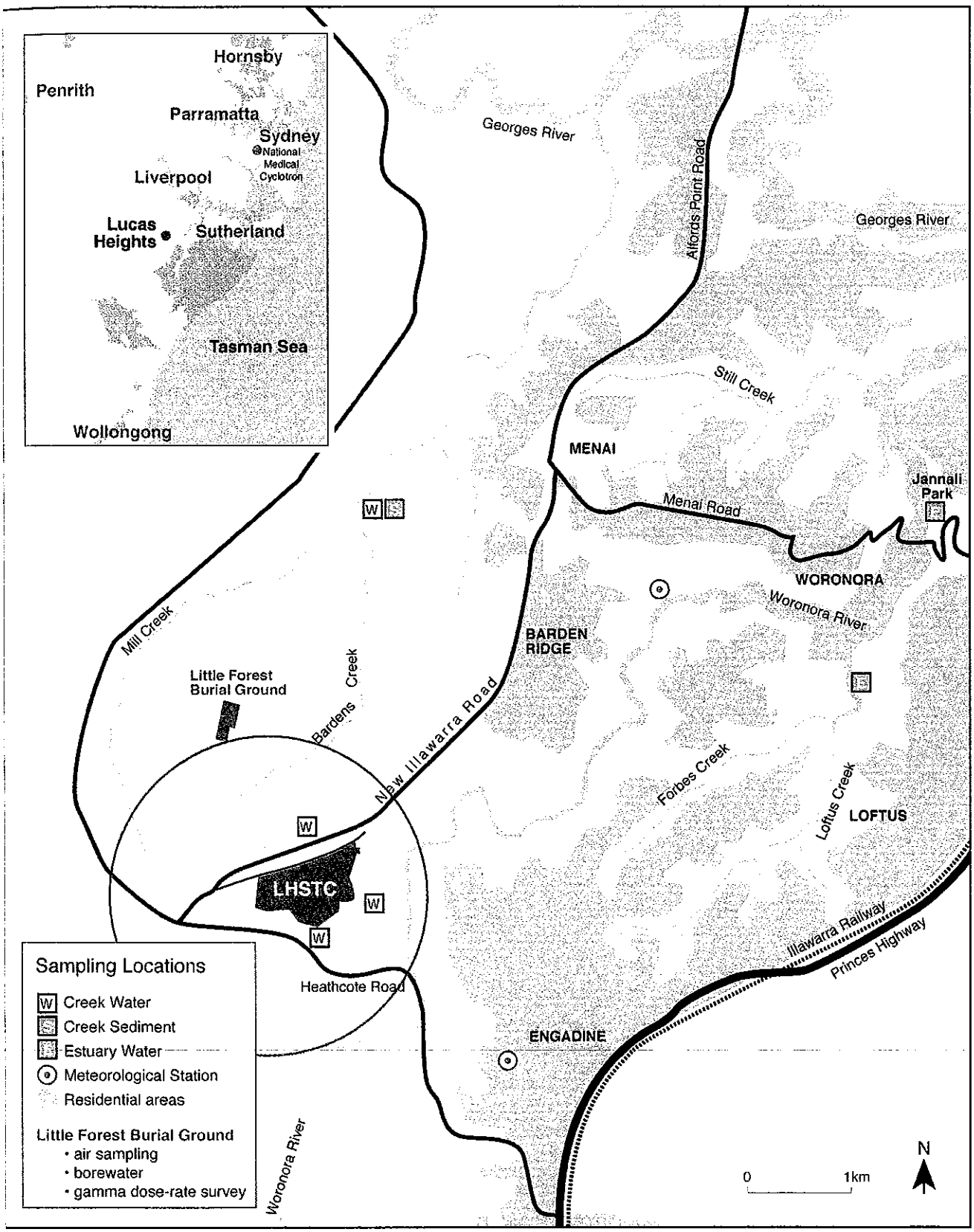

FIGURE 1
Location of LHSTC & Offsite Sampling points

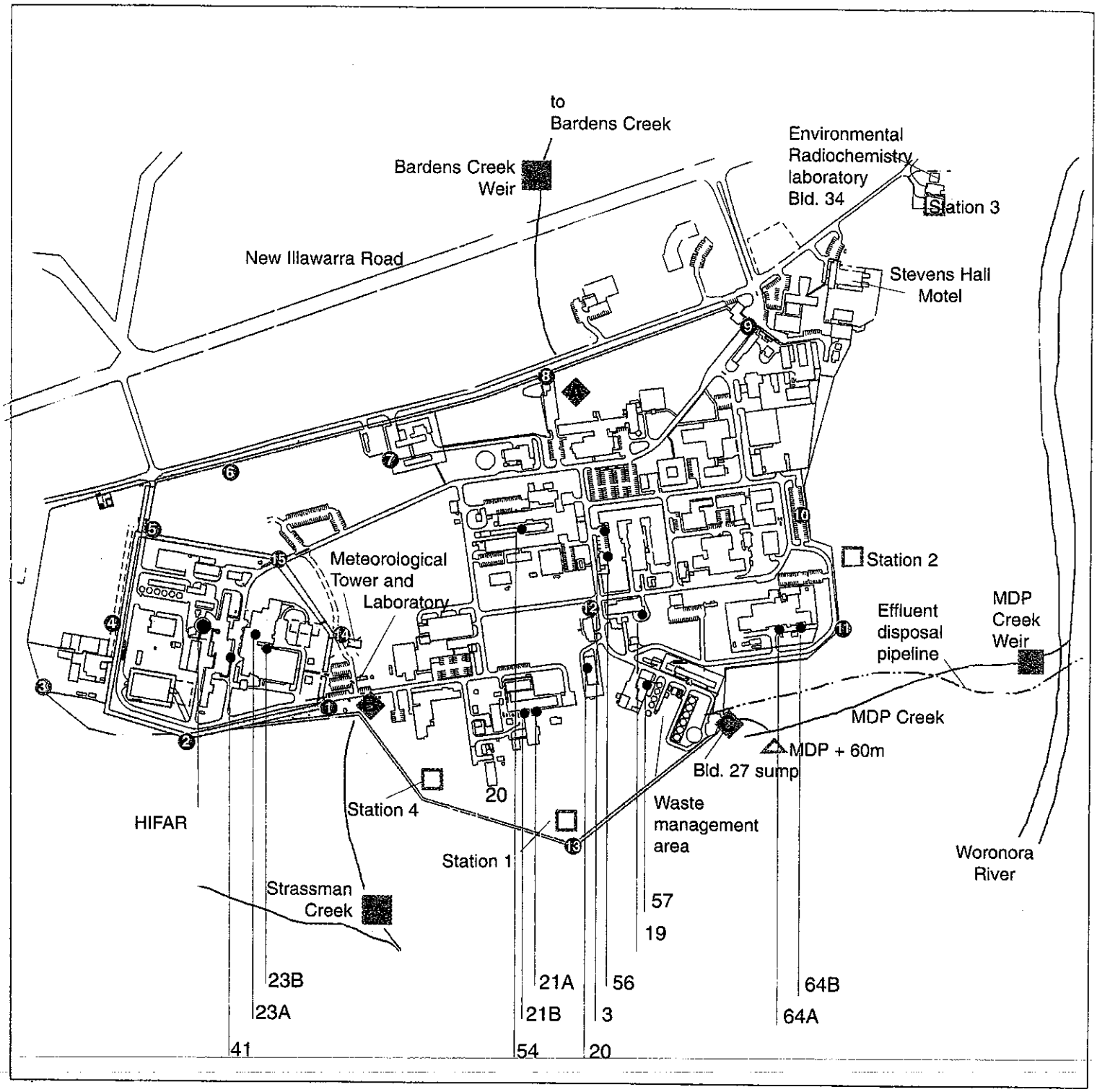

FIGURE 2

Locations of Stormwater, Air and External Radiation Monitoring Points at LHSTC

Stormwater and air sampling points

- □ Continuous air sampling stations
- ■ SPCC sampling point (water)
- △ MDP + 60m (water)

Stormwater retention bunds

- ◆ Behind building 1
- ◆ Opposite meteorological tower
- ◆ MDP

- ● Airborne effluent release stacks
- ② External radiation dosimeters (TLDs)

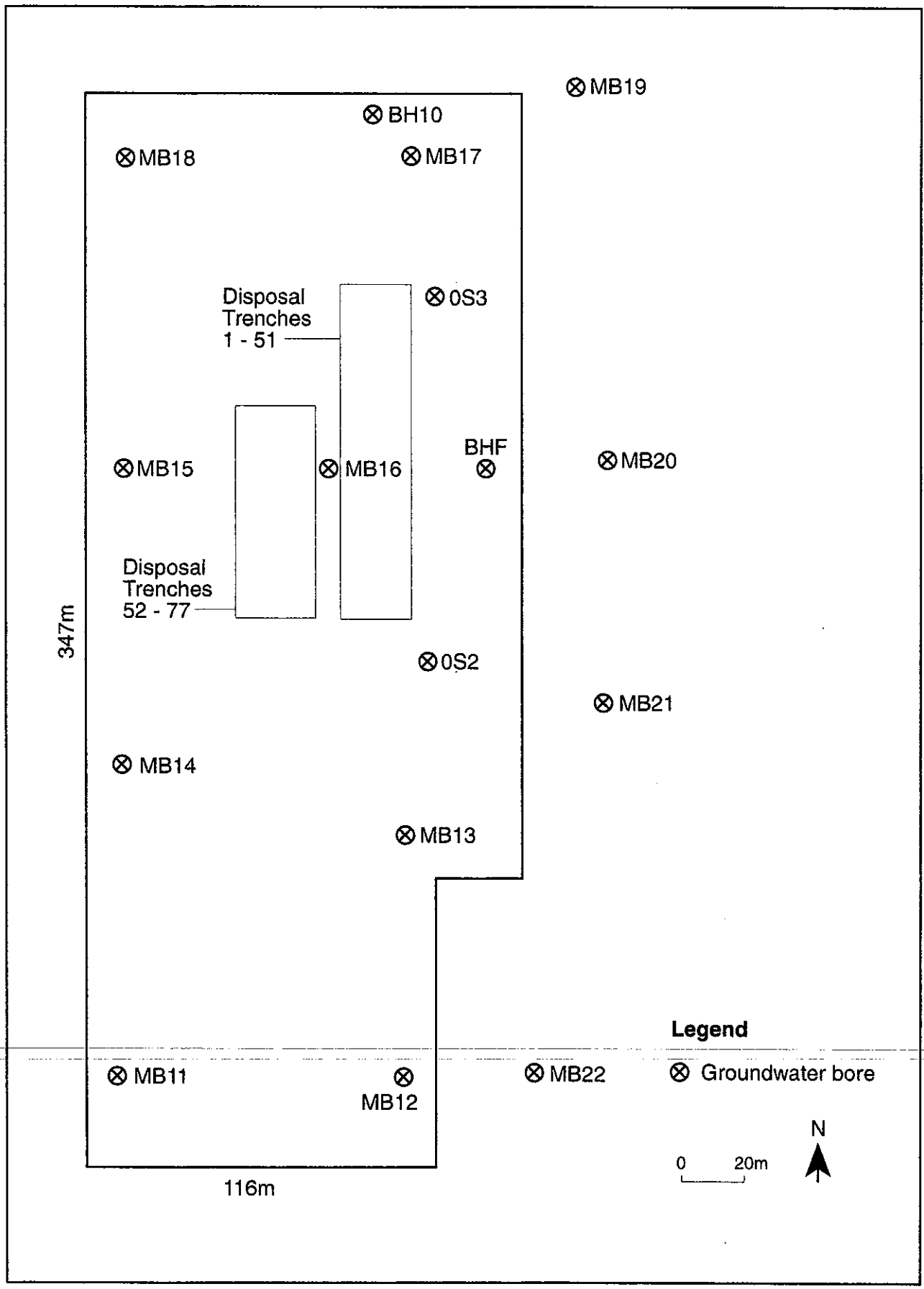

FIGURE 3
Little Forest Burial Ground - Location of Trenches & Groundwater Bores

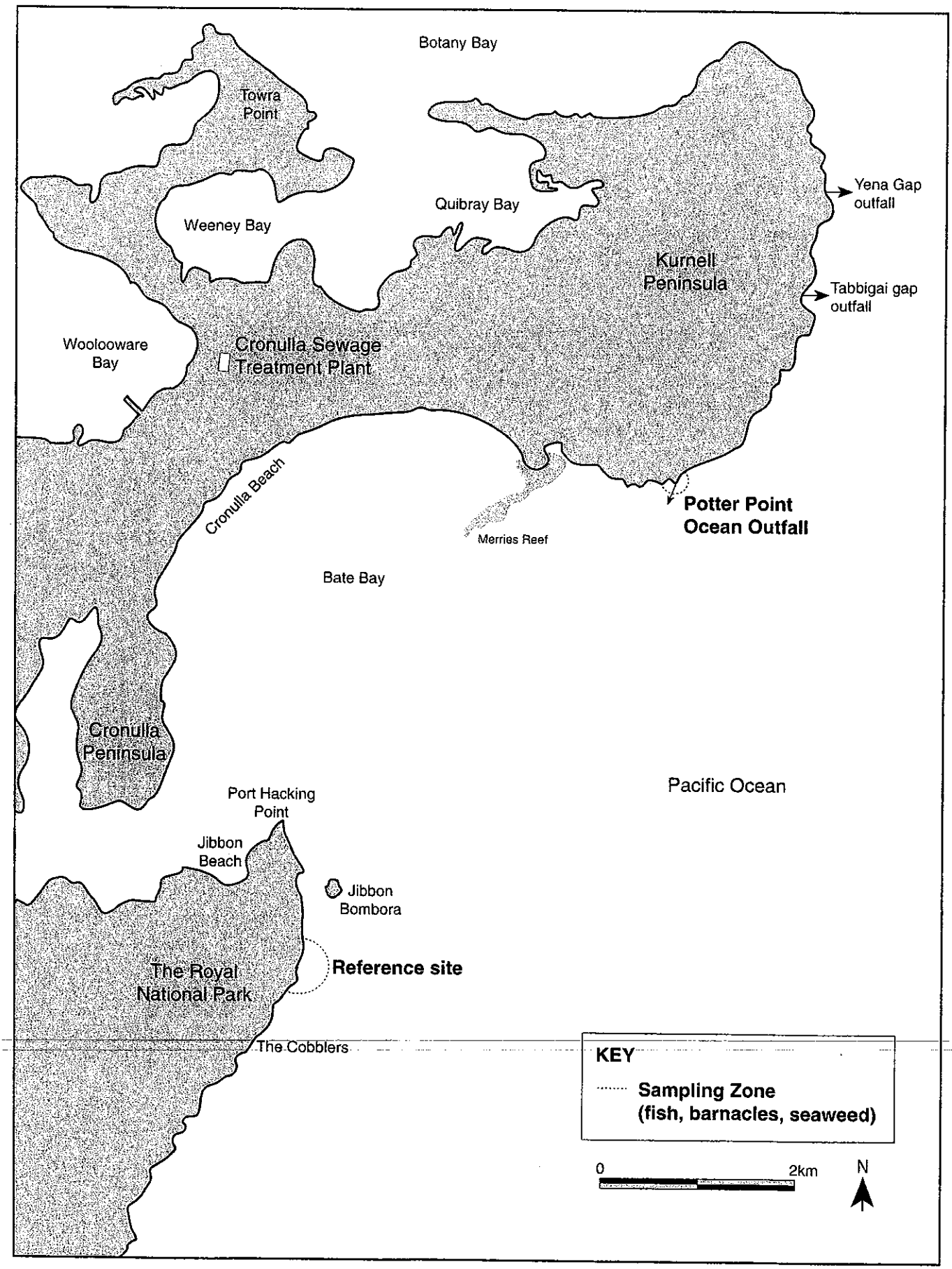

FIGURE 4
Location of Sampling Zones at Potter Point Ocean Outfall and the Royal National Park

1 INTRODUCTION

The Australian Nuclear Science and Technology Organisation (ANSTO) is a research and development agency of the Commonwealth Government of Australia. ANSTO owns and operates several large nuclear science and technology-based facilities, including the HIFAR research reactor, the National Medical Cyclotron (NMC) and the Australian National Tandem Accelerator. ANSTO provides services to industry, government, the research and development community and the community at large.

Figure 1 shows the location of the main ANSTO site at the Lucas Heights Science and Technology Centre (LHSTC), in relation to local roads, waterways and residential areas. The 1.6 kilometre radius buffer zone boundary around HIFAR is also shown. The National Medical Cyclotron is located next to the Royal Prince Alfred Hospital, in inner city Sydney (inset, **Figure 1**).

The activities undertaken by ANSTO are supported by specialist nuclear science and technology capabilities that include:

- the operation of national facilities;
- the manufacture of radiopharmaceuticals;
- occupational health and safety associated with the nuclear fuel cycle;
- application of radioisotopes, neutrons and radioanalytical techniques;
- mineral and chemical processing technologies;
- structural integrity assessment;
- advanced ceramics; and
- the management of radioactive waste.

