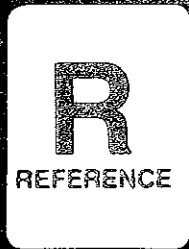


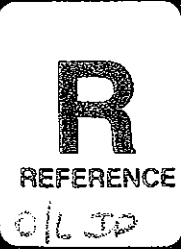
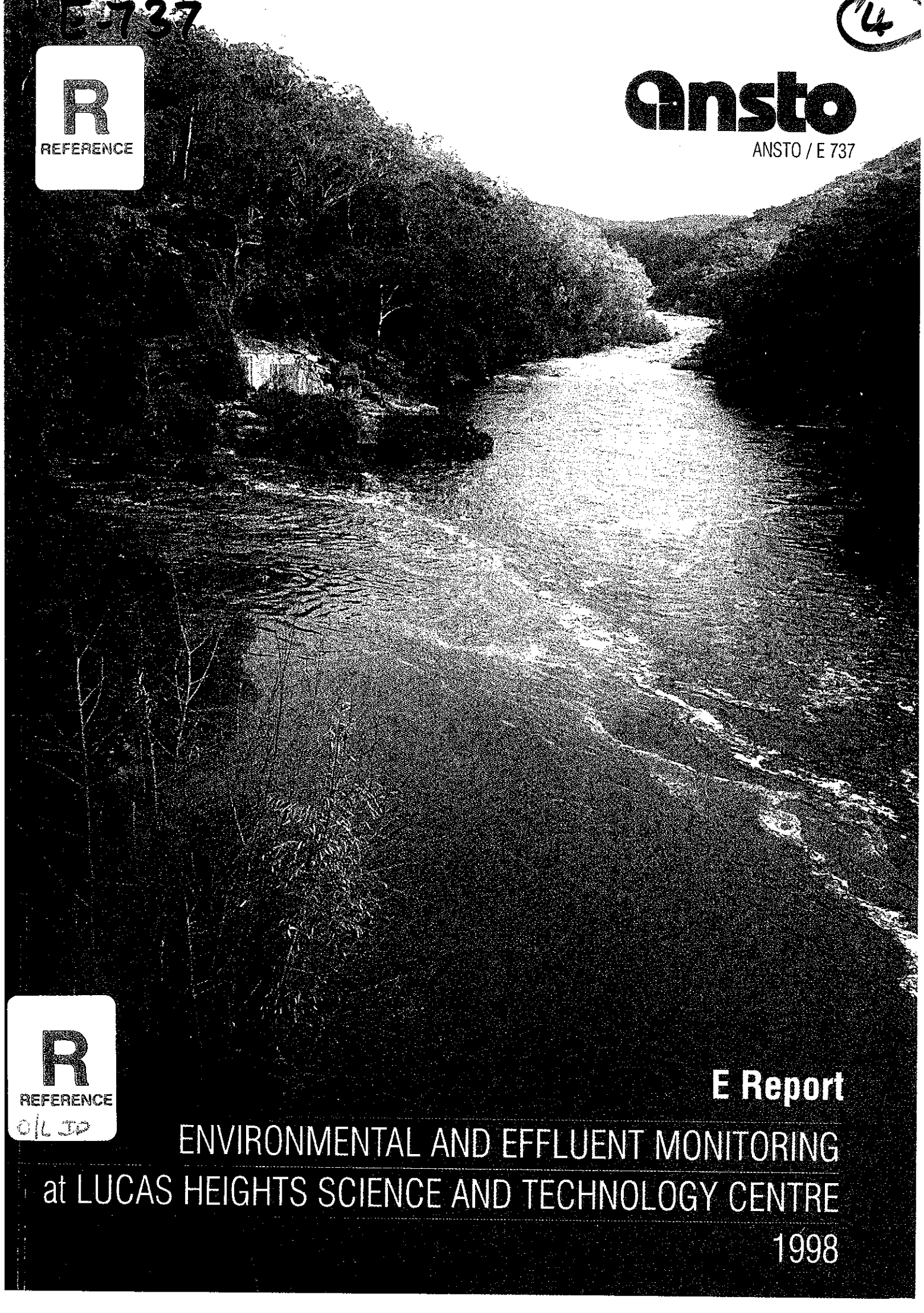
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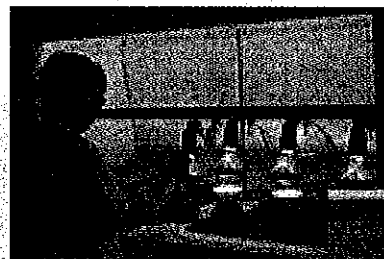