ANSTO operations which involve radiation or radioactive material are regulated under the Australian Radiation Protection and Nuclear Safety Act 1998. The object of this Act is to protect the health and safety of people and to protect the environment from the harmful effects of radiation. The Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) has been established within the Health and Aged Care portfolio to implement the provisions of the Act and the associated regulations. Under the Act ARPANSA has the authority to undertake independent audit of the effluent and environmental monitoring programs at ANSTO sites.

ARPANSA is developing criteria against which the environmental monitoring performance, with respect to radiation, of Commonwealth organisations such as ANSTO will be assessed. These criteria include the identification and analysis of potential exposure pathways; the establishment, maintenance and regular review of pathways where exposure could be significant and the detailed documentation of any decision not to monitor a specific potential exposure pathway. A commitment to ensure that the environmental monitoring regime complies with relevant standards and codes and is in accordance with international best practice is also required. The criteria are drawn from the following sources:

- Commonwealth of Australia (1998), *Australian Radiation Protection and Nuclear Safety Act 1998*, Commonwealth Government Printer: Canberra
- Commonwealth of Australia (1999), *Australian Radiation Protection and Nuclear Safety Regulations 1999*, Commonwealth Government Printer: Canberra
- International Atomic Energy Agency (1996), *Health and Environmental Aspects of Nuclear Fuel Cycle Facilities*, IAEA-TECDOC-918, IAEA: Vienna;
- International Atomic Energy Agency (1996), *International Basic Safety Standards for Protection Against Ionising Radiation and for the Safety of Sources*, Safety Series No 115, IAEA: Vienna;
- Nuclear Energy Agency and International Atomic Energy Agency (1999), *Environmental Activities in Uranium Mining and Milling*, OECD: France;
- Worksafe Australia (1995), *National Standard for Limiting Exposure to Ionising Radiation* [NOHSC:1013(1995)], AGPS: Canberra

ANSTO has a Health, Safety and Environment Policy, which commits the Organisation to undertaking its activities in a manner that protects human health and the environment and is consistent with national and international standards. The Policy further mandates that all procedures are not only in accordance with Commonwealth legislation but also take account of relevant NSW regulations and Australian and international standards on environmental management and quality systems.

ANSTO provides verifiable evidence of the fulfilment of the policy through a program of monitoring and audit. In addition, the monitoring program is designed to detect and quantify any accidental releases of radioactive materials, should they occur.

This report summarises the results from the environmental and effluent surveys carried out at the LHSTC and NMC sites during 1999, and assesses the effects of radioactive discharges on both the local population and the environment. The results obtained in earlier surveys have been published regularly and are listed in **Appendix A**.

2 ENVIRONMENTAL EXPOSURE PATHWAYS

2.1 ENVIRONMENTAL PATHWAYS - LHSTC

The main environmental pathways by which radionuclides from LHSTC may potentially enter the environment and lead to radiation exposure of members of the general public are:

- atmospheric discharges from stacks (including tritium, volatile 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 disposal site at Little Forest; and
- accidental airborne releases, or liquid spills which enter the stormwater system.

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

2.1.1 Atmospheric Discharges from LHSTC

Atmospheric discharges from LHSTC have been regulated since 1968 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 now approximately 13 kilometres away (NSW Dairy Corporation, 2000). At this distance the milk pathway is not significant and is not considered further.

The hypothetical critical group for inhalation of airborne activity is people living close to the LHSTC perimeter at the 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 the Stevens Hall Motel and the air sampling stations.

The pathway for potential transfer of deposited airborne radioactivity to humans via ingestion of contaminated drinking water or vegetable produce is not considered to be significant, for the following reasons:

- any (small) ANSTO contribution to public dose would be dominated by external radiation from short-lived noble gases, which cannot be concentrated in the environment (ie water or foodstuffs) since they are inert;
- 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.

Never the less, the ingestion pathway for locally grown vegetables is included in the assessment of doses due to ANSTO's airborne effluent releases. The computer code used to model ANSTO's airborne effluent releases is called PC-Cream, see **Section 3.2**. In addition, levels of integrated external radiation at the LHSTC and in nearby suburban locations were measured during 1999 using dosimeters issued by ARPANSA.

As in the past, ANSTO would be pleased to measure the levels of environmental radioactivity in samples identified by the local community. Contact the Communications Manager at ANSTO for further information.

2.1.2 Low-Level Liquid Effluent Discharges from LHSTC

The low-level liquid effluent generated from various operations at the LHSTC is chemically treated, analysed and documented to verify compliance with authorised discharge limits before discharge to the Sydney Water sewer. In accordance with the Sydney Water Trade Wastewater Agreement (No. 4423, 1999) the authorised discharge limits for radioactivity are based upon the WHO Guidelines for Drinking Water Quality (1993), see **Section 3.1**.

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 consumption of fish caught around the Potter Point outfall and incidental ingestion of seawater near the outfall by swimmers and surfers.

Monitoring of the level of radionuclides from the LHSTC around 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 1999 results for tritium in seawater a short distance from the Potter Point ocean outfall are discussed in **Section 7** 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.

From July 1999 external gamma radiation levels at the CSTP were monitored using thermoluminscent dosimeters. The measurements were at background levels (see **Section 5.10**).

The monitoring programs at Potter Point confirm that the pre-discharge treatment of effluent at ANSTO, combined with the large dilution effects measured 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.

2.1.3 The Little Forest Burial Ground (LFBG)

Between 1960 and 1968 the 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 (non-radioactive) beryllium oxide that originated predominantly from LHSTC.

The disposal site was selected and wastes disposed of using international guidelines and best practice relevant at the time. Near-surface disposal is still 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 are 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.

Various government agencies and private companies have used areas adjacent to LFBG for the disposal of liquid industrial wastes, solid municipal wastes and nightsoil. Some nearby areas were quarried for clay and shale, until the closure of the quarries in December 1998.

Ground water and surface water associated with the LFBG and surrounding area are 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 strongly adsorbed onto the clay subsoil of the LFBG site.

Airborne contamination at LFBG could potentially occur through wind suspension of any 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 normal background radiation levels (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 soil cover, or if dissolved radionuclides were transported to the surface by ground water.

2.2 Environmental Pathways - The National Medical Cyclotron

The National Medical Cyclotron (NMC) is a national facility that provides isotopes for research, clinical evaluations and routine nuclear medicine procedures. It is owned and operated by ANSTO and is located adjacent to the Royal Prince Alfred Hospital in Camperdown, Sydney. The NMC supplies the hospital with very short-lived radiopharmaceuticals (such as fluorine-18 and nitrogen-13 compounds) and positron emission tomography (PET) dedicated pharmaceuticals.

The pathways by which radionuclides from the NMC may enter the environment are:

- atmospheric discharges of short-lived isotopes from stacks (such as iodine-123);
- discharge of low-level liquid effluent to the Sydney Water sewer system (typically containing thallium-201, thallium-202, gallium-67, cobalt-57, zinc-65 and iodine-123).

These emissions are monitored continuously and the monitoring results for 1999 are discussed in **Section 8** of this report.

3 DISCHARGE AUTHORISATIONS

ARPANSA is developing expectation guidelines for the routine discharge of radioactive waste to the sewage system and to the atmosphere. Broadly speaking, these guidelines are based on the following documents:

- Commonwealth of Australia (1999), *Australian Radiation Protection and Nuclear Safety Regulations 1999*, Commonwealth Government Printer, Canberra; and
- National Health and Medical Research Council (1985), *Code of Practice for the Disposal of Radioactive Wastes by the User (1985)*, AGPS: Canberra;

Key elements of these expectations include comprehensive documentation, monitoring and review of all discharges. ANSTO will need to ensure that appropriate Statutory Authorities are notified and the requisite approvals are obtained. ANSTO's Health, Safety and Environment Policy is fully consistent with these expectation guidelines.

In 1999 ANSTO complied with:

- new requirements prescribed by ARPANSA;
- all provisions of relevant NSW acts and regulations; and in particular
- provisions of the Sydney Water Trade Waste Service Agreements No. 4423 (1999) and No. 13966 (1994) for the LHSTC and NMC sites.

In 1999 ARPANSA began the process of independently auditing ANSTO's effluent and environmental monitoring programs at the LHSTC and NMC sites.

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 - LHSTC

In 1999 a revised Trade Waste Service Agreement was negotiated with Sydney Water. Under the terms of this Agreement ANSTO complied with:

- discharge levels for radioactive pollutants listed in Schedule 1, paragraph 1(b) of the agreement at the ANSTO composite effluent sampling and discharge point;
- the World Health Organisation (WHO) "Guidelines for Drinking-Water Quality" (1993) reference activity concentrations for radionuclides in drinking water at the Cronulla Sewage Treatment Plant; and
- concentration limits for non-radioactive components of the effluent.

The basis for compliance with the World Health Organisation (WHO) "Guidelines for Drinking-Water Quality" are set out in Schedule 1, paragraph 1(c) in the following terms:

" ...average monthly activity concentrations of discharges by ANSTO to the Sydney Water Corporation sewer shall not exceed 25 times the reference activity

concentrations for radionuclides as determined by the application of the methodology specified in the WHO "Guidelines for Drinking-water Quality" Volume 1 Recommendations, Second Edition (1993), corresponding to the reference level of dose of 0.1 mSv/year."

The drinking water reference concentrations for specific radionuclides are calculated by the following formula taken from the WHO Guidelines (1993):

Equation 1:

$$\text{Reference Activity Concentration (Bq/L)} = \frac{1.4 \times 10^{-7}}{\text{Dose conversion factor (Sv/Bq)}}.$$

It should be noted that the WHO drinking water guidelines assume that the water in question is the sole source of drinking water for 12 months of the year.

The dose conversion factors are those specified in the International Atomic Energy Agency International Basic Safety Standards (IAEA, 1996) Table II – VI and are listed in the following table.

TABLE A: Reference Activity Concentrations for Selected Radionuclides

Radionuclide Equivalent discharged	Dose Conversion Factor *From IAEA Safety Series No. 115* (Sv/Bq)	Drinking Water Reference Activity Concentration *Equivalent to a dose of 0.1 mSv/year* (Bq/L)	Activity Concentration in liquid effluent from ANSTO *25 x drinking water reference activity* (Bq/L)
Tritium	1.8×10^{-11}	7800	195000
Cobalt-60	3.4×10^{-9}	40	1000
Strontium-89	2.6×10^{-9}	54	1350
Strontium-90	2.8×10^{-8}	5	125
Iodine-131	2.2×10^{-8}	6	150
Caesium-134	1.9×10^{-8}	7	175
Caesium-137	1.3×10^{-8}	10	250
Radium-226	2.8×10^{-7}	0.5	12.5
Uranium-238	4.5×10^{-8}	3	75
Plutonium-239	2.5×10^{-7}	0.6	15

3.1.1 Radioactivity Concentration Limits

When monitoring liquid effluent at the ANSTO point of discharge to the sewer, all discharges must be below the relevant Activity Concentration Equivalent (ACE), which is defined as 25 times the drinking water Reference Activity Concentration (RAC). The ACE values are listed in the table above and are based on a conservative agreed dilution factor for ANSTO's discharges of 25 (allowing for dilution between ANSTO and the Cronulla Sewage Treatment Plant). The dilution factor is conservative, and was previously determined by tracer measurement and known flow rates.

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

Equation 2:
$$\sum_i \frac{C_i}{\mathrm{RAC}_i} \leq 1$$

For a mixture of unspecified alpha and beta radionuclides and tritium, the monthly concentration quotient is calculated using the summation formula in Equation 2, based on the ACE for the most restrictive alpha-emitters, beta-emitters and for tritium, ie

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

Where:

α = average gross alpha concentration in effluent discharged;
β = average gross beta concentration in effluent discharged;
^{3}H = average tritium concentration in effluent discharged; and
ACE = Activity Concentration Equivalent for the most restrictive radionuclide (or tritium), as specified by the Sydney Water Trade Waste Service Agreement, 1999.

Within the terms of the Trade Waste Service Agreement, it is assumed that all alpha and beta radiation come from the most restrictive nuclide of each type as defined in the table. Where the presumed most restrictive alpha or beta emitting radionuclide can be shown to be an insignificant fraction of the overall alpha emitting components in the effluent, then the activity concentration equivalent of the next most restrictive radionuclides shall be used.

In addition, ANSTO is required to:

- confirm that Ra-228 is not present in the waste water discharged to the sewer by analysing the monthly composite sample specifically for the Ra-228 content; and
- continue the investigation of reducing tritium in the waste stream. This activity is implemented through ANSTO's Waste Management Action Plan.

Composite samples of ANSTO's monthly liquid effluent discharges (proportionately sampled from all discharges for the month) are analysed for the beta-emitters radium-228 and lead-210, and for the alpha emitter radium-226. The results for samples analysed in 1999 were all less than the limit of detection, indicating that radium-228 and lead-210 are not present in the liquid effluent in significant proportions. Therefore unspecified (gross) alpha and beta emitting isotopes continue to be reported in terms of the ACE's for radium-226 and strontium-90 respectively.

3.1.2 Compliance Auditing of Liquid Effluent Discharges

In 1999, ARPANSA randomly requested some of the monthly pipeline composite samples from ANSTO's Waste Operations and carried out independent analyses. These analyses confirmed that discharges were in compliance with the Sydney Water Trade Wastewater Agreement. In addition, Sydney Water also collected random liquid effluent samples from the ANSTO discharge pipeline at LHSTC, to assess compliance with their requirements for the acceptance of liquid trade waste. Sydney Water did not raise any non-conformances against ANSTO in 1999. **Section 6.2** presents the results of ANSTO's compliance monitoring of LHSTC liquid effluent discharges.

3.2 Atmospheric Discharges from LHSTC

From 1968 until 1988, radioactive airborne emissions from AAEC/ANSTO were subject to a discharge authorisation approved by the NSW Radiological Advisory Council (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, to changes in site operations, to advances in radiation dosimetry and to increased knowledge of the meteorology at LHSTC. The revised authorisation limit 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 RAC accepted the proposal subject to a number of conditions, which were subsequently complied with.

3.2.1 LHSTC 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 Nuclear Safety Bureau (now ARPANSA) 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. It also confirmed

that a dose constraint of 0.3 mSv was appropriate for the whole site. As indicated above, the site dose constraint previously authorised by the NSW RAC was 0.5 mSv.

In June 1998 the Nuclear Safety Bureau authorised the use of a European computer code, PC-Cream [1] to replace the ANSTO-developed ADDCOR code[2] for estimating effective doses due to airborne discharges from the LHSTC site. This is an internationally accepted code that includes the latest ICRP dose conversion factors. The PC-Cream computer code has been used to generate estimated effective doses due to all site discharges from 1997 onwards. See **Section 6.1.**

3.2.2 PC-Cream Code Assumptions

Although the small ANSTO contribution to public dose is dominated by external radiation from noble gases, other pathways such as ingestion of vegetables are included in the PC-Cream dose assessment. A number of assumptions are used by PC-Cream for defining the critical groups of members of the public. These assumptions are generally conservative and may lead to some overestimation of the dose received. The following assumptions are included:

- a person is assumed to be outdoors at the boundary of the buffer zone 100% of the time for an entire year. Because they are assumed to be outdoors, shielding is not taken into account;
- 25% of the hypothetical person's diet of green vegetables (47 kg/annum), root vegetables (84 kg/annum) and fruit (148 kg/annum) is grown at the buffer zone boundary, and all other food is grown away from the local area. Diet is based on Australian Bureau of Statistics data;
- that the effective release height for airborne effluent is the same as the stack height (buoyancy, velocity and building wake effects are not included); and
- only adult doses are included (note that the calculated child and infant doses are approximately the same as the adult dose, due to the dominance of the contribution from noble gases).

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

3.2.3 Compliance Auditing of Atmospheric Discharges from LHSTC

ANSTO has monitored all stack discharges during the reporting period and ARPANSA has undertaken compliance auditing of ANSTO's stack discharge samples. See **Section 6.1** for a discussion of the stack monitoring results.

3.3 Surface Waters Near LHSTC

The Protection of the Environment Operations Act (1997) references the Clean Waters Regulations (1972) which were formerly associated with the Clean

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

Waters Act 1970. These regulations limit the gross alpha and gross beta activity in Class C surface waters to 1.1 and 11.1 Bq/L, respectively.

In 1985, in order to assess ANSTO's compliance with the regulations existing at the time, three sampling points on local streams were selected by the NSW State Pollution Control Commission (SPCC) [3] at Strassman, MDP and Bardens Creeks. These creeks, shown on **Figure 2**, receive most of the stormwater running off the LHSTC site. Results of stormwater and surface water sampling are discussed in **Sections 5.4** and **5.5** of this report.

3.4 National Medical Cyclotron

At the NMC the processes of manufacturing, purifying and preparing radionuclides for medical use results in the controlled release of small quantities of airborne and liquid effluent to the atmosphere and to the sewer. The radionuclides produced by the NMC are typically of a very short half-life ranging from minutes to a number of days. The airborne emissions are governed by limits set by the NSW EPA while the liquid waste discharges to the Sydney Water sewer are covered by a separate Trade Waste Agreement, No.13966 (1994).

All NMC emissions during 1999 were within the concentration limits prescribed by the NSW EPA and Sydney Water. See **Section 8** of this report.

4 MEASUREMENT OF RADIOACTIVITY

This section presents a brief description 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 keV to 2000 keV. The gamma photopeaks in the spectrum are then analysed for

[3] Now the NSW Environment Protection Authority (EPA)

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: is a fission-product that was widely dispersed around the world by atmospheric nuclear weapons testing. It has a half-life of 30.14 years. The isotope is deposited in precipitation or as 'dry' fallout, and adsorbs strongly onto fine sediments (like clays). A typical value for soils in the Sydney region is 1350 Bq/m^2 (Cole-Clark, 1993). 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.

Cobalt-60: is an activation product formed by the neutron activation of stable cobalt-59. 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: is a beta/gamma-emitting radionuclide with a relatively short half-life of 8 days. Iodine-131 is used in hospitals to diagnose and treat various diseases associated with the thyroid. It is biologically important because atmospheric releases of iodine-131 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. See **Appendix B** for the sources of airborne iodine-131 at the LHSTC. If present in water, iodine is more readily concentrated by marine biota than by freshwater organisms.

Tritium (^3H): is a radioisotope of hydrogen, with a half-life of 12.26 years. It decays with 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 WHO drinking water reference level for tritium is therefore relatively high in comparison with other radionuclides having more energetic radiations (see **Table A** in **Section 3.1**).

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). It is also produced 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 biological half-life of tritium is relatively short, with one half of the absorbed tritium being excreted from the body typically in the order of days. When present, tritium is found more or less uniformly distributed throughout living species, not accumulated in any particular organ. 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.

Tritiated water does not undergo geochemical processes such as ion exchange, adsorption or precipitation during transport through geologic media and can therefore be used as a tracer for groundwater movement.

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 progeny produced by their decay are ubiquitous in nature, occurring to varying degrees in soils, water, vegetation and air. When present in environmental samples, the decay 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, because of their natural origin. 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 products 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 1.28×10^9 years) is a primordial radioisotope of potassium, found in essentially all rocks, natural waters and material of plant and animal origin. 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 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 Quality Management

ANSTO's 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. Consistent with this policy, a formal commitment to quality systems is fundamental to obligations accepted by ANSTO within the framework of the environmental assessment process for the replacement reactor. ANSTO is currently introducing an ISO 9000/2000 regime across the site, (including the monitoring laboratories) and has made a commitment to Environment Australia to implement the ISO 14000 standard for Environmental Management.

4.3.1 Methods - Environmental Radiochemistry Laboratory

Australian or International Standard methods for radiological analyses are used, where they are available. Methods for gamma spectrometry, gross alpha, gross beta and tritium analyses of waters are documented and incorporate techniques based on those used by the Australian Radiation Laboratory (now ARPANSA). See **Appendix D** for details of sample analysis techniques.

Blanks and standards are either counted regularly or 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 were counted up to five times. Long counting times of 23 hours were employed for low-level gamma spectrometry samples.

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

4.3.2 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. See **Appendix D** for more information on counting statistics.

5 ENVIRONMENTAL MONITORING AT LHSTC

The monitoring program at LHSTC involves measurements of the radioactivity in local environmental samples as well as the liquid and airborne effluent discharged from the site. Details of the LHSTC effluent monitoring programs are presented in **Sections 6** and **7** of this report. Results of environmental monitoring at the National Medical Cyclotron site are presented in **Section 8**.

This section deals with the results of environmental monitoring carried out at the LHSTC in 1999. The Environmental Monitoring group is located in the Environmental Radiochemistry 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 1999 at the sites shown in **Figures 1 to 4** 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 environmental sample collection and preparation schedule is shown in **Table 1**. More detailed information on the collection, preparation and analysis

of environmental samples is available in **Appendix D**. Environmental survey results for 1999 are presented in **Tables 2 to 18b**.

5.1 Woronora River

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 1999 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 the confluence of Forbes and Loftus Creeks (tributaries of the Woronora River) was sampled monthly in 1999 and analysed for tritium. The samples were taken after rain, if possible, in Prince Edward Park where the Sydney Water supply pipeline crosses the creek, shown on **Figure 1**.

Sampling at Forbes/Loftus 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 1999, 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 commenced in 1995 and was designed to maximise the chance 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 6.5 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	*Enteromorpha sp. and Cladophora sp.*
Surf barnacles	Mainly *Tesseropera rosea*

The approximate quantities of biological material collected in 1999 were:

Total Mass of Biota Collected (kg fresh weight)			
	Blackfish	*Macroalgae*	*Barnacles*
Potter Point	0.91	3.09	1.80
The Royal National Park	0.49	0.70	0.60

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 unwashed and 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 4** and the results for fish, algae and barnacles are presented in **Tables 4, 5 & 6.** The radioactivity is expressed as becquerels per kilogram fresh weight. For details of the offshore monitoring at Potter Point, see **Section 7**.

Biological Monitoring Results

Gamma spectrometry of the biological samples collected in 1999 from Potter Point and The Royal National Park showed typical levels of naturally occurring radioisotopes, which are commonly found in marine specimens. These included beryllium-7, potassium-40 (ubiquitous in biological samples) and progeny of the uranium-238 and thorium-232 decay series, such as lead-210, thorium-224 and thallium-208.

In 1999, fish and barnacles sampled from Potter Point and The Royal National Park contained only natural radioactivity. Macroalgal samples (seaweed) collected from the reference site at The Royal National Park also contained only natural radioactivity.

Macroalgae sampled from the shore near the Potter Point ocean outfall contained small amounts of iodine-131 and cobalt-60 as well as the expected natural radioactivity. These isotopes have previously been detected in macroalgae from Potter Point at similar concentrations.

Iodine-131 is a beta/gamma-emitting radionuclide with a relatively short half-life of 8 days. It is an important medical isotope used in the treatment of thyroid cancer and is produced by the Radiopharmaceuticals Division at LHSTC. Cobalt-60 is also a beta/gamma-emitting radionuclide, with a half-life of 5.3 years. It is formed by the neutron activation of cobalt-59 (normal cobalt).

In the 1998 environmental monitoring report (ANSTO/ E-737) no cobalt-60 was reported in macroalgae from Potter Point. These samples were checked for cobalt-60 and the trace amounts present were calculated to be less than the minimum detectable activity.

It is now recognised that the presence of cobalt-60 in the 1998 samples was underestimated because the counting was undertaken on a high efficiency, high resolution gamma spectrometer with Compton-suppression capability. The Compton suppression system excludes counts that occur coincidentally in the sample and background detectors, providing a "suppressed" spectrum with lower background for many radionuclides. However, its effect was to discriminate against cobalt-60 because the isotope emits two gamma rays (1.17 and 1.33 MeV) essentially in coincidence. When the 1998 algal samples were subsequently re-assayed they showed low, detectable levels of cobalt-60. For completeness, all available cobalt-60 data for Potter Point algae are reported in the table below. The levels are far too low to be of any health significance.

Concentrations* of Cobalt-60 in Macroalgae (seaweed) from Potter Point Bq/kg FW					
	1995	1996	1997	1998	1999
January					
February	N.D.				
March				2.4 ± 0.3	
April					1.0 ± 0.2
May		N.D.			
June			N.D.		
July					
August					
September					2.8 ± 0.3
October		N.D.	N.D.	0.8 ± 0.2	
November	2.4 ± 0.4				
December					

*where several samples were collected, the maximum value is reported.

Consistent with ARPANSA guidelines, a further study is being made of the cobalt-60 environmental pathway, however it is worth noting the following:

- A simple calculation of dilution and subsequent concentration in the algae assumes dilution ratios taken from the 1994 Environmental Monitoring Report (Hoffmann *et al.* 1995), followed by a recommended concentration factor (CF) for cobalt of 10 000 in macro-algae (IAEA 1985). Using averages of the recorded cobalt-60 in released effluent (5 - 6 Bq/L for 1998 and 1999), the predicted activity in the algae is 3.7 - 4.4 Bq/kg, compared with 2.4 - 2.8 Bq/kg actually measured in the algae (see table above). The uncertainties associated with both the CF and the dilution ratio make this a surprisingly good agreement and support the conclusion that the environmental pathway of cobalt-60 between ANSTO and the macroalgae growing at Potter Point is adequately understood.

The levels of iodine-131 and cobalt-60 found in algae (seaweed) from Potter Point are of no health significance to humans, particularly since no cobalt-60 has been detected in blackfish (despite the fact that these fish consume the algae). The potential radiation dose to members of the general public as a result of ANSTO's discharges to the sewer is extremely low, at least 1000 times less than the NH&MRC recommended dose limit for members of the public.

It should be noted that ANSTO is not the only source of radionuclides entering the sewer system in the Sutherland Shire, since hospitals using nuclear medicines would also be a source of radionuclides such as iodine-131. Stormwater can also contain low levels of natural radioactivity from sediments in catchment run-off.

5.4 STORMWATER

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.

Stormwater Retention Bunds

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

Bund A - Opposite Building 1;
Bund B - Opposite the meteorological tower;
Bund C - (MDP) below the Waste Management area.

The MDP bund is on the drain previously known as Stormwater Outlet No.1, which drains the Waste Management area into MDP creek.

The stormwater bunds are inspected and discharged daily.

5.4.1 Tritium in Stormwater Bunds

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. Further information on tritium is presented in **Section 4.1**.

In 1999 bunds A & B were sampled monthly, while bund C samples were collected weekly. All of these samples were analysed for tritium and the results are shown in **Tables 7a** and **7b.**

Tritium was detected in stormwater bunds B & C at levels well below the WHO drinking water reference concentration of 7800 Bq/L (**Section 3.1.2**). The range of tritium values recorded for bunds B and C were < 20 to 150 and < 20 to 180 Bq/L, respectively.

Apart from one sample, the levels of tritium measured in 1999 at Building 1 bund did not exceed 230 Bq/L. The 26 July sample recorded 8260 Bq/L. This is slightly above the WHO drinking water reference concentration of 7800 Bq/L, which assumes 12 months of ingestion from a single source of drinking water. This bund is on-site and stormwater from the Building 1 bund clearly does not contribute to a drinking water source.

The 26 July value was observed during a period when HIFAR was shut down for routine maintenance, subsequently three actions were initiated. Firstly, under the Waste Management Action Plan, all operations during shutdowns were reviewed to minimise any potential tritium releases. Secondly, under the Environmental Management Action Plan, an investigation is being implemented to better understand the source term of tritium in stormwater. Thirdly, a change has been made to the bund sampling procedure for the year 2000, whereby daily water samples are now collected at each bund. The daily samples are combined to form a monthly composite for each bund, which is then distilled and analysed for tritium. The tritium levels recorded in the Building 1 bund in 1999 had no health consequences for humans or the environment.

5.4.2 Radioactivity in Water from MDP Bund C - Monthly Composite

The MDP bund weekly water samples were combined to make a monthly composite sample, which was analysed for gross alpha, gross beta and gamma radioactivity. The results are given in **Table 7c**.

The average gross alpha/beta activities of the monthly MDP bund C composite samples for 1999 (including less-than values) were: gross alpha < 0.04 Bq/L; gross beta 0.72 Bq/L.

These values can be equated with average weekly results for 1999 and are well below the limits prescribed in regulations associated with the Protection of the Environment Operations Act (1997): for Class C waters the gross alpha and gross beta activity limits are 1.1 Bq/L and 11.1 Bq/L respectively.

Gamma spectrometry performed on the monthly composite samples showed low caesium-137 concentrations measured in 11 out of 12 months. The only other significant gamma-emitters detected were potassium-40 and beryllium-7, both of natural origin. The average weekly concentration of caesium-137 in MDP bund C was 0.042 Bq/L, or 0.4% of the WHO reference value for caesium-137 in drinking water. Similar, low levels of caesium-137 have been detected in previous years.

5.4.3 Sediment from Stormwater Bunds

Sediment that has accumulated in the stormwater bunds is removed at least once each year. These sediments are analysed for gross alpha, gross beta and gamma radioactivity. Results for sediment collected from the three bunds in 1999 are given in **Table 8**. Gross alpha/beta activities found in 1999 corresponded to normal levels for similar sandy soils of the Sydney region. Gamma-emitters detected included potassium-40, progeny of the uranium-238 and thorium-232 decay series and small concentrations of fission and activation products. The low-level activities found do not have any health consequences for humans or the environment.

5.5 Surface Waters

5.5.1 MDP Creek (MDP+60m)

Stormwater and groundwater from the southeast corner of the site drain into MDP creek (**Figure 2**). Historically, the water from this area has been sampled about 60 metres below the actual stormwater outlet itself, known as MDP+60m.

In 1999, as in previous years, part 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 also analysed for tritium.

Tritium in Water from MDP+60m - Weekly
Tritium results for the weekly MDP+60m water samples are shown in **Table 9a** and varied from < 30 to 160 Bq/L. The average tritium concentration of weekly

samples for the year was about 75 Bq/L, which is less than 1% of the WHO drinking water reference concentration.

Radioactivity in MDP+60m - Monthly Composite
Gross alpha and gross beta radioactivity results for monthly composite MDP+60m water samples were at background levels throughout the year, see **Table 9b**. The average activities were < 0.03 Bq/L for gross alpha and 0.43 Bq/L for gross beta. These values can be equated with average weekly results for 1999 and are well below the relevant NSW regulations limits for Class C waters: 1.1 Bq/L for gross alpha and 11.1 Bq/L for gross beta activity.

The levels of caesium-137 in creek water from the MDP+60m sampling point ranged from non-detectable to 0.038 Bq/L. The maximum value observed represents < 0.4% of the WHO drinking water reference concentration.

5.5.2 SPCC Creek Sampling Points

Sampling locations on Strassman Creek, Bardens Creek and MDP Creek (shown on **Figure 2**) are known as the "SPCC" creek sampling points because they were originally selected in 1975 by the State Pollution Control Commission [4]. Stormwater from the LHSTC flows into these small local streams, which are classified as Class C waters under the NSW regulations associated with the Protection of the Environment Operations Act (1997).

Table 10 contains the results of gross alpha and gross beta analyses conducted on the 1999 SPCC creek water samples. Note that the gross beta results include the contribution of natural potassium-40 activity. All results for 1999 were well below the limits for gross alpha and gross beta activity in the relevant NSW regulations. The gross alpha and beta results were also below the more restrictive Australian Drinking Water Guidelines levels of 0.1 Bq/L for gross alpha and 0.5 Bq/L for gross beta activity.

5.5.3 Bardens Creek Weir

In addition to the monthly sampling (see above), weekly water samples were also collected from the sampling weir on Bardens Creek during 1999. The results of tritium analyses performed on these samples are shown in **Table 11**. The highest value recorded during the year was 400 Bq/L, which is 5% of the WHO reference concentration for tritium in drinking water (**Section 3.1**). The average weekly concentration at this location was less than 70 Bq/L, or < 1% of the WHO reference concentration. It should be noted that water from Bardens Creek is not part of any known drinking water supply.

5.5.4 Surface and Stormwater Summary

Except for one bund A sample discussed above, the levels of tritium and gamma activity found in stormwater at LHSTC and associated watercourses are very low when compared to the WHO drinking water quality guidelines. Gross alpha/beta results are well below the limits specified in the relevant NSW regulations. Since the levels of detected activity are very low, and stormwater

[4] Now the NSW Environment Protection Authority

does not enter any known human drinking water supply, it is concluded that there are no environmental or health consequences to humans from the measured radioactivity in stormwater from LHSTC.

5.6 Effluent Discharge Pipeline Gamma Survey

The ANSTO liquid effluent disposal pipeline, which runs above ground for part of its length, is shown on **Figure 2**. Surveys of the dose rates along this pipeline were carried out in 1999, and the results are summarised in **Table 12**. These surveys are performed as part of the regular program of inspection and maintenance of the pipeline in order to detect any past or present leaks.

The dose rates were recorded along the pipeline in 1999 using a Nuclear Enterprises PDR-1 dose-rate meter. The dose rates recorded did not exceed 0.6 μSv/hour and were principally due to natural background radiation.

On May 25, 1999 contractors performing excavations for Sydney Water in Engadine accidentally damaged part of the underground ANSTO discharge pipeline. The damage was limited to a five-centimetre rupture of a scour valve. Effluent was not being discharged through the pipeline at the time, so the residual wastewater that escaped (estimated at around 1500 L) was restricted to a small area.

In response to this event, the Environmental Monitoring group collected samples of the effluent and surrounding soil. The analysis of these samples for gross alpha/beta, tritium and gamma radioactivity showed that the effluent contained low levels of radioactivity, typical of a routine discharge. There were no effects to humans or the environment as a result of this incident.

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 on **Figure 3**.

5.7.1 Gamma 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 in December 1999 ranged from 0.5 to 1.0 μSv/hour and were consistent with the background readings. Two points near the centre of the trenches, known as #5 and #6, have shown slightly elevated readings in the past. These were also at background levels in 1999.