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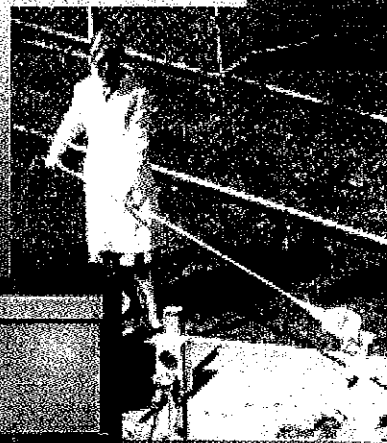
**ENVIRONMENTAL AND EFFLUENT MONITORING
at LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE**

1998

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ENVIRONMENTAL AND EFFLUENT MONITORING

LUCAS HEIGHTS SCIENCE AND TECHNOLOGY CENTRE

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Cover: Woronora River after exceptional rainfall (late 1980's),
taken from the Heathcote Road Bridge.

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ENVIRONMENTAL AND EFFLUENT MONITORING
at LUCAS HEIGHTS SCIENCE and TECHNOLOGY CENTRE,
1998

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Y. FARRAR
L. MOKHBER-SHAHIN

ABSTRACT

Results are presented of environmental and effluent monitoring conducted in the vicinity of the Lucas Heights Science and Technology Centre (LHSTC) during 1998. All low-level liquid and gaseous effluent discharges complied with existing discharge authorisations and relevant environmental regulations. Potential effective doses to the general public from controlled airborne discharges were estimated for the years 1997 and 1998 using the PC-Cream atmospheric dispersion and dosimetry code. The potential effective doses to the public in 1997 and 1998 were estimated to be less than 0.010 mSv/year for all receptor locations on the 1.6 km buffer zone boundary around the HIFAR research reactor. This value represents 1% of the 1 mSv/year dose limit for long term exposure that is recommended by the National Health and Medical Research Council and 3.3% of the site dose constraint of 0.3 mSv/year approved by the Nuclear Safety Bureau. 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 LHSTC.

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.

AIR, ALGAE, ALPHA DECAY RADIOISOTOPES, ALPHA PARTICLES, AMERICIUM-241, ANSTO, ARGON-41, ARSENIC-76, AUSTRALIA, BERYLLIUM 7, BETA DECAY RADIOISOTOPES, CESIUM-137, CHEMICAL EFFLUENTS, COBALT-60, CONTAMINATION, DOSE EQUIVALENTS, DOSE-CONSTRAINT, DOSE LIMITS, DRINKING WATER, ENVIRONMENT, ENVIRONMENTAL EXPOSURE, ENVIRONMENTAL EXPOSURE PATHWAY, ENVIRONMENTAL IMPACTS, ENVIRONMENTAL TRANSPORT, EVALUATED DATA, EXPERIMENTAL DATA, FISHES, FISSION PRODUCT RELEASE, FRESH WATER, GAMMA RADIATION, GASEOUS WASTES, GROUND WATER, HEALTH HAZARDS, IODINE-131, LIQUID WASTES, LOW LEVEL COUNTING, LOW LEVEL RADIOACTIVE WASTE, MEASURING METHODS, MERCURY-197, MERCURY 203, NOBLE GASES, PARTICULATES, PLUTONIUM-239, POTASSIUM-40, PUBLIC HEALTH, RADIATION DOSES, RADIATION MONITORING, RADIOACTIVE EFFLUENTS, RADIOACTIVITY, RIVERS, SAMPLING, SEAWATER, SEDIMENTS, SOILS, STANDARDS, STATISTICS, STORAGE FACILITIES, STRONTIUM-90, SURFACE WATERS, THERMOLUMINESCENT DOSIMETRY, THORIUM-232, TRACER TECHNIQUES, TRITIUM, URANIUM-238,