5.7.2 Soil

The criterion for collection of soil samples from the LFBG is as follows: if the gamma radiation survey of the trenches indicates an area that shows more than three times the background reading, soil samples are collected. This criterion was not met in 1999 therefore no soil samples were collected. During the year several areas in the trench zone were top-dressed with clay/shale of local origin.

5.7.3 Groundwater Monitoring at LFBG

Groundwater from 15 monitoring bores located both inside and outside the fenced LFBG area were collected in May and November 1999 and analysed for tritium, gross alpha, gross beta and gamma activities. Results are listed in **Table 14**.

Gamma-emitters in Groundwater
No artificial radionuclides were detected in any bores other than OS2 (one of the older series of bores) and MB16 (in the centre of the trench area). Bore OS2 contained a low level of americium-241 (0.017 ± 0.003 Bq/L) and MB16 contained traces of cobalt-60 and caesium-137. The concentrations of cobalt-60 and caesium-137 in MB16 were less than 1% of the relevant WHO drinking water reference concentrations. The amount of americium-241 found in OS2 was below 3% of the WHO drinking water reference concentration (0.69 Bq/L).

Gross Alpha/Beta Activity in Groundwater
The levels of gross alpha and gross beta activity in groundwater from LFBG comply with the NSW regulations associated with the Protection of the Environment Operations Act (1997) for Class C waters. Except for the gross alpha activity in bore MB16, all the gross alpha and gross beta groundwater results were below the NH&MRC Australian Drinking Water Guidelines levels (0.1 and 0.5 Bq/L respectively). The 1999 results continue to show a reduction in gross alpha and gross beta activities when compared to pre-1996 values and this trend is attributed to improved sampling methods implemented in 1996, which exclude sediment from the water samples.

Tritium in Groundwater
For bores inside the fenced area, tritium concentrations in 1999 were within the range of previous measurements, with detectable tritium levels in eight out of fifteen bores sampled: BHF, BH10, OS2, OS3, MB13, MB16, MB17 and MB18. Bore MB16, being in the centre of the trenches, had the highest tritium concentration at 6460 Bq/L, 83% of the WHO reference concentration for tritium in drinking water.

Tritium concentrations in the seven remaining bores remain at background levels including the three bores that are outside the fenced LFBG area: MB19, MB20 and MB21.

5.7.4 Stream 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.

5.7.5 Airborne Particulates at LFBG

An Ecotech high-volume air sampler was operated at the Little Forest Burial Ground once every two weeks for 4 to 6 hours during normal working hours. Sampling was not performed during wet weather when airborne dust levels will be negligible. Built to United States Environmental Protection Authority specifications, the sampler was commissioned in October 1997 to replace the

previous solar-powered monitoring station. The Ecotech sampler is capable of collecting far greater quantities of air than the previous system. See **Appendix D** for further details.

The results for airborne particulate monitoring at LFBG in 1999 are given in **Table 16**. At the end of each three-month sampling period, the exposed filter was divided into four equal portions. Two of these were used for beryllium and plutonium analyses; the remaining two portions were stored. Beryllium and plutonium were not detected on the filter portions analysed in 1999.

5.7.6 Wind Speeds at LFBG

In 1999, during periods of air sampling at the LFBG, the average wind speed at LHSTC was 3.6 metres per second and the data range was 1.7 to 6.7 metres per second. This information was obtained from 15-minute averages of wind speed data recorded at the 10 metre high ANSTO meteorological tower, during the actual periods that sampling was undertaken at the LFBG. The wind data collected at ANSTO is considered to be representative of conditions at the nearby LFBG (G. Clark, ANSTO Meteorologist, personal communication, 1999). For further information on the meteorological monitoring carried out at Lucas Heights see **Section 5.9**.

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. 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. Nigel Holmes and Associates (1991) 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.

The LFBG has an established vegetation cover consisting of grass and scattered shrubs, which considerably minimises the potential for dust generation. Analysis of all wind speed data from Lucas Heights for the period April 1991 to June 1998 showed only 4% of cases where the wind speeds exceeded 5.6 metres per second (G. Clark, 1999 unpublished data).

5.7.7 LFBG Summary

The LFBG is a stable, grass-covered area, which rarely experiences winds capable of significant dust generation. The possibility that contaminated airborne particulates could be transported off-site is remote. Radiological exposures to members of the public from the LFBG continue to be assessed as negligible.

5.8 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.** Iodine-131 is the nuclide of interest since it could

potentially be incorporated into the food chain. Noble gas emissions cannot be detected using this method as they are inert and very short-lived.

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 airflow-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).

No iodine-131 was detected in ambient air at the site boundary during 1999. All results were below the detectable level of 0.0025 Bq/m^3 (see **Table 17**). The minimum 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 the fifty-two measurements in 1999 showed no detectable iodine-131, the average annual dose to the public from iodine-131 is clearly far less than 0.01 mSv [5].

5.9 METEOROLOGICAL MONITORING AT LHSTC

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 LHSTC 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 [6], which is used to compute the effective dose to an individual due to the routine airborne or accidental release of radionuclides from the LHSTC.

The meteorological data are collected and analysed continuously. The long-term climatology data for Lucas Heights are updated and published every five years. The on-site meteorological tower and associated laboratory are shown on **Figure 2.**

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**). Due to repeated vandalism, the meteorological station at the Lucas Heights Community School was removed in September 1998.

Wind Speed and Direction

Annual average wind speeds recorded at Lucas Heights from 1991 to 1996 were approximately 2.5 metres per second (Clark, 1997).

[5] Based on the Committed Effective Dose per Unit Activity given in the International Basic Safety Standards (1996), Safety Series No 115.

[6] Refer to ANSTO Safety and Reliability Report SD/SR/TN98-7 revision 1, August 1998.

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*	*Wind Direction*
SUMMER	Daytime sea-breeze	From NE – ENE sectors
	Night / early morning	From SSE – SSW sector
WINTER	Daytime	From W – NW and S – SE sectors
	Night / early morning	From S – WSW sectors

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 total rainfall at Lucas Heights in 1999 was 1130 mm, recorded on 139 rainy days. The wettest month was October, with 211 mm of rainfall. The average annual rainfall recorded since 1958 has varied from a minimum of 556 mm to a maximum of 1658 mm.

Temperature
The coldest month at Lucas Heights in 1999 was June with an average midday temperature of 13.8 ^{0}C while the warmest month was January, when the average afternoon temperature was 26.6 ^{0}C.

The temperature extremes recorded in 1999 were:
Minimum: 4.2 ^{0}C in June and July;
Maximum: 37.2 ^{0}C in January.

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.

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 1999 with both ANSTO and ARPANSA thermoluminescent dosimeters (TLD).

The dosimeters issued by ARPANSA 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 2 shows the locations of dosimeters 1 to 15.

TLD Results

Table 18a shows the integrated annual absorbed dose to air, in millisieverts, as monitored by the ARPANSA dosimeters for the calendar year 1999, and compares these figures with results for 1995 through to 1998. Measurements were made over quarterly monitoring periods, the dosimeters were returned to ARPANSA for measurement, and the readings were reported to ANSTO as annual absorbed dose to air in terms of milligrays (mGy). The absorbed dose was then converted to effective dose (millisieverts) using the conservative conversion factor of one [7].

The 1999 annual doses measured at or within the LHSTC perimeter fence, apart from location 2, ranged from 0.7 mSv to 1.1 mSv. The dose at location 2 was 3.2 mSv. The 1999 annual absorbed dose to air due to environmental radiation measured outside three homes in the vicinity of the LHSTC averaged 0.8 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 Australian Radiation Laboratory (now ARPANSA) 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 local residences have remained constant (within measurement tolerances) since the introduction of TLD monitoring in 1994.

The external gamma dose at location 2 (on the inner perimeter fence) has been slightly elevated since 1997, when stored radioactive materials were relocated to the area. In 1998, Safety Division conducted a comprehensive dose rate survey both inside and outside the perimeter fence. The results of this survey, together with a consideration of occupancy factors, indicate that there is no need for further shielding of the storage building. This location is about 1.8 km away from any residential areas and there is no public occupancy of the area.

In July 1999 an additional dosimeter was placed at the Cronulla Sewage Treatment Plant at the request of Sydney Water, for the reassurance of personnel working at the plant. The annual effective dose values for the Cronulla Sewage Treatment Plant were at background levels (estimated from the two quarterly measurements in the last half of 1999).

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

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

6 EFFLUENT MONITORING AT LHSTC

ANSTO's Safety Division performs the routine monitoring of the airborne effluent released from LHSTC stacks. The Waste Operations group within Nuclear Technology Division is responsible for the routine handling, treatment, sampling and authorised discharge of liquid effluent arising from operations at LHSTC. ARPANSA performs an independent role in auditing the monitoring programs at both the LHSTC and NMC sites. 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 2**. **Appendix B** summarises the types of stack discharges that occur at LHSTC and comments on their causes.

Stack Sampling
During 1999, 12 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).

The Maypack cartridges are initially analysed by gamma spectrometry and the particulate filters for gross alpha/beta activity. The cartridges and the filters are then stored for 4 weeks. Some of the particulate filters are measured again for gross alpha and gross beta activity 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 in airborne effluent are measured in situ by a gamma spectrometer as the effluent passes through a 250 mL sampling flask.

Airborne Emission Data
Tables 19a, 19b, 19c and 19d present the 1999 airborne emission data for the individual stack release points at LHSTC, on a quarterly basis.

During the January-March quarter of 1999 the levels of iodine-131 and beta activities discharged from the building 23A radiopharmaceutical production facility were above routine (**Table 19a**). An anomalous release of iodine-131 was reported for the week ending 16 February 1999, which was investigated by ARPANSA and ANSTO. Since iodine-131 is a beta/gamma emitter, an

associated increase in beta activity from the building 23A stack was also observed. The outcome was that ANSTO installed an on-line monitoring system to provide immediate information on discharge levels, thereby limiting further occurrences.

The airborne effluent stack discharge data for the 1999 calendar year were used to estimate possible doses to members of the public due to airborne releases from the LHSTC site in 1999 (see **Section 9.1**).

It should be noted that the public doses due to the discharges are very low. At the 1.6km exclusion zone boundary the estimated doses were less than 0.010 mSv/year, well below the 0.3 mSv site dose constraint and much smaller than the public dose limit of 1 mSv/year, or the natural background of 2 mSv/year.

Independent Audit of Stack Emissions
Throughout the year, upon ARPANSA's request, ANSTO provided sets of weekly stack samples to ARPANSA for the purpose of auditing ANSTO's emissions. These independent checks confirmed that ANSTO's stack monitoring system was operating correctly in 1999.

6.2 Low-Level Liquid Effluent Discharges

The Waste Operations group at ANSTO is responsible for the handling, treatment, monitoring and authorised discharge of liquid effluent arising from operations at LHSTC. The Waste Operations facilities are located on the south-east corner of the site, see **Figure 2**.

Treatment and Discharge
To facilitate treatment, wastewater is segregated into three categories:

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

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

The liquid trade waste, treated low activity effluent and treated sewage are combined in the effluent plant holding tanks. The levels of radioactivity in each holding tank are checked for compliance with the Trade Wastewater Agreement prior to discharge to the Sydney Water sewer. Proportional samples from the discharge pipeline are also collected during each release of 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 Wastewater Agreement (as are the individual pipeline samples that make up the monthly composite).

Liquid Effluent Results

Radioactivity levels in liquid effluent discharges to the Sydney Water sewer are summarised in **Table 21**. The monthly average gross alpha, gross beta and tritium concentrations were calculated using the results for proportional samples collected during each discharge. **Table 21** also shows the concentration quotients calculated using equation 3, **Section 3.1**. All quotients were below the limit (ie < 1), demonstrating compliance with the Sydney Water Trade Wastewater Agreement.

In 1999 the concentrations of alpha emitters were below the detection limits and, for this reason, quotients are reported as less than values.

Groundwater seepage from the area below Building 27 was analysed monthly in 1999 (**Table 20**). Building 27 houses the in-ground storage of the HIFAR spent fuel elements. No significant gamma activity was detected other than naturally occurring potassium-40. Tritium levels were less than 8 % of the WHO drinking water guideline value of 7800 Bq/L.

Liquid Effluent Compliance

The average monthly quotient term (based on the WHO Activity Concentration Equivalents at the ANSTO discharge point) for radioactivity in liquid effluent for 1999 was < 0.16. This represents less than 16% of the limit. Individual monthly quotients ranged from < 0.11 to < 0.22. Levels of radium-228 and lead-210 were measured in monthly composite effluent samples for 1999 and showed that concentrations of these beta-emitting radionuclides were below detectable levels. ANSTO is therefore continuing to report gross alpha and gross beta activities in terms of radium-226 and strontium-90.

Non-Radioactive Components of Liquid Effluent

All discharges for the year were analysed for the following non-radioactive components: suspended solids; pH; ammonia; biological oxygen demand; grease and chromium. The data are listed in **Table 22** as yearly averages recorded from 1996 to 1999. The standards for acceptance of the trade waste are also listed against each component. All discharges in 1999 complied with the relevant standards for acceptance of trade wastes to the sewer, as required by Sydney Water.

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 of NSW (**Figure 4**).

Some public interest groups have in the past expressed concern that treated liquid effluent discharged to the sewer from LHSTC may be a radiation hazard to swimmers and surfers in the vicinity of the Potter Point ocean outfall.

In order to address these concerns ANSTO has carried out biannual investigations at Potter Point since 1995, with the following objectives:

- to measure the transit times and dilution factors between Lucas Heights and the Cronulla Sewage Treatment Plant (CSTP);
- to study the dispersion of tritium in the vicinity of the outfall; and
- to continue the biological monitoring program at Potter Point outfall.

Two routine effluent releases from LHSTC were monitored during 1999. See **Section 5.3** for the Potter Point biological monitoring results.

Modelling of the Effluent Plume
In 1997 ANSTO commissioned Unisearch Water Research Laboratory (WRL) to model the plume dispersion using the conditions prevailing during an effluent release in May 1997. See ANSTO/ E-732, Section 7.3 for a full report on the WRL modelling of the Potter Point plume.

It is now possible to calculate the concentrations of tritium at any location at sea and at any time since the implementation of the WRL model, given:

- the concentration and times of effluent release at ANSTO;
- the average transit times and dilution factors between ANSTO and Potter Point; and
- offshore dilution factors calculated from the model.

Two releases of ANSTO treated liquid effluent to the sewer were monitored in 1999, the first was in June and the second in December. The effluent was sampled at three stages: prior to its release from LHSTC; at the exit to the CSTP; and in the sea offshore of the Potter Point (near the ocean outfall). Details of these two surveys follow.

7.1 JUNE 1999 - EFFLUENT STUDY

Tritium levels in the offshore effluent plume at Potter Point were investigated on 10 June 1999. The contents of a holding tank at Lucas Heights were released between 22:00 hours on 9 June 1999 and 01:00 hours on the following morning. The total volume released over three hours was 220 kilolitres, with an average tritium concentration of 5042 Bq/L. On this occasion the tritium concentration in effluent released to the sewer from LHSTC was less than the WHO drinking water reference value.

Effluent Transit Time to Cronulla STP Outlet
An automatic sampler was used to collect hourly samples of effluent near the outflow of the CSTP. 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 maximum tritium concentration observed at the CSTP, was approximately 9.5 hours. This is consistent with effluent transit times obtained in previous studies, ranging from 9.6 to 12 hours.

Offshore Sampling
On exiting the CSTP, the treated sewage travels via a pipeline to the Potter Point outfall where it enters the ocean (this takes approximately one hour). The ANSTO Environment Division research vessel Imara conducted an hourly

sampling program from 09:00 to 15:00 hours on 10 June 1999. Two-litre samples of water were taken from the visible effluent plume, at depths of 0.5, 1.0 and 2 metres.

The samples were taken from three points 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 20 metres from the ocean outfall. Of the remaining stations, #2 was positioned 80 metres ESE of the outfall and #3 at 130 metres SSE, within the sewage plume.

Tritium Results

The water samples were analysed for tritium concentration by liquid scintillation counting. Tritium was detected in 4 of 21 samples taken from station #1. Very little tritium was found in samples from stations #2 or station #3 (detected in only 2 and 3 cases of 21 samples, respectively). Due to the calm sea conditions, which were unfavourable for dispersion, the effluent tended to "pond" in the vicinity of the outfall. Despite this, the maximum tritium concentration at the outfall (station #1) was only 36 Bq/L (at 0.5 metre depth, collected about 12 hours after the release began). This value is 0.5% of the WHO reference value for tritium in drinking water.

The average tritium concentration in the effluent released from LHSTC on 10 June 1999 was 5042 Bq/L and the highest concentration in samples taken the next day at the outflow of the Cronulla STP was 170 Bq/L. The *minimum in-line dilution ratio* was therefore approximately 30:1. This is consistent with previously observed values for overnight releases outside normal business hours, which were 27, 22, 29, 32 and 50. 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. This means that even higher dilution factors are expected during the more routine daytime releases.

On this occasion, the *offshore dilution ratio* (from the outlet of the sewage treatment plant to the sampling station nearest the outfall) was calculated at around 5:1. This value is lower than offshore dilution ratios previously observed, due to the fact that the sea was extremely calm and it was possible to position the sampling vessel *Imara* within a few metres of the outfall. Further, the sewage effluent has a lower density than seawater and tends to concentrate near the surface under calm conditions.

7.2 DECEMBER 1999 – EFFLUENT STUDY

ANSTO's Environment Division investigated tritium levels in the offshore effluent plume at Potter Point on 23 December 1999. Between 22:00 hours on 22 December 1999 and 01:00 hours on the following day, 210 kilolitres of treated liquid effluent was released from Lucas Heights to the Sydney Water sewer. The tritium concentration of the effluent in the holding tank was 8113 Bq/L.

The maximum tritium concentration of effluent passing through the Cronulla sewage treatment plant occurred at 10:10 am on the 23 December at 177 Bq/L.

The *minimum in-line dilution ratio* from Lucas Heights to the Cronulla STP was approximately 45:1 and the transit time 10.5 hours.

Sampling of the effluent plume offshore of the Potter Point outfall was undertaken from the *Imara* vessel, at hourly intervals from 09:00 until 13:00 hours. After this time, the increasing wind strength and worsening sea conditions meant that sampling had to be discontinued. Sampling station #1 was located 65 metres south of the outfall (not as close as usual) due to the choppy seas. Station #2 was approximately 85 metres southeast of the outfall whilst station #3 was about 80 metres SSE.

The weather conditions on the day ensured effective dispersion of the effluent. No tritium was detected in any of the 45 samples taken from the three sampling points at depths of 0.5, 1 and 2 metres (all were less than the 15 Bq/L limit of detection for tritium).

8 THE NATIONAL MEDICAL CYCLOTRON

The National Medical Cyclotron (NMC) is one of ANSTO's national facilities and is located at the Royal Prince Alfred Hospital in Camperdown, Sydney (see **Figure 1** inset). It is primarily used to produce radiopharmaceuticals for use in two diagnostic imaging systems - positron emission tomography (PET) and single photon emission computed tomography (SPECT). The radionuclides produced by the NMC are typically of a very short half-life (particularly for PET), ranging from minutes to a number of days. Because of the very short half-life of some of the radiopharmaceuticals, they need to be administered to the patient very soon after they are produced. The NMC was therefore located physically close to major Sydney hospitals to minimise the delay between production and patient use.

SPECT radiopharmaceuticals produced at the NMC include:

- Gallium-67, which is used to diagnose soft tissue tumours and some inflammatory lesions. It has a half-life of 78 hours;
- Thallium-201, which is used to assess heart conditions. It has a half-life of 74 hours; and
- Iodine-123, which is used to diagnose certain thyroid diseases. It has a half-life of 13 hours.

PET radiopharmaceuticals produced at the NMC include:

- Fluorine-18 Fluorodeoxyglucose, which is used to diagnose brain disease and to assess the spread of cancers. It has a half-life of 110 minutes;
- Nitrogen-13 Ammonia, which is used for the early detection of coronary disease. It has a half-life of 10 minutes; and
- Oxygen-18, which is used to study oxygen metabolism. It has a half-life of 2 minutes.

As a result of the manufacture, purification and preparation of radiopharmaceuticals, small quantities of radionuclides are discharged from the NMC to the atmosphere and to the sewer. These emissions are monitored continuously and the monitoring results for 1999 are detailed in **Tables 23a** and **23b**. The tables also list the authorised airborne and liquid effluent discharge limits as prescribed by the NSW EPA and in the Trade Waste Agreement with Sydney Water, respectively.

An increase in the discharge of iodine-123 (**Table 23a**) from the NMC was recorded in July 1999 and was reported to ARPANSA. The July value was 12 % of the NSW EPA limit. The change in levels of iodine-123 recorded during the second half of 1999 resulted from a combination of improved production yields and an increased monitoring efficiency for post-production releases. In December 1999, the iodine-123 discharge was less than 2 % of the EPA limit. Additional work has been undertaken to further reduce the emissions.

All airborne and liquid effluent emissions from the NMC during 1999 were well within the NSW EPA and Sydney Water limits.

9 POTENTIAL RADIATION EXPOSURE TO MEMBERS OF THE PUBLIC FROM OPERATIONS AT ANSTO SITES

The principal sources of potential radiation exposure to members of the public from routine ANSTO operations at the LHSTC and NMC are from airborne emissions and low level liquid effluent discharges to the sewer. As indicated in **Section 3**, ANSTO complied with all relevant Commonwealth and New South Wales regulations and international guidelines during 1999. It is concluded that there is no impact on the health of the community, staff or the environment as a consequence of operations at the Lucas Heights Science and Technology Centre or the National Medical Cyclotron.

9.1 LHSTC AIRBORNE EMISSIONS

The discharge authorisation for airborne emissions at the LHSTC is 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. 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 24** shows the estimated effective doses due to airborne discharges from LHSTC in 1999 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 kilometre radius LHSTC buffer zone, were calculated to be less than 0.010 mSv per year in 1999. That is, less than 1% of the NH&MRC recommended annual dose limit of 1 mSv and less than 3.3 % of the site dose constraint of 0.3 mSv. For members of the general public residing at the boundary of the 1.6 kilometre buffer zone 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. No iodine-131 was detected in ambient air in 1999. Assuming continuous exposure to iodine-131 at the 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 all 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 is consistent with the

results obtained from the PC-Cream model and represents 1% of the NH&MRC recommended annual dose limit of 1 mSv and about 3% of the site dose constraint.

Table 25, 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.

The estimated potential dose 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.

9.2 Low-Level Liquid Effluent from LHSTC

Liquid effluent is chemically treated and analysed before controlled discharge to the Sydney Water sewer. Prior to 1980, such 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 Cronulla Sewage Treatment Plant and the Potter Point ocean outfall area in 1995 through to 1999 determined the dilution effects on radionuclides contained in the treated effluent discharged by ANSTO to the sewer. The predictions of the Unisearch WRL plume transport and dilution model have been confirmed using these measurements. The model may now be used to predict tritium concentrations in the sea near Potter Point at any time since 1995.

The 1999 levels of iodine-131 and cobalt-60 found in algae collected near the Potter Point 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 using the ocean in the vicinity of the outfall or ingesting seafood from the area. The potential dose is at least a factor of 1000 below the NH&MRC recommended dose limits for members of the public.

9.3 External Radiation at LHSTC

The levels of external gamma radiation at LHSTC were measured by thermoluminescent dosimeters located at private residences in Barden Ridge, Engadine and Woronora (see **Tables 18a & 18b**). The local absorbed doses in air were consistent with levels recorded in Australian capital cities (using similar dosimeters) in Australian 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 external gamma radiation reading of 3.2 mSv/year was measured at location 2 on the southern sector of the perimeter fence. This area is affected by the nearby storage of radioactive materials. This location is 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. All other external dose rates recorded on site were at normal background levels.

9.4 The Little Forest Burial Ground

The 1999 environmental survey results for the LFBG show similar trends to past years.

Tritium was detected in ground water near the burial trenches and at low levels in several other monitoring bores within the fenced area. All 15 bores sampled were below the WHO drinking water guideline level for tritium and no tritium was detected outside the fenced LFBG area.

Groundwater from 13 of the monitoring bores contained gamma-emitters of natural origin. Very low levels of cobalt-60 and caesium-137 were detected in bore MB16, which lies in the centre of the trenches. A small amount of americium-241, below 3% of the WHO drinking water reference concentration, was found in the OS2 bore.

With the exception of gross alpha activity in bore MB16, the gross alpha and gross beta activities measured in LFBG groundwater were below levels considered safe for Australian drinking water (NH&MRC, 1996).

The groundwater bores outside of the LFBG fenced area showed background levels of naturally occurring radioactivity. Surface water sampled from Mill and Bardens Creeks also contained background levels of activity.

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 carried out using a high-volume air sampler built to US-EPA specifications. No beryllium or plutonium was detected on air filters in 1999. 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 were consistent with normal background levels. Radiation readings around the LFBG site boundary fence were also at background levels, confirming that possible doses to members of the public from external radiation can also be regarded as negligible.

9.5 THE NATIONAL MEDICAL CYCLOTRON

All airborne and liquid effluent emissions from the National Medical Cyclotron during 1999 were well within the approved limits. Due to the short-lived nature of the radioisotopes concerned, the impact on humans and the environment from NMC emissions is 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 ambient air samples and supplied details of airborne effluent sampling and analysis procedures.

Dosimeter readings for external gamma radiation at LHSTC (Tables 18a & 18b), airborne effluent release data (Tables 19a to 19d, 24) and details of the environmental monitoring at the National Medical Cyclotron (Tables 23a & 23b) were supplied by Safety Division.

Liquid effluent release data (Tables 21 & 22) and details of waste treatment were supplied by Waste Operations, Nuclear Technology Division.

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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, *ie* 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):

1 curie = 3.7×10^{10} 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 Concentration in consumer 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.

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 emissions.

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.

Progeny: A nuclide formed from the radioactive decay of another, called the parent.

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.

APPENDICES

APPENDIX A: PREVIOUS ENVIRONMENTAL SURVEY REPORTS

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APPENDIX B: STACK DISCHARGES OF RADIOACTIVITY AT LUCAS HEIGHTS

RADIONUCLIDE	HALF-LIFE	STACK	RELEASE FORM
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 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 99.97% effective for particle sizes > 0.3 microns.

ARGON-41	1.8 HOURS	HIFAR	GAS

Air is used to cool some of the irradiation rigs in HIFAR. The naturally occurring argon-40 in air becomes activated in passing through the reactor by the absorption of a neutron to form radioactive argon-4, 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.

OTHER ACTIVITY:			
MERCURY-197	64 HOURS	HIFAR	VAPOUR
MERCURY-203	46 DAYS		
ARSENIC-76	26 HOURS		

Slight traces of mercury and arsenic 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. The arsenic vapour is being slowly emitted from wood, treated with preservative, which was used when renewing the thermal cladding of the containment building.

RADIONUCLIDE	HALF-LIFE	STACK	RELEASE FORM
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.

NOBLE GASES:			
XENON-133	5.3 DAYS	BLD 54	GAS
XENON-135	9.1 HOURS		
XENON-135M	15 MINS		
KRYPTON-87	76 MINS		
KRYPTON-85M	4.5 HOURS		
KRYPTON-88	2.8 HOURS		

These are all fission product noble gases. The radionuclide 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 are 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.

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	VAPOUR

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	Half-life
α	alpha	
β	beta	
γ	gamma	
^{241}Am	americium-241	432.2 years
^{7}Be	beryllium-7	53 days
^{144}Ce	cerium-144	284.9 days
^{134}Cs	caesium-134	2.06 years
^{137}Cs	caesium-137	30.14 years
^{51}Cr	chromium-51	27.7 days
^{57}Co	cobalt-57	271.8 days
^{60}Co	cobalt-60	5.3 years
^{67}Ga	Gallium-67	3.3 days
^{3}H	tritium	12.3 years
^{123}I	iodine-123	13.2 hours
^{131}I	iodine-131	8.02 days
^{132}I	iodine-132	2.3 hours
^{133}I	iodine-133	20.8 hours
K	stable potassium	
^{40}K	potassium-40	1.3×10^{9} years
^{240}Pu	plutonium-240	6.56×10^{3} years
^{90}Sr	strontium-90	28.6 years
^{201}Tl	thallium-201	3.04 days
^{202}Tl	thallium-202	12.23 days
^{232}Th	thorium-232	1.4×10^{10} years
^{238}U	uranium-238	4.5×10^{9} years
^{65}Zn	zinc-65	244.1 days

SI UNITS

Quantity	SI Unit and Abbreviation
Absorbed Dose	Gray (Gy)
Dose Equivalent	Sievert (Sv)
Radioactivity	Becquerel (Bq)

MULTIPLES AND SUBMULTIPLES OF SI UNITS

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

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 green algae (Enteromorpha intestinalis) 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. Once the dry weight was recorded, the sample was ignited at 450 ^{0}C in a muffle furnace, cooled and re-weighed. The whole, ashed sample was sub-sampled 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 from creek beds and stormwater bunds were prepared and counted in the same manner as soils.

Waters

All water samples were collected in polyethylene 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).

Groundwater

Groundwater from bores at Little Forest Burial Ground was 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 water from the centre of each bore into a sample bottle, 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 is mounted on a trailer with a petrol powered generator and is deployed in the centre of the trench area for about 4 hours, 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 particulate sampling method used at the LFBG 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 (Standards Association of Australia).

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.

The exposed filters (measuring 175 x 225 mm) are divided into four equal portions: two are used for beryllium and plutonium analyses; the remaining two are stored. A beryllium analyses is carried out for every sampling period (3 months). 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). The analysis is performed by ANSTO's Environment Division chemistry group.

To maximise the probability of detecting any plutonium, an annual composite sample is used for the alpha spectrometry analysis, which is performed by ANSTO's Environment Division Radiochemistry Laboratory. The annual composite is made up of (1/4) portions from each filter sample collected during the year.

Environmental Radiation - ARPANSA 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 (ARPANSA). 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 analogous with those of the ARPANSA TLD's.

Measurements were made over four consecutive exposure periods of approximately three months duration, and the ARPANSA-issued TLD badges were sent back to ARPANSA 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.

ANALYSIS METHODS

Environmental Radiochemistry Laboratory
Australian or International Standard methods for radiological analyses are used, where they are available. Methods for gamma spectrometry, gross alpha, gross beta and tritium analyses of waters are documented and incorporate techniques based on those used by ARPANSA.

Blanks and standards are either counted regularly or 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 were counted up to five times. Long counting times (23 hours) were employed for low-level gamma spectrometry samples.

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

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 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 level).

Gross Alpha/Beta Activity in Soils
Soils/sediments were counted for gross beta activity in a Geiger-Mueller tube with a 25mm 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 scintillator 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. Sand, 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 the water samples for 1999 were analysed using ISO methods 9696 & 9697(1992).

Prior to 1997, 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 ^{0}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 potassium-40 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 reproducible 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.

ARPANSA 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 150 mL. The pH of the cooled solution was adjusted to 3-4 with the addition of 10 molar sodium hydroxide. The sample was further evaporated down to about 50 mL, quantitatively transferred to a 65 mm petri dish, mixed with about 2 grams of agar and allowed to set. The lid was sealed with silicone glass sealant and the sample counted for gamma-emitters. This method was adapted (by permission) from a technique used at the ARPANSA. 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 standard solution containing 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 the

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 ARPANSA. The other set is analysed at ANSTO, by placing the four cartridges simultaneously under a large (8 x 4 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 contain 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:

- 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; and
- all the measured activity was released at one point (there are actually four locations being measured).

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 justifiable 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 per cent probability 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 that there is less than a 5 per cent probability that the observed peak was due to a random fluctuation in the background. This being so, the peak is attributed to the radionuclide and its activity concentration (together with the experimental uncertainty) is calculated.

iii) If the sample's net count (or peak area) is less than L_C, there is deemed to be no statistical evidence for the radionuclide and an upper count limit, L_U is calculated (Gilmore and Hemingway, Section 5.6.2, page 121). The L_U value is the upper activity level of the radionuclide which yields a count rate which is embedded in (ie cannot be separated from) the background. This activity level is equated with the minimum detectable activity.

APPENDIX E : AIRBORNE EFFLUENT SAMPLE COLLECTION AND ANALYSIS

Sampling For Gases, Vapours and Particulates

The authorised airborne effluent discharges from LHSTC stacks are monitored weekly by ANSTO's Safety Division. 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 litre flask, topped-up to 1 litre, and a 1 mL sub-sample 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 sodium iodide crystal (NaI) detector is used to count the noble gas activity.

TABLE 1

ENVIRONMENTAL MONITORING SCHEDULE, 1999

SAMPLE	LOCATION [1]	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.	2 x 5 L sampled with polyethylene bottle.	As above.
	Bunds A & B	Monthly.	1 L sampled with polyethylene bottle.	250 mL 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.	250 mL 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.

Notes:

1. Sampling locations are shown on **Figures 1 through 4**.

Continued next page...

TABLE 1 Continued...

SAMPLE	LOCATION [1]	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Ground water	**Little Forest Burial Ground.**	Twice yearly.	Bores are pumped dry & allowed to refill. Seven litres sampled from the centre of the bore, avoiding the bottom sediments.	Decanted, evaporated and counted for α,β,γ. 250 mL distilled for tritium analysis. Two litres acidified & stored.
	Sump near Bld 27.	Monthly.	1 L ground water seepage collected with clean sponge.	Distilled for tritium analysis. Immediate gamma spectrometry of 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 were collected on 40 cm^2 filter paper using *Ecotech* air sampler at 60 m^3 per hour.	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 portions are stored.
Ambient iodine-131 in air	**Stations 1, 2 ,3 & 4**: along the eastern boundary of LHSTC.	Continuous samples, changed weekly.	Collected on activated charcoal filters (Maypacks).	Gamma spectrometry of Maypacks using a 20 x 10 cm NaI crystal.
Soil / sediment	**Stormwater bunds A, B & C.**	Yearly, or whenever bunds are emptied.	Bund water 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.	1 kg from each creek bed (upstream of their confluence).	As above.