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Glossary of Terms

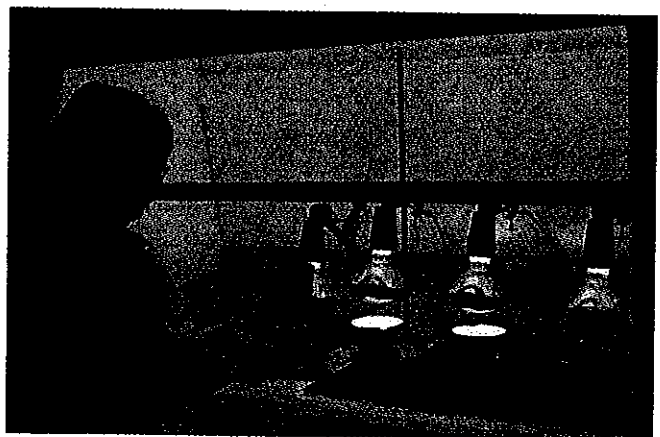
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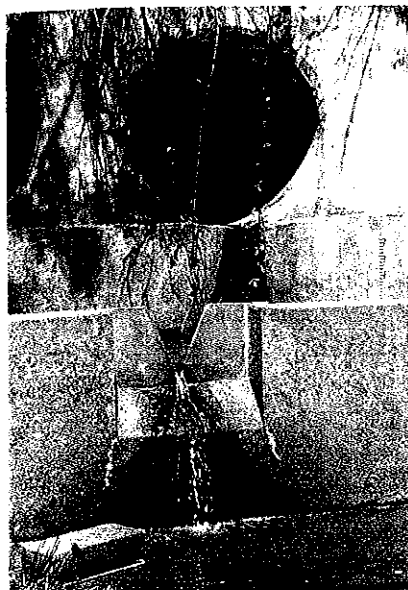
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Gross alpha/beta analysis of waters

Environmental and Effluent Monitoring at Lucas Heights Science and Technology Centre, 1998

Summary



Bardens Creek Weir



Potter Point



Low-level liquid effluent pipeline

The Australian Nuclear Science and Technology Organisation (ANSTO) has a Health, Safety and Environment Policy that commits the Organisation to undertaking its activities in a manner which 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. The Organisation is committed to an on-going community dialogue on this policy and its implementation. ANSTO is also committed to providing verifiable evidence of the fulfilment of the policy through a program of monitoring and audit.

On 5 February 1999, the regulation of ANSTO's operations changed with the establishment of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). As this report covers the calendar year 1998, reference will be made to the regulatory regime applicable at that time. This involved principally the Nuclear Safety Bureau (NSB) and the Australian Radiation Laboratory (ARL). The environmental and effluent monitoring results for 1998 show that ANSTO complied with effluent discharge authorisations and relevant environmental regulations.

Liquid Effluent

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

- The former NSW Radioactive Substances Regulations (1959);
- 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 1998, radionuclide concentrations in liquid effluent discharged to the sewer were below the limits specified in the Sydney Water Trade Wastewater Agreement. The average monthly radionuclide concentration quotients were less than 45% and 39% of the limits with respect to (a) and (b) above. 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

Potential effective doses to local members of the public from controlled airborne discharges in 1997 and 1998 were estimated to be less than 0.010 millisieverts per year for receptor locations on the 1.6 kilometre radius buffer zone boundary around the HIFAR research reactor. This represents 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 approved by the Nuclear Safety Bureau.

Stormwater and Surface Waters

Stormwater drainage from the Lucas Heights Science and Technology Centre (LHSTC) complied with the NSW Clean Waters Regulations (1972) for gross alpha and gross beta activity at the on-site sampling bunds and 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 are very low when compared with WHO drinking water guidelines. Water samples collected at the confluence of Mill and Bardens Creeks, from the Woronora River and Forbes Creek, did not contain any detectable levels of tritium.

Little Forest Burial Ground

Groundwater monitoring at the Little Forest Burial Ground (LFBG) indicated that tritium levels were similar to past years. The gross alpha and gross beta activities in borewater were lower than pre-1996 levels, and, except for gross alpha activity in MB16 and BH10, all were at levels safe for drinking water. Traces of cobalt-60 and caesium-137 were detected in bore MB16 which is in the centre of the burial trenches. These levels were less than 1% of the WHO drinking water guideline values and have no health significance to humans.

A mobile high-volume air sampler (approved by the US Environment Protection Agency) was used to monitor airborne particulates at the LFBG throughout 1998. 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 1998. 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 1.0 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 3.3 mSv/year was registered at location 2 in the southern sector of the LHSTC perimeter fence. This area was affected by the movement of stored nuclear material to the new storage facility in building 59. This part of the site is not readily accessed by the general public and is approximately 1.8 kilometres away from any residential areas. Other locations exhibited normal background dose rates ranging from 0.8 to 1.5 mSv/year.

Potter Point Ocean Outfall

Biological and seawater monitoring continued at the Potter Point ocean outfall during 1998. Treated sewage effluent for the Sutherland Shire, including low-level effluent from the LHSTC, passes through the Cronulla Sewage Treatment Plant and is discharged at Potter Point. The seawater and biological sampling programs are aimed at assessing potential doses to members of the public who may recreate in the ocean off Potter Point and/or 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. No activity, which could be directly attributed to ANSTO, was found in any biological samples taken from Potter Point in 1998, with the possible exception of iodine-131. However, iodine-131 could also come from hospitals using nuclear medicines and has a half-life of only 8 days. The concentrations of iodine-131 found were of no radiological significance.

The tritium levels offshore in the immediate vicinity of Potter Point were investigated on 3 December 1998. Of twenty-one seawater samples taken 50 metres from the outfall, eight showed detectable levels of tritium. The maximum tritium level observed in the seawater was 6.2 Bq/L which is less than 0.1% of the WHO reference value for tritium in drinking water. No tritium was detected in seawater collected 100, 150, 200 or 250 metres from the outfall. The time taken for wastewater to flow from Lucas Heights to the Cronulla Sewage Treatment Plant was 12 hours and the minimum in-line dilution factor was 29. These results are consistent with results obtained from 1993 to 1997.

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.

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, the Organisation will analyse samples from the local community for environmental radioactivity levels. Contact the ANSTO Communications Manager on (02) 9717 3770 for further information.