Notes:
1. Sampling locations are shown on **Figures 1 through 4.**

Continued next page...

TABLE 1 Continued...

SAMPLE	LOCATION [1]	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 and ground samples prepared in duplicate.
	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; plus **Local suburbs**: 3 sites.	Quarterly.	Two types of Thermoluminescent Dosimeter (TLD) badges, exposed to ambient gamma radiation.	Personal-type TLDs sent to ARL for analysis. Environmental TLDs analysed at ANSTO. Results reported as effective dose in mSv/year.

Notes

1. Sampling locations are shown on **Figures 1 through 4.**

TABLE 2

TRITIUM IN WORONORA ESTUARY WATER [1]
STATION E5.9, 1999

Date	Tritium [2] (Bq/L)
13-1-99	< 10 [3]
23-2-99	< 10
2-3-99	< 20
20-4-99	< 10
4-5-99	< 10
8-6-99	< 30
30-7-99	< 10
10-8-99	< 10
7-9-99	< 10
12-10-99	< 10
2-11-99	< 10
7-12-99	< 10

Notes:

1. Refer to **Figure 1** for the Woronora Estuary sampling point.
2. The Reference Activity Concentration for tritium in drinking water is 7800 Bq/L (WHO, 1993).
3. Values quoted as "less than" figures were below the stated minimum detectable activity, calculated with 95 % confidence.

TABLE 3

TRITIUM IN FORBES CREEK [1]
WATER SAMPLES, 1999

Date	Tritium [2] (Bq/L)
13-1-99	< 10
23-2-99	< 20
2-3-99	< 20
20-4-99	< 10
4-5-99	< 10
8-6-99	< 10
8-7-99	< 10
10-8-99	< 10
7-9-99	< 10
12-10-99	< 10
2-11-99	< 10
7-12-99	< 10

Notes:
1. **Figure 1** shows the sampling location.
2. 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, 1999

Sampling Location [1]	Date Sampled	Gamma-emitters in FISH [2] Bq/kg FW [3]					
		U&Th Series [4]	**^{7}Be**	**^{40}K**	^{60}Co	^{137}Cs	^{131}I
POTTER POINT Ocean Outfall	13-4-99	N.D.	N.D.	150 ± 15	N.D.	N.D.	N.D.
	13-4-99	N.D.	N.D.	145 ± 15	N.D.	N.D.	N.D.
	9-12-99	N.D.	N.D.	180 ± 20	N.D.	N.D.	N.D.
	9-12-99	N.D.	N.D.	200 ± 20	N.D.	N.D.	N.D.
The Royal National Park Reference site	18-5-99	N.D.	N.D.	140 ± 15	N.D.	N.D.	N.D.
	18-5-99	N.D.	N.D.	140 ± 15	N.D.	N.D.	N.D.

Notes:
1. Two separate samples were collected on each occasion, see **Figure 4** for locations.
2. Fish samples were unwashed, gutted and filleted (with scales & skin intact).
3. Radioactivity in units of becquerels per kilogram of fresh (wet) sample.
4. "N.D." means the activity was not detected. "✓" in the **U&Th Series** column indicates the presence of decay products from the natural uranium-238 or thorium-232 series. **U&Th Series, ^{7}Be** and **^{40}K** are all of natural origin.

TABLE 5

RADIOACTIVITY IN **ALGAE** FROM POTTER POINT
OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1999

Sampling Location [1]	Date Sampled	Gamma Emitters in ALGAE [2] Bq/kg FW [3]					
		U&Th Series [4]	**^{7}Be**	**^{40}K**	^{60}Co	^{137}Cs	^{131}I
POTTER POINT Ocean Outfall	13-4-99	✓	28 ± 3	120 ± 10	0.8 ± 0.2	N.D.	65 ± 6
	13-4-99	✓	32 ± 3	110 ± 10	1.0 ± 0.2	N.D.	110 ± 10
	9-12-99	✓	5 ± 1	120 ± 10	2.6 ± 0.3	N.D.	110 ± 10
	9-12-99	✓	5 ± 1	120 ± 10	2.8 ± 0.3	N.D.	100 ± 10
The Royal National Park Reference site	11-5-99	✓	38 ± 4	170 ± 20	N.D.	N.D.	N.D.
	11-5-99	✓	39 ± 4	160 ± 20	N.D.	N.D.	N.D.

TABLE 6

RADIOACTIVITY IN **BARNACLES** FROM POTTER POINT
OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1999

Sampling Location [1]	Date Sampled	Gamma-emitters in BARNACLES [2] Bq/kg FW [3]					
		U&Th Series [4]	**^{7}Be**	**^{40}K**	^{60}Co	^{137}Cs	^{131}I
POTTER POINT Ocean Outfall	13-4-99	✓	N.D.	42 ± 6	N.D.	N.D.	N.D.
	13-4-99	✓	N.D.	38 ± 5	N.D.	N.D.	N.D.
	9-12-99	✓	N.D.	21 ± 6	N.D.	N.D.	N.D.
	9-12-99	✓	N.D.	20 ± 5	N.D.	N.D.	N.D.
The Royal National Park Reference site	11-5-99	✓	7 ± 2	35 ± 5	N.D.	N.D.	N.D.
	11-5-99	✓	7 ± 2	35 ± 5	N.D.	N.D.	N.D.

Notes for Tables 5 & 6:

1. See **Figure 4** for sampling locations. Two separate samples were collected on each occasion.
2. Algae (*Enteromorpha sp.*, *Cladophora sp.*) and barnacles (*Tesseropera rosea*) were analysed whole and unwashed.
3. Radioactivity in units of becquerels per kilogram of fresh (wet) sample.
4. "N.D." means the radionuclide was not detected. "✓" in the **U&Th Series** column indicates the unquantified presence of decay products from the natural uranium-238 or thorium-232 series. **U&Th Series, ^{7}Be** and **^{40}K** are all of natural origin.

TABLE 7a

TRITIUM IN MONTHLY WATER SAMPLES FROM STORMWATER BUNDS A and B, 1999

Date	**Tritium** [1] (Bq/L)	
	BUND A [2] Behind Building 1	**BUND B** Opposite Meteorological Tower
19-1-99	120 ± 20	< 20
23-2-99	170 ± 10	70 ± 20
22-3-99	80 ± 10	150 ± 10
27-4-99	60 ± 10	50 ± 10
19-5-99	50 ± 10	80 ± 10
25-6-99	80 ± 10	50 ± 10
27-7-99	8260 ± 80	40 ± 10
25-8-99	40 ± 10	30 ± 10
21-9-99	80 ± 20	90 ± 10
27-10-99	230 ± 10	40 ± 10
17-11-99	130 ± 10	60 ± 10
21-12-99	< 30	40 ± 10

Notes:

1. The WHO reference concentration for tritium in drinking water is 7800 Bq/L.
2. Refer to **Figure 2** for the sampling point locations.

TABLE 7b

TRITIUM IN WEEKLY WATER SAMPLES FROM MDP BUND C,[1] 1999

Date	**Tritium** [2,3] Bq/L	Date	**Tritium** Bq/L
5-1-99	130 ± 20	6-7-99	80 ± 10
12-1-99	40 ± 10	13-7-99	50 ± 10
19-1-99	40 ± 10	20-7-99	60 ± 40
27-1-99	70 ± 10	27-7-99	40 ± 10
2-2-99	30 ± 10	3-8-99	70 ± 10
9-2-99	< 20 [4]	10-8-99	80 ± 10
16-2-99	70 ± 10	17-8-99	100 ± 20
23-2-99	120 ± 10	25-8-99	110 ± 10
2-3-99	40 ± 10	31-8-99	110 ± 10
9-3-99	80 ± 20	7-9-99	120 ± 10
16-3-99	110 ± 10	14-9-99	50 ± 10
23-3-99	90 ± 10	21-9-99	40 ± 20
30-3-99	100 ± 10	28-9-99	120 ± 10
6-4-99	100 ± 10	5-10-99	90 ± 10
13-4-99	160 ± 10	12-10-99	180 ± 10
20-4-99	130 ± 10	19-10-99	40 ± 10
27-4-99	120 ± 10	27-10-99	50 ± 10
4-5-99	70 ± 10	2-11-99	50 ± 10
11-5-99	140 ± 10	9-11-99	30 ± 10
19-5-99	130 ± 10	16-11-99	< 20
25-5-99	80 ± 10	23-11-99	110 ± 10
1-6-99	150 ± 10	30-11-99	100 ± 10
8-6-99	90 ± 10	7-12-99	90 ± 10
15-6-99	110 ± 20	16-12-99	40 ± 10
22-6-99	80 ± 10	21-12-99	90 ± 10
29-6-99	80 ± 10	30-12-99	60 ± 10

Notes:

1. Refer to **Figure 2** for the location of this sampling point.
2. The average tritium level in MDP Bund C during 1999 was around 80 Bq/L, which is 1% of the WHO drinking water 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, 1999

Monthly Composite [1]	RADIOACTIVITY (Bq/L)				
	Gross α [2]	Gross β [4]	Gamma emitters		
			^{137}Cs [5]	^{7}Be	^{40}K
January	< 0.04 [3]	0.96 ± 0.02	0.240 ± 0.023	N.D.[6]	< 0.10
February	< 0.03	0.75 ± 0.01	0.053 ± 0.006	0.14 ± 0.02	< 0.10
March	< 0.03	0.56 ± 0.01	0.030 ± 0.004	0.06 ± 0.02	< 0.10
April	< 0.07	1.68 ± 0.04	0.015 ± 0.003	N.D.	0.14 ± 0.03
May	0.03 ± 0.01	0.62 ± 0.02	0.017 ± 0.003	0.07 ± 0.02	< 0.14
June	< 0.03	0.64 ± 0.01	0.020 ± 0.003	0.07 ± 0.02	< 0.10
July	< 0.03	0.43 ± 0.01	N.D.	N.D.	< 0.14
August	< 0.03	0.54 ± 0.01	0.010 ± 0.003	N.D.	0.14 ± 0.04
September	0.03 ± 0.01	0.51 ± 0.01	0.013 ± 0.004	0.31 ± 0.04	0.15 ± 0.05
October	< 0.03	0.70 ± 0.01	0.060 ± 0.007	0.15 ± 0.03	< 0.26
November	< 0.03	0.51 ± 0.01	0.015 ± 0.003	0.27 ± 0.04	< 0.20
December	< 0.03	0.73 ± 0.02	0.030 ± 0.004	0.08 ± 0.03	< 0.30

Notes:

1. Refer to **Figure 2** for the sampling location. MDP Bund C was sampled weekly for tritium (see **Table 7b**). The remainder of the weekly samples were combined to make a monthly composite water sample for gross alpha, beta and gamma analysis.
2. 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.
3. A less-than value indicates that the result was below the minimum detectable activity (stated at the 95 % confidence level).
4. The gross beta results include the contribution from potassium-40 (a natural beta-gamma emitter).
5. The average weekly concentration of ^{137}Cs in MDP Bund C in 1999 was < 0.042 Bq/L, which is < 0.4% of the WHO reference value for ^{137}Cs in drinking water (10.5 Bq/L).
6. "N.D": the radionuclide was not detected.

TABLE 8

RADIOACTIVITY IN SEDIMENT FROM STORMWATER BUNDS, 1999

Location [1]	Date	RADIOACTIVITY in SEDIMENT (Bq/g DW) [2]			
		Gross α	**Gross β**	**Gamma Emitters**	**^{40}K**
BUND A: Behind Building 1	27-3-99	0.40 ± 0.07	0.51 ± 0.02	^{7}Be = 0.092 ± 0.010 ^{137}Cs = 0.007 ± 0.001 ^{60}Co < 0.003 [3]	0.41 ± 0.04
BUND B: Opposite Meteorological Tower	27-3-99	0.29 ± 0.07	0.33 ± 0.02	^{7}Be = 0.213 ± 0.021 ^{60}Co = 0.005 ± 0.001 ^{137}Cs < 0.003	0.20 ± 0.02
BUND C: MDP (on Stormwater Outlet No.1)	16-3-99	0.41 ± 0.07	0.62 ± 0.02	^{7}Be = 0.092 ± 0.010 ^{137}Cs = 0.290 ± 0.027 ^{60}Co = 0.015 ± 0.002 ^{241}Am = 0.018 ± 0.002 ^{144}Ce = 0.014 ± 0.003 ^{134}Cs = 0.004 ± 0.001	0.17 ± 0.02

Notes:

1. See **Figure 2** for the location of the stormwater bunds.
2. Refers to the radioactivity per gram (dry weight) of sample.
3. A less-than value indicates that the result was below the minimum detectable activity (stated at the 95% confidence level).

TABLE 9a

TRITIUM IN WEEKLY WATER SAMPLES FROM MDP + 60m,[1] 1999

Date	Tritium [2,3] Bq/L	Date	Tritium Bq/L
5-1-99	130 ± 10	6-7-99	80 ± 10
12-1-99	100 ± 10	13-7-99	50 ± 10
19-1-99	90 ± 10	20-7-99	40 ± 10
27-1-99	80 ± 10	27-7-99	40 ± 10
2-2-99	30 ± 10	3-8-99	60 ± 10
9-2-99	< 20 [4]	10-8-99	70 ± 10
16-2-99	70 ± 10	17-8-99	70 ± 10
23-2-99	90 ± 20	25-8-99	100 ± 10
2-3-99	40 ± 10	31-8-99	80 ± 10
9-3-99	80 ± 10	7-9-99	70 ± 10
16-3-99	100 ± 20	14-9-99	80 ± 10
23-3-99	70 ± 10	21-9-99	70 ± 10
30-3-99	70 ± 10	28-9-99	160 ± 10
6-4-99	90 ± 10	5-10-99	50 ± 10
13-4-99	160 ± 10	13-10-99	80 ± 10
20-4-99	120 ± 10	19-10-99	30 ± 10
27-4-99	100 ± 20	27-10-99	40 ± 10
4-5-99	100 ± 20	2-11-99	70 ± 10
11-5-99	110 ± 10	9-11-99	30 ± 10
19-5-99	100 ± 10	16-11-99	20 ± 10
25-5-99	70 ± 10	23-11-99	90 ± 10
1-6-99	90 ± 20	30-11-99	90 ± 10
8-6-99	100 ± 10	7-12-99	80 ± 10
15-6-99	100 ± 20	16-12-99	60 ± 10
22-6-99	80 ± 20	21-12-9	70 ± 10
29-6-99	80 ± 10	30-12-99	60 ± 10

Notes:

1. Refer to **Figure 2** for the location of this sampling point, 60m downstream of Stormwater Outlet No. 1 on MDP Creek.
2. The average tritium level during 1999 was < 80 Bq/L, representing < 1 % of the WHO reference concentration for tritium in drinking water (7800 Bq/L).
3. The weekly water samples were combined to make monthly composite samples, then analysed for gross alpha/beta and gamma activity. See **Table 9b** 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 9b

RADIOACTIVITY IN MONTHLY COMPOSITE
WATER SAMPLES FROM MDP+60m, 1999

Monthly Composite [1]	RADIOACTIVITY (Bq/L)			
	Gross α [2]	Gross β	Gamma emitters	
			^{137}Cs [4]	^{40}K
January	0.03 ± 0.01	0.48 ± 0.01	0.014 ± 0.003	0.09 ± 0.04
February	< 0.03 [3]	0.56 ± 0.01	0.038 ± 0.005	< 0.08
March	< 0.03	0.43 ± 0.01	0.026 ± 0.004	< 0.10
April	< 0.03	0.64 ± 0.01	0.027 ± 0.004	0.21 ± 0.04
May	< 0.03	0.46 ± 0.01	0.019 ± 0.003	< 0.10
June	0.03 ± 0.01	0.49 ± 0.01	0.020 ± 0.003	< 0.08
July	< 0.03	0.36 ± 0.01	N.D.	< 0.20
August	< 0.03	0.38 ± 0.01	0.016 ± 0.003	0.10 ± 0.03
September	< 0.03	0.31 ± 0.01	N.D.	0.10 ± 0.04
October	0.03 ± 0.01	0.34 ± 0.01	N.D.	< 0.20
November	0.03 ± 0.01	0.34 ± 0.01	N.D.	< 0.20
December	< 0.03	0.34 ± 0.01	N.D.	< 0.20

Notes:

1. Refer to **Figure 2** for the location of this sampling point. This location was sampled weekly for tritium (see **Table 9a**). The remaining weekly samples were combined into a monthly composite water sample for gross alpha, beta and gamma analyses.
2. 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. 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 maximum ^{137}Cs concentration measured in 1999 was less than 0.4 % of the WHO reference value for ^{137}Cs in drinking water (10.5 Bq/L).

TABLE 10

RADIOACTIVITY IN WATER FROM SPCC [1] SAMPLING POINTS, 1999

Date	RADIOACTIVITY [2] (Bq/L)					
	Strassman Creek		**Bardens Creek Weir**		**MDP Creek Weir**	
	Gross α	Gross β	Gross α	Gross β	Gross α	Gross β
3-2-99	< 0.02 [3]	0.05 ± 0.01	< 0.02	0.05 ± 0.01	< 0.01	0.20 ± 0.01
2-3-99	< 0.01	0.05 ± 0.01	< 0.01	0.06 ± 0.01	< 0.03	0.27 ± 0.01
23-3-99	< 0.02	0.04 ± 0.01	< 0.02	0.04 ± 0.01	< 0.01	0.32 ± 0.01
15-4-99	< 0.01	0.05 ± 0.01	< 0.02	0.05 ± 0.01	< 0.01	0.21 ± 0.01
27-5-99	< 0.02	0.04 ± 0.01	< 0.01	0.05 ± 0.01	< 0.03	0.30 ± 0.01
25-6-99	< 0.02	0.06 ± 0.01	< 0.03	0.06 ± 0.01	< 0.02	0.24 ± 0.01
26-7-99	< 0.02	0.04 ± 0.01	0.05 ± 0.01	0.09 ± 0.01	< 0.01	0.13 ± 0.01
30-8-99	< 0.02	0.06 ± 0.01	< 0.02	0.07 ± 0.01	< 0.02	0.23 ± 0.01
30-9-99	< 0.01	0.03 ± 0.01	0.03 ± 0.01	0.07 ± 0.01	< 0.02	0.23 ± 0.01
14-10-99	< 0.03	0.04 ± 0.01	< 0.03	0.05 ± 0.01	< 0.03	0.25 ± 0.01
3-12-99	< 0.02	0.05 ± 0.01	< 0.02	0.05 ± 0.01	< 0.03	0.29 ± 0.01
20-12-99	< 0.01	0.05 ± 0.01	< 0.02	0.05 ± 0.01	< 0.02	0.21 ± 0.01

Notes:

1. See **Figure 2** for the location of the former SPCC (now NSW EPA) sampling points.
2. 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. All gross beta results include the contribution from the naturally-occurring beta-gamma emitter, potassium-40.
3. Values which are quoted as "less than" figures were below the stated minimum detectable activity (calculated with 95 % confidence).

TABLE 11

TRITIUM IN WATER FROM BARDENS CREEK WEIR [1]
(at SPCC sampling point), 1999

Date	**Tritium** [2] Bq/L	Date	**Tritium** Bq/L
5-1-99	100 ± 10	6-7-99	30 ± 10
12-1-99	70 ± 10	13-7-99	50 ± 10
19-1-99	30 ± 10	20-7-99	70 ± 50
27-1-99	80 ± 10	27-7-99	400 ± 20
2-2-99	30 ± 10	3-8-99	40 ± 10
9-2-99	40 ± 10	10-8-99	20 ± 10
16-2-99	60 ± 10	17-8-99	40 ± 10
23-2-99	70 ± 10	24-8-99	30 ± 10
2-3-99	70 ± 10	31-8-99	390 ± 30
9-3-99	40 ± 10	7-9-99	110 ± 10
16-3-99	30 ± 10	14-9-99	110 ± 10
23-3-99	140 ± 10	21-9-99	40 ± 10
30-3-99	40 ± 10	28-9-99	30 ± 10
6-4-99	170 ± 10	5-10-99	150 ± 10
13-4-99	60 ± 10	12-10-99	50 ± 10
20-4-99	40 ± 10	19-10-99	40 ± 10
27-4-99	< 40 [3]	27-10-99	80 ± 10
4-5-99	30 ± 10	2-11-99	50 ± 10
11-5-99	40 ± 10	9-11-99	90 ± 10
19-5-99	30 ± 10	16-11-99	110 ± 10
25-5-99	50 ± 10	23-11-99	60 ± 10
1-6-99	< 40	30-12-99	30 ± 10
8-6-99	60 ± 10	7-12-99	< 30
15-6-99	< 40	14-12-99	30 ± 10
22-6-99	30 ± 10	21-12-99	50 ± 10
29-6-99	20 ± 10	30-12-99	30 ± 10

Notes:

1. See **Figure 2** for the location of this sampling point.
2. The average weekly tritium concentration at Bardens Creek weir during 1999 was less than 70 Bq/L, which is < 1% of the WHO drinking water reference activity concentration.
3. 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, 1999

Date	Location [1,2]	Doserate (μSv/hour)		Background Doserate (μSv/hour)
		Ground Below Joint	Pipe Joint	
27-4-99	Joints No.1-22	0.1 – 0.3	0.1 – 0.3	0.1 – 0.2
28-10-99	Joints No.1-22	0.2 – 0.3	0.1 – 0.6	0.2 – 0.4

Notes:
1. Survey of exposed portions of pipeline between LHSTC and the Sydney Water sewer connection, using a calibrated Nuclear Enterprises PDR-1 dose-rate meter.
2. The survey excluded joints number 18 & 19, which are inaccessible.

TABLE 13

GAMMA SURVEY - BURIAL TRENCHES
LITTLE FOREST BURIAL GROUND, 1999

Date	Location [1,2]	Doserate (μSv/hour)
30 December 1999	Background reading (outside LFBG fence)	0.5 – 1.0
	Readings over all trenches	0.5 – 1.0
	Point #5	0.5 – 1.0
	Point #6	0.5 – 1.0

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 Nuclear Enterprises PDR-1 dose rate meter.

TABLE 14

RADIOACTIVITY IN GROUNDWATER FROM LITTLE FOREST BURIAL GROUND, 1999

Bore [1]	Date Sampled	RADIOACTIVITY [2,3] Bq /L				
		^{3}H	Gross α	Gross β	Gamma Emitters	
					Other	^{40}K
BHF	28-5-99	180 ± 20	0.07 ± 0.02	0.13 ± 0.01	N.D	< 0.37
BH10	"	270 ± 10	0.04 ± 0.01	0.06 ± 0.01	N.D	< 0.18
OS2	"	810 ± 20	0.04 ± 0.01	0.09 ± 0.01	N.D	N.D
OS3	"	790 ± 10	0.03 ± 0.01	0.31 ± 0.01	N.D	N.D
MB11	"	< 10	< 0.03	0.03 ± 0.01	N.D	< 0.38
MB12	"	< 10	< 0.02	< 0.03	N.D	< 0.14
MB13	"	1590 ± 60	< 0.03	< 0.08	N.D	N.D
MB14	"	< 20	0.08 ± 0.03	0.19 ± 0.02	N.D	N.D
MB15	"	< 10	0.03 ± 0.01	0.06 ± 0.01	N.D	< 0.25
MB16 [4]	"	6460 ± 60	0.10 ± 0.02	0.26 ± 0.01	^{60}Co = 0.10 ± 0.02	< 0.21
MB17	"	520 ± 20	< 0.02	0.04 ± 0.01	N.D	N.D
MB18	"	70 ± 10	0.05 ± 0.03	0.13 ± 0.02	N.D	N.D
MB19 [5]	"	< 40	< 0.22	0.39 ± 0.06	N.D	< 0.36
MB20	"	< 10	< 0.08	0.31 ± 0.03	N.D	< 0.24
MB21	"	< 10	< 0.05	0.17 ± 0.01	N.D	< 0.26
BHF	11-11-99	230 ± 10	0.03 ± 0.01	0.14 ± 0.01	N.D	< 0.28
BH10	"	700 ± 10	< 0.05	0.09 ± 0.02	N.D	< 0.29
OS2 [6]	"	900 ± 30	0.03 ± 0.01	0.13 ± 0.01	^{241}Am = 0.017 ± 0.003	0.36 ± 0.05
OS3	"	710 ± 20	< 0.02	0.27 ± 0.01	N.D	< 0.22
MB11	"	< 20	0.05 ± 0.01	0.09 ± 0.01	N.D	< 0.33
MB12	"	< 30	< 0.01	0.04 ± 0.01	N.D	< 0.33
MB13	"	1330 ± 30	< 0.03	0.11 ± 0.01	N.D	< 0.33
MB14	"	< 10	< 0.02	0.10 ± 0.01	N.D	< 0.28
MB15	"	< 10	0.03 ± 0.01	0.06 ± 0.01	N.D	< 0.33
MB16	"	1700 ± 40	0.23 ± 0.01	0.24 ± 0.01	^{137}Cs = 0.018 ± 0.008 ^{60}Co = 0.059 ± 0.011	< 0.26
MB17	"	500 ± 20	< 0.03	0.04 ± 0.01	N.D	< 0.25
MB18	"	< 20	0.08 ± 0.02	0.16 ± 0.01	N.D	< 0.34
MB19	"	< 10	0.05 ± 0.01	0.15 ± 0.01	N.D	< 0.27
MB20	"	< 10	0.03 ± 0.01	0.19 ± 0.01	N.D	0.36 ± 0.12
MB21	"	< 10	< 0.03	0.24 ± 0.01	N.D	< 0.41

Notes:

1. See **Figure 3** for the location of the groundwater bores at the Little Forest Burial Ground.
2. The Australian Drinking Water Guidelines (1996) recommended limits are: < 0.1 Bq/L for gross alpha activity; and < 0.5 Bq/L for gross beta activity. Gross beta results include the contribution from natural potassium-40. The WHO guideline value 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). "N.D." indicates that the radionuclide was not detected.
4. The maximum ^{60}Co and ^{137}Cs levels in MB16 were <1% of the relevant WHO drinking water concentrations.
5. Shading indicates those bores which are outside the fenced area of the LFBG.
6. The ^{241}Am measured in bore OS2 was < 3% of the WHO drinking water reference concentration.

TABLE 15

RADIOACTIVITY IN CREEKS RECEIVING RUNOFF FROM THE LITTLE FOREST BURIAL GROUND AREA, 1999

Sample Location	Date	RADIOACTIVITY in **SEDIMENT** (Bq/g DW)		
		Gross α	Gross β	γ-emitters
Mill Creek	4-11-99	0.81 ± 0.08	0.20 ± 0.02	^{40}K = 0.06 ± 0.01 U + Th series
Bardens Creek	4-11-99	0.29 ± 0.07	0.07 ± 0.02	^{40}K = 0.02 ± 0.01 U + Th series

Sample Location	Date	RADIOACTIVITY in **WATER** (Bq/L)			
		Gross α	Gross β	γ-emitters	Tritium
Mill Creek	4-11-99	0.04 ± 0.01	0.19 ± 0.01	N.D.	30 ± 10
Bardens Creek	4-11-99	< 0.03	0.07 ± 0.01	N.D.	< 20

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, 1999

Sampling Period [1, 2]	Average Windspeed [3] ($m.s^{-1}$)	Equivalent Volume [4] (m^3)	**Beryllium** [5]		$^{239/240}$ **Plutonium** [6]	
			µg (total)	µg m^{-3}	Bq (total)	Bq m^{-3}
Jan – Mar	3.4	418.9	< 0.05	< 1.2×10^{-4}	-	-
Apr – Jun	3.3	261.9	< 0.03	< 1.1×10^{-4}	-	-
July – Sept	3.9	427.1	< 0.05	< 1.2×10^{-4}	-	-
Oct – Dec	3.7	273.3	< 0.05	< 1.1×10^{-4}	-	-
1999 Composite	3.6	1381.2	-	-	< 0.001	< 7.2×10^{-7}

Notes:
1. Samples were collected using a mobile Ecotech high-volume air sampler (US-EPA-approved).
2. Airborne particulate samples at LFBG were accumulated on a single filter over a period of 3 months. The sampling duration and frequency was approximately 4 hours, every 2 weeks. The filter paper was then divided into four equal parts with one being used per Be & Pu analysis and two retained as duplicates.
3. The average windspeed during each sampling period was calculated from the data recorded at the 10m point on the LHSTC meteorological tower.
4. The Equivalent Volume is 25% of the total volume of air sampled, since one-quarter of the filter is used for each analysis.
5. The Worksafe Australia Exposure Standard for atmospheric contaminants such as beryllium in air is 2 µg m^{-3} for Be (applicable to workers exposed 8 hours per day, 50 weeks per year).
6. The limit of detection for plutonium-239/240 in Bq/m^3 would equate to a committed effective dose to adults of < 0.0002 mSv/year, or < 0.02% of the allowable public dose limit of 1 mSv/y.

TABLE 17

AMBIENT IODINE-131 IN AIR at LHSTC, 1999

Sampled during the week ending:	**Iodine-131**[1,2] Air Concentration Bq / m^3	Sampled during the week ending:	**Iodine-131** Air Concentration Bq / m^3
5-1-99	< 0.0025	6-7-99	< 0.0025
12-1-99	< 0.0025	13-7-99	< 0.0025
19-1-99	< 0.0025	20-7-99	< 0.0025
27-1-99	< 0.0025	27-7-99	< 0.0025
2-2-99	< 0.0025	3-8-99	< 0.0025
9-2-99	< 0.0025	10-8-99	< 0.0025
16-2-99	< 0.0025	17-8-99	< 0.0025
23-2-99	< 0.0025	24-8-99	< 0.0025
2-3-99	< 0.0025	31-8-99	< 0.0025
9-3-99	< 0.0025	7-9-99	< 0.0025
16-3-99	< 0.0025	14-9-99	< 0.0025
23-3-99	< 0.0025	21-9-99	< 0.0025
30-3-99	< 0.0025	28-9-99	< 0.0025
6-4-99	< 0.0025	5-10-99	< 0.0025
13-4-99	< 0.0025	12-10-99	< 0.0025
20-4-99	< 0.0025	19-10-99	< 0.0025
27-4-99	< 0.0025	28-10-99	< 0.0025
4-5-99	< 0.0025	2-11-99	< 0.0025
11-5-99	< 0.0025	9-11-99	< 0.0025
19-5-99	< 0.0025	16-11-99	< 0.0025
25-5-99	< 0.0025	23-11-99	< 0.0025
1-6-99	< 0.0025	30-11-99	< 0.0025
8-6-99	< 0.0025	7-12-99	< 0.0025
15-6-99	< 0.0025	14-12-99	< 0.0025
22-6-99	< 0.0025	21-12-99	< 0.0025
29-6-99	< 0.0025	30-12-99	< 0.0025

Notes:

1. Four air samplers are located along the eastern boundary of the LHSTC site. where suburban residences are closest (see **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 a concentration of 0.0025 Bq/m^3 would receive an effective dose of less than 0.01 mSv per year (IAEA, 1994).

TABLE 18a

EXTERNAL GAMMA RADIATION AT LHSTC
(ARPANSA Dosimeter Results), 1995 to 1999

	Dosimeter Location: on-site [1]	Effective Dose [2] ARPANSA Dosimeters [3] (mSv / year)				
		1995	1996	1997	1998	1999
1	Hifar fence - south east	1.2 ± 0.3	0.8 ± 0.3	0.9 ± 0.4	1.0 ± 0.4	1.0 ± 0.5
2	Hifar fence - south	2.4 ± 0.5	2.2 ± 0.3	3.3 ± 0.5	3.3 ± 0.5	3.2 ± 0.5
3	Perimeter fence - west	1.4 ± 0.3	1.0 ± 0.4	1.2 ± 0.5	1.3 ± 0.5	1.0 ± 0.5
4	Hifar fence - west	1.5 ± 0.5	2.1 ± 0.3	1.5 ± 0.6	1.2 ± 0.5	1.5 ± 0.2
5	Hifar fence - north west	1.2 ± 0.4	3.0 ± 0.5	1.2 ± 0.5	0.9 ± 0.4	1.1 ± 0.5
6	Perimeter fence - north A	1.0 ± 0.4	0.8 ± 0.3	0.9 ± 0.4	0.8 ± 0.4	0.8 ± 0.4
7	Internal fence - north	1.1 ± 0.5	0.8 ± 0.3	1.1 ± 0.4	0.8 ± 0.4	0.8 ± 0.4
8	Perimeter fence - north B	1.2 ± 0.7	0.7 ± 0.3	1.0 ± 0.4	0.8 ± 0.4	1.0 ± 0.4
9	Perimeter fence - north east	1.0 ± 0.4	0.7 ± 0.3	0.8 ± 0.3	0.8 ± 0.3	0.7 ± 0.3
10	Perimeter fence - east	1.2 ± 0.3	0.7 ± 0.3	0.9 ± 0.4	0.8 ± 0.4	0.8 ± 0.4
11	Perimeter fence - south east	1.0 ± 0.3	0.5 ± 0.2	0.9 ± 0.3	0.9 ± 0.4	0.6 ± 0.3
12	Corner of Curie and Roentgen Streets	1.2 ± 0.5	0.8 ± 0.3	1.2 ± 0.5	0.8 ± 0.4	1.1 ± 0.5
13	Perimeter fence - south	0.9 ± 0.4	0.6 ± 0.2	0.7 ± 0.3	0.8 ± 0.4	0.7 ± 0.3
14	Hifar fence - east	1.1 ± 0.4	0.8 ± 0.3	1.0 ± 0.4	1.1 ± 0.5	1.0 ± 0.4
15	Hifar fence - north east	1.2 ± 0.4	0.9 ± 0.4	1.1 ± 0.5	1.0 ± 0.4	1.1 ± 0.5
	Dosimeter Location: off-site	**1995**	**1996**	**1997**	**1998**	**1999**
16	Private house - Barden Ridge	0.9 ± 0.3	0.7 ± 0.3	0.8 ± 0.3	0.9 ± 0.4	0.7 ± 0.3
17	Private house - Engadine	1.0 ± 0.4	0.8 ± 0.3	1.1 ± 0.4	0.9 ± 0.4	1.0 ± 0.4
18	Private house - Woronora	1.1 ± 0.5	0.7 ± 0.3	0.9 ± 0.4	0.9 ± 0.4	0.8 ± 0.3
19	Cronulla Sewage Treatment Plant	-	-	-	-	0.5 ± 0.2 [4]

Notes:

1. Refer to **Figure 2** for the locations of dosimeters 1 to 15.
2. 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.
3. The ARPANSA 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 uncertainties (at the 95% confidence level) have been estimated from the standard deviation of the results for several dosimeters placed at the same location
4. Estimated value based on two measurements.