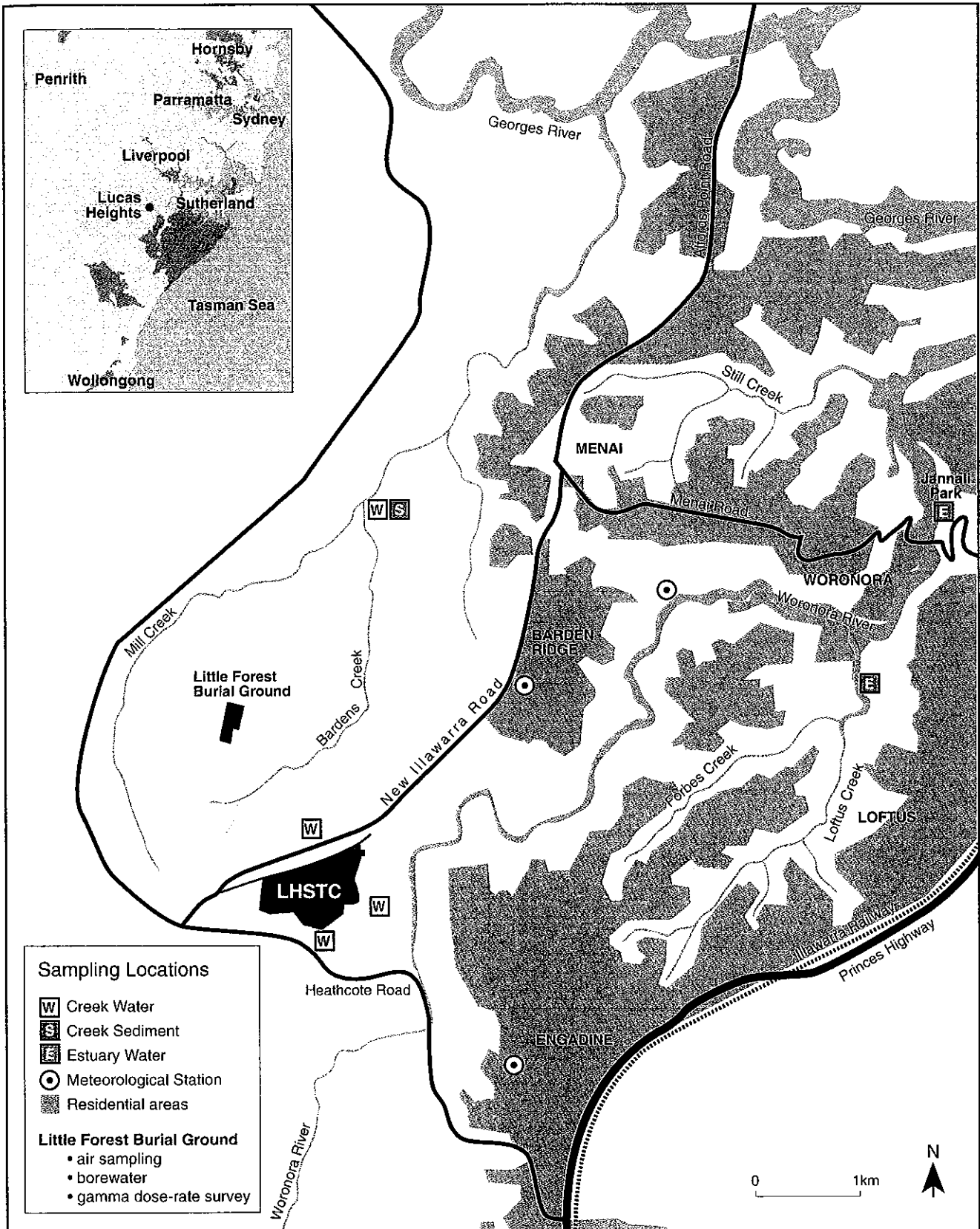


FIGURE 1
Location of LHSTC & Offsite Sampling points

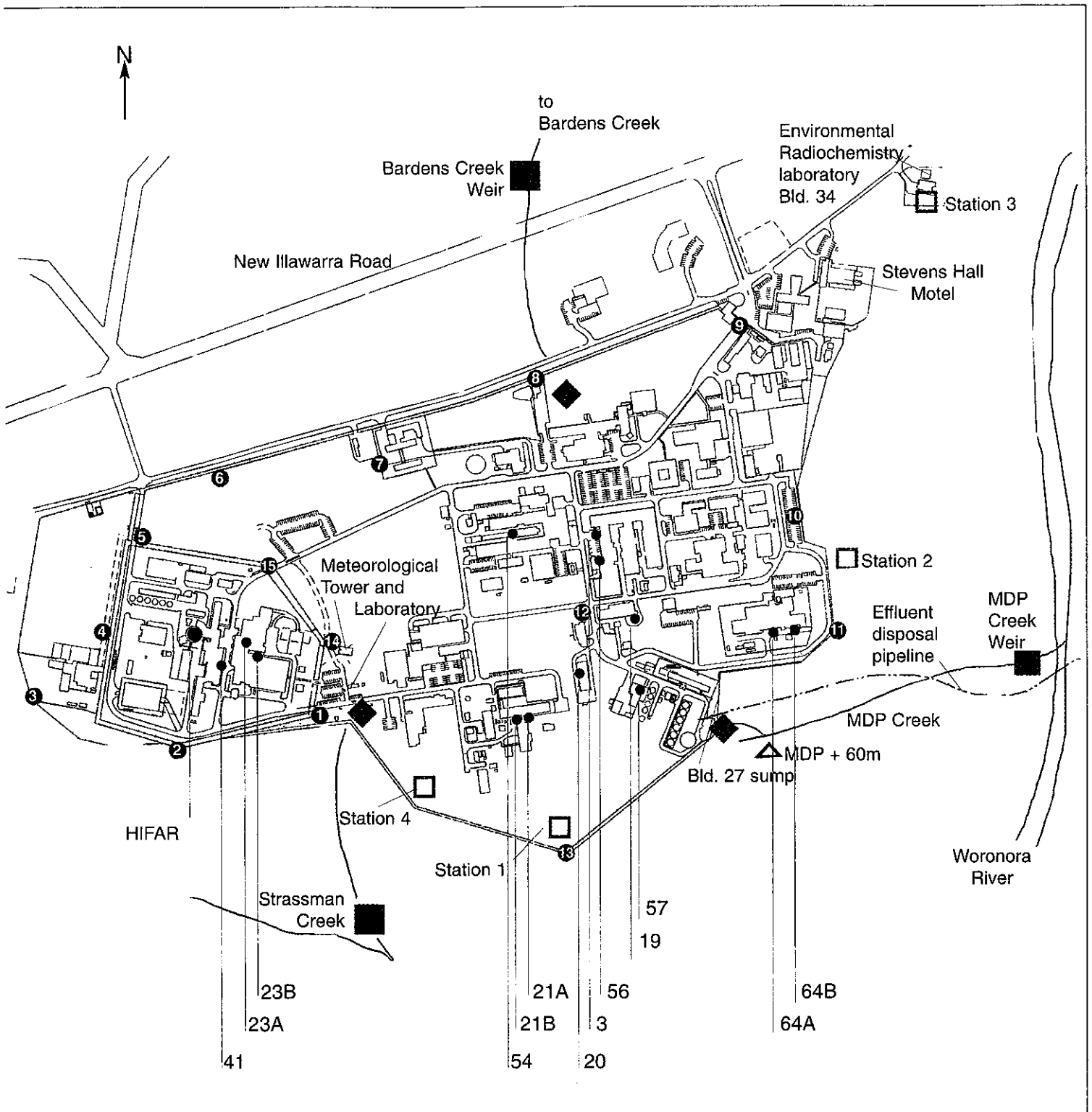


FIGURE 2
Locations of Stormwater, Air and External Radiation Monitoring Points at LHSTC