TABLE 18b

EXTERNAL GAMMA RADIATION AT LHSTC,
Comparison of ARPANSA and ANSTO Results, 1999

	Dosimeter Location: on-site [1]	Thermoluminescent Dosimeter Results 1999 Effective Dose [2] (mSv / year)	
		ARPANSA [3]	ANSTO [4]
1	Hifar fence - south east	1.0 ± 0.5	1.0 ± 0.1
2	Hifar fence - south	3.2 ± 0.5	3.1 ± 0.2
3	Perimeter fence - west	1.0 ± 0.5	1.2 ± 0.1
4	Hifar fence - west	1.5 ± 0.2	1.5 ± 0.1
5	Hifar fence - north west	1.1 ± 0.5	1.2 ± 0.1
6	Perimeter fence - north A	0.8 ± 0.4	1.0 ± 0.1
7	Internal fence - north	0.8 ± 0.4	1.0 ± 0.1
8	Perimeter fence - north B	1.0 ± 0.4	1.0 ± 0.1
9	Perimeter fence - north east	0.7 ± 0.3	0.9 ± 0.1
10	Perimeter fence - east	0.8 ± 0.4	1.0 ± 0.1
11	Perimeter fence - south east	0.6 ± 0.3	0.9 ± 0.1
12	Corner of Curie and Roentgen St	1.1 ± 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	**ARPANSA**	**ANSTO**
16	Private house - Barden Ridge	0.7 ± 0.3	0.8 ± 0.1
17	Private house - Engadine	1.0 ± 0.4	1.3 ± 0.1
18	Private house - Woronora	0.8 ± 0.3	0.9 ± 0.1
19	Cronulla Sewage Treatment Plant	0.5 ± 0.2 [5]	0.6 ± 0.1 [5]

Notes:

1. Refer to **Figure 2** for the locations of thermoluminsecent dosimeters (TLD's) 1 to 15.
2. 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.
3. The ARPANSA 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.
4. The ANSTO environmental dosimeters contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters.The uncertainties for ANSTO results have been estimated (at the 95% confidence level) from the standard deviation of the results for several dosimeters placed at the same location.
5. Estimated value based on two measurements.

TABLE 19a

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS at LHSTC,

January – March 1999

STACK [1]	Alpha (kBq)	Beta [2] (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases [3] (TBq)	Other Nuclides (MBq)			
3	N.D. [4]	N.D.	0.44						
15A	N.D.	120	1.8	530	44	Hg-197	Hg-203	As-76	Br-82
						31	1.9	41	1.4
15M	N.D.	N.D.	0.4	26	0.0016				
19S	N.D.	N.D.	1.3						
19D	N.D.	N.D.	0.2						
20	N.D.	N.D.	1.8	1.5					
21A	N.D.	N.D.	0.12						
21B	N.D.	N.D.	0.068						
23A	N.D.	10000	6000						
23B	N.D.	N.D.	1.4						
41A	N.D.	N.D.	11						
41B	N.D.	N.D.	1.2						
54	N.D.	N.D.	3400		250	I-132	I-133		
						22000	1000		
56	N.D.	N.D.	3.0						
57	N.D.	N.D.	1.2	7.3					

Notes:

1. See **Figure 2** for the location of the discharge stacks and **Appendix B** for explanations of the different types of airborne discharges.
2. Any long-lived beta activity is assumed to be Strontium-90, although this nuclide is not a likely candidate.
3. Noble gases emitted from building 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. "N.D." indicates that the radioactivity was not detected.

TABLE 19b

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS at LHSTC,

April – June 1999

STACK [1]	Alpha (kBq)	Beta [2] (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases [3] (TBq)	Other Nuclides (MBq)			
3	N.D. [4]	N.D.	0.87						
15A	N.D.	260	1.4	610	32	Hg-197	Hg-203	As-76	Br-82
						22	2.9	41	2.7
15M	N.D.	N.D.	0.47	53	0.27				
19S	N.D.	N.D.	0.70						
19D	N.D.	N.D.	0.16						
20	N.D.	N.D.	4.7	1.1					
21A	N.D.	N.D.	0.091						
21B	N.D.	N.D.	0.069						
23A	N.D.	240	470						
23B	N.D.	N.D.	0.67						
41A	N.D.	N.D.	1.3						
41B	N.D.	N.D.	0.59						
54	N.D.	N.D.	2700		210	I-132	I-133		
						12000	800		
56	N.D.	N.D.	3.2						
57	N.D.	N.D.	0.47	46					

Notes:

1. See **Figure 2** for the location of the discharge stacks and **Appendix B** for explanations of the different types of airborne discharges.
2. Any long-lived beta activity is assumed to be Strontium-90, although this nuclide is not a likely candidate.
3. Noble gases emitted from building 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. "N.D." indicates that the radioactivity was not detected.

TABLE 19c

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS at LHSTC,
July – September 1999

STACK [1]	Alpha (kBq)	Beta [2] (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases [3] (TBq)	Other Nuclides (MBq)			
3	N.D. [4]	N.D.	0.34						
15A	N.D.	37	1.0	900	29	Hg-197	Hg-203	As-76	Br-82
						35	3.4	34	2.2
15M	N.D.	N.D.	0.26	69	1.8				
19S	N.D.	N.D.	0.58						
19D	N.D.	N.D.	0.049						
20	N.D.	N.D.	2.5	21					
21A	N.D.	N.D.	0.11						
21B	N.D.	N.D.	0.1						
23A	N.D.	1100	640						
23B	N.D.	N.D.	5.1						
41A	N.D.	N.D.	15						
41B	N.D.	N.D.	0.2						
54	N.D.	N.D.	4100		240	I-132	I-133		
						21000	1100		
56	N.D.	N.D.	2.6						
57	N.D.	N.D.	0.4	43					

Notes:

1. See **Figure 2** for the location of the discharge stacks and **Appendix B** for explanations of the different types of airborne discharges.
2. Any long-lived beta activity is assumed to be Strontium-90, although this nuclide is not a likely candidate.
3. Noble gases emitted from building 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. "N.D." indicates that the radioactivity was not detected.

TABLE 19d

AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS at LHSTC,
October – December 1999

STACK [1]	Alpha (kBq)	Beta [2] (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases [3] (TBq)	Other Nuclides (MBq)			
3	N.D. [4]	N.D.	0.59						
15A	N.D.	78	1.8	1200	24	Hg-197	Hg-203	As-76	Br-82
						28	1.5	46	1.1
15M	N.D.	N.D.	0.26	67	2				
19S	N.D.	N.D.	1.0						
19D	N.D.	N.D.	0.047						
20	640	N.D.	1.5	3.3					
21A	N.D.	N.D.	0.049						
21B	N.D.	N.D.	0.096						
23A	N.D.	460	960						
23B	N.D.	N.D.	0.81						
41A	N.D.	N.D.	1.4						
41B	N.D.	N.D.	0.14						
54	N.D.	N.D.	5600		300	I-132	I-133		
						26000	2100		
56	N.D.	N.D.	0.61						
57	N.D.	N.D.	0.28	21					

Notes:

1. See **Figure 2** for the location of the discharge stacks and **Appendix B** for explanations of the different types of airborne discharges.
2. Any long-lived beta activity is assumed to be Strontium-90, although this nuclide is not a likely candidate.
3. Noble gases emitted from building 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. "N.D." indicates that the radioactivity was not detected.

TABLE 20

RADIOACTIVITY IN GROUNDWATER
FROM THE VICINITY OF BUILDING 27 [1], 1999

Date Sampled	RADIOACTIVITY (Bq/L)	
	Gamma-emitters [2,3]	Tritium [4]
19-1-99	N.D.	470 ± 10
17-2-99	N.D.	500 ± 10
31-3-99	N.D.	580 ± 10
30-4-99	N.D.	420 ± 10
31-5-99	N.D.	410 ± 30
28-6-99	N.D.	320 ± 20
2-8-99	N.D.	340 ± 10
25-8-99	N.D.	420 ± 10
27-9-99	N.D.	360 ± 30
29-10-99	N.D.	310 ± 20
17-11-99	N.D.	330 ± 10
21-12-99	N.D.	350 ± 10

Notes:

1. See **Figure 2** for the location of the groundwater sump near building 27. Building 27 is the intermediate waste and spent fuel storage facility.
2. Gamma spectrometry was performed on a 500mL acidified sample in a Marinelli beaker.
3. N.D:- no significant peak detected.
4. The average of tritium levels recorded in the groundwater for 1999 was 400 Bq/L. This is 5% of the WHO reference concentration for tritium in drinking water (7800 Bq/L).

TABLE 21

RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED FROM LHSTC TO THE SYDNEY WATER SEWER, 1999

MONTH	TOTAL VOLUME Discharged m^3	AVERAGE CONCENTRATION IN DISCHARGES			Average MONTHLY Concentration QUOTIENT [3,4]
		ALPHA [1] Bq/m^3	BETA [2] Bq/m^3	TRITIUM Bq/m^3	
January	7959	$< 9.0 \times 10^2$	6.06×10^3	4.49×10^6	< 0.14
February	6084	$< 7.2 \times 10^2$	4.34×10^3	3.18×10^6	< 0.11
March	9299	$< 6.5 \times 10^2$	8.51×10^3	3.81×10^6	< 0.14
April	6790	$< 7.0 \times 10^2$	6.09×10^3	2.98×10^6	< 0.12
May	8368	$< 7.0 \times 10^2$	1.64×10^4	7.33×10^6	< 0.22
June	7519	$< 6.9 \times 10^2$	1.26×10^4	3.65×10^6	< 0.17
July	10637	$< 6.7 \times 10^2$	1.42×10^4	3.06×10^6	< 0.18
August	6910	$< 7.6 \times 10^2$	8.65×10^3	4.19×10^6	< 0.15
September	7717	$< 7.0 \times 10^2$	4.13×10^3	3.54×10^6	< 0.11
October	9551	$< 6.9 \times 10^2$	1.24×10^4	2.60×10^6	< 0.17
November	6288	$< 6.2 \times 10^2$	1.46×10^4	2.43×10^6	< 0.18
December	8239	$< 7.1 \times 10^2$	1.39×10^4	2.51×10^6	< 0.18
Average	7947	$< 6.6 \times 10^2$	1.02×10^4	3.65×10^6	< 0.16
Activity Concentration Equivalent at ANSTO		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 alpha, beta and tritium radioactivity in the liquid effluent divided by the Activity Concentration Equivalent for that radionuclide. The final quotient term must be no greater than one to comply with the requirements of the Sydney Water Trade Wastewater Agreement.
4. All discharges for 1999 were below the Activity Concentration Equivalents at ANSTO (based on the WHO Guidelines for Drinking-Water Quality).

TABLE 22

NON-RADIOACTIVE COMPONENT OF LIQUID EFFLUENT
DISCHARGED FROM LHSTC TO THE SYDNEY WATER SEWER,
February 1995 – December 1999

Component mg/L	YEARLY AVERAGE [1]				**AVERAGE** 1996 to 1999	Standard for Acceptance mg/L [2]
	1996	**1997**	**1998**	**1999**		
Suspended Solids	23	22	22	19	22	200
pH	7.2	7.3	7.6	7.3	7.4	7 – 10
Ammonia	17.8	16.0	10.7	10	13.6	50
BOD	36	23	12	14	21	85 [3]
Grease	14	13	12	7	12	50
Chromium	1.34	1.36	1.18	0.76	1.16	3

Notes:

1. Yearly averages are slightly overestimated since "less-than" values were included. Five samples per month were analysed for their non-radioactive components.
2. 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.
3. 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 23a

AIRBORNE EMISSIONS OF IODINE-123 FROM THE NATIONAL MEDICAL CYCLOTRON, 1999

Month	Total ^{123}I Emission (GBq/month)	Average ^{123}I Concentration (Bq/m^3)
January	0.09	3.0
February	0.09	3.5
March	0.09	3.2
April	0.07	2.6
May	0.02	0.8
June	0.19	6.9
July	3.44	119.0
August	0.67	23.1
September	1.74	62.3
October	0.45	15.7
November	0.98	35.2
December	0.52	18.6
NSW EPA Limits	N/A (1)	1000

Notes:
1. N/A:- not applicable since the limit is based on concentration not total emission.

TABLE 23b

AVERAGE CONCENTRATION OF RADIONUCLIDES IN LIQUID EFFLUENT FROM THE NATIONAL MEDICAL CYCLOTRON, 1999

Month	Monthly Average Concentration in Liquid Effluent (MBq/m^3)					
	^{201}Tl	^{202}Tl	^{67}Ga	^{57}Co	^{65}Zn	^{123}I
January	8.73	4.07	0.29	9.10	2.45	N.D.
February	N.D.	0.12	28.20	1.15	0.51	N.D.
March	0.04	N.D.	1.18	0.73	0.22	N.D.
April	0.14	0.34	0.05	3.30	0.57	N.D.
May	0.40	N.D.	0.08	0.95	0.35	N.D.
June	0.38	0.41	0.24	6.68	1.27	N.D.
July	0.20	0.05	0.07	2.48	0.54	N.D.
August	0.28	0.01	N.D.	0.51	0.40	N.D.
September	0.08	0.32	N.D.	4.14	0.44	N.D.
October	N.D.	N.D.	N.D.	0.16	0.10	N.D.
November	N.D.	N.D.	N.D.	0.21	0.08	0.004
December	N.D.	N.D.	N.D.	0.92	1.16	N.D.
NSW EPA Limits	**200**	**100**	**600**	**400**	**1008**	**6.00**

TABLE 24

ESTIMATED EFFECTIVE DOSES FROM LHSTC AIRBORNE DISCHARGES, 1999

Receptor Location	Percent of site dose constraint [1]	Percent of annual public dose limit [2]	Effective dose 1999 mSv/yr
Nearest resident	0.74	0.22	0.0022
LHSTC Library	1.78	0.53	0.0053
LHSTC Building 9	1.85	0.55	0.0055
LHSTC Main gate	1.25	0.38	0.0038
Stevens Hall Motel	3.32	0.99	0.0010
LH Waste Service (tip)	0.49	0.15	0.0015
BMX track	0.29	0.09	0.0009
Woronora Valley	0.30	0.09	0.0009
At 1.6 kilometre radius from HIFAR			
NORTH	2.60	0.78	0.0078
NNE	3.17	0.95	0.0095
NE	1.79	0.54	0.0054
ENE	1.25	0.37	0.0037
EAST	0.79	0.24	0.0024
ESE	0.59	0.18	0.0018
SE	0.71	0.21	0.0021
SSE	0.57	0.17	0.0017
SOUTH	0.53	0.16	0.0016
SSW	0.54	0.16	0.0016
SW	1.00	0.30	0.0030
WSW	0.78	0.23	0.0024
WEST	0.43	0.13	0.0013
WNW	0.41	0.12	0.0012
NW	0.62	0.18	0.0018
NNW	1.22	0.36	0.0036
At 4.8 kilometre radius from HIFAR			
NORTH	0.85	0.26	0.0026
NNE	0.44	0.13	0.0013
NE	0.39	0.12	0.0012
ENE	0.26	0.08	0.0008
EAST	0.15	0.05	0.0005
ESE	0.10	0.03	0.0003
SE	0.13	0.04	0.0004
SSE	0.14	0.04	0.0004
SOUTH	0.09	0.03	0.0003
SSW	0.12	0.04	0.0004
SW	0.24	0.07	0.0007
WSW	0.17	0.05	0.0005
WEST	0.10	0.03	0.0003
WNW	0.09	0.03	0.0003
NW	0.17	0.05	0.0005
NNW	0.36	0.11	0.0011

Notes:

1. The site dose constraint is 0.3 mSv/year.
2. The NH&MRC annual dose limit for members of the public is 1 mSv/year.

TABLE 25

ANNUAL EFFECTIVE DOSES TO ADULTS
FROM NATURAL SOURCES [1]

Source of exposure	Annual effective dose (mSv)	
	Typical [2]	Elevated [3]
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.