- | | |
|---|--|
| 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 (Building number) |
| | ② External radiation dosimeters (TLDs) |

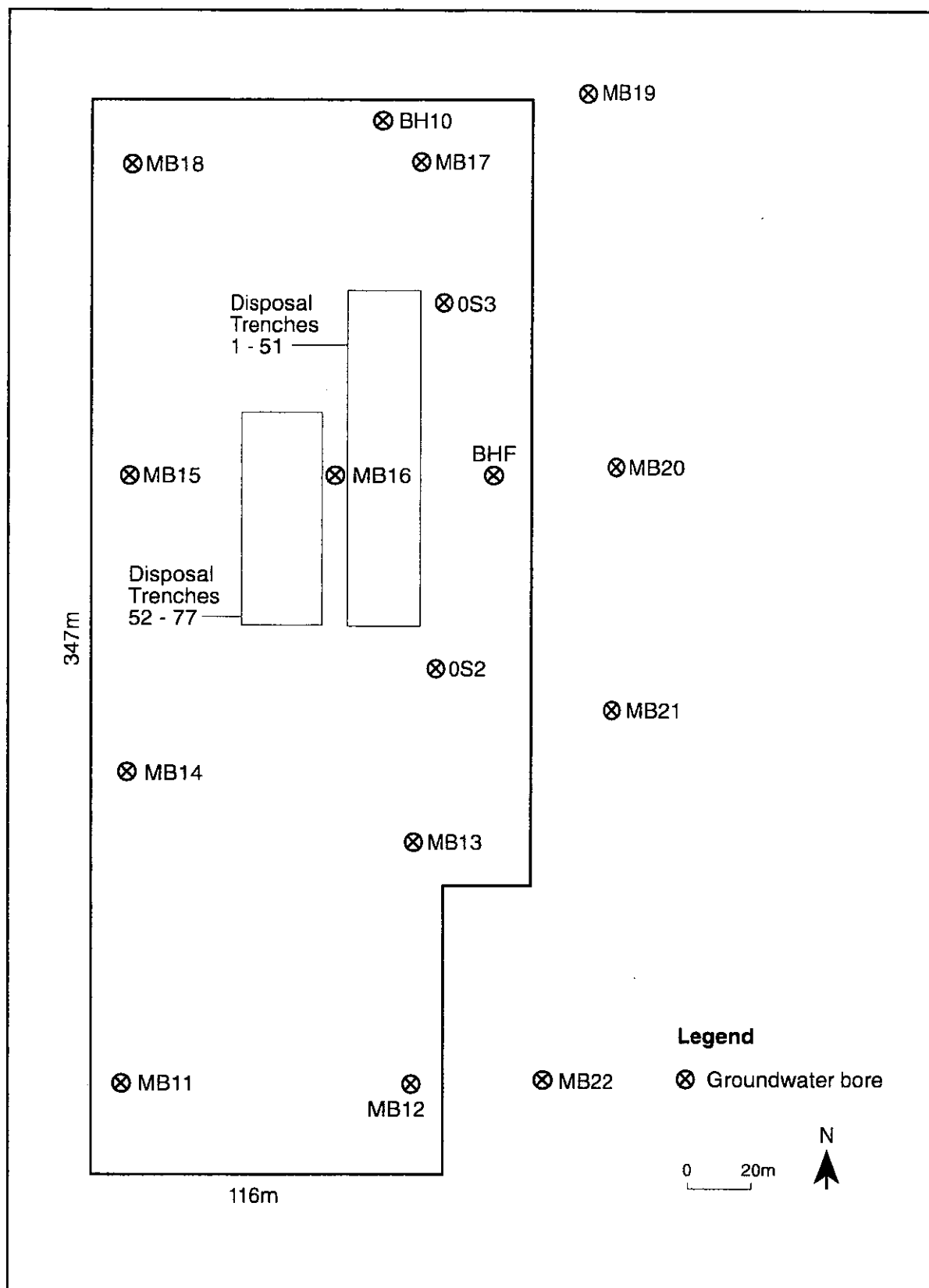


FIGURE 3
Little Forest Burial Ground - Location of Trenches & Groundwater Bores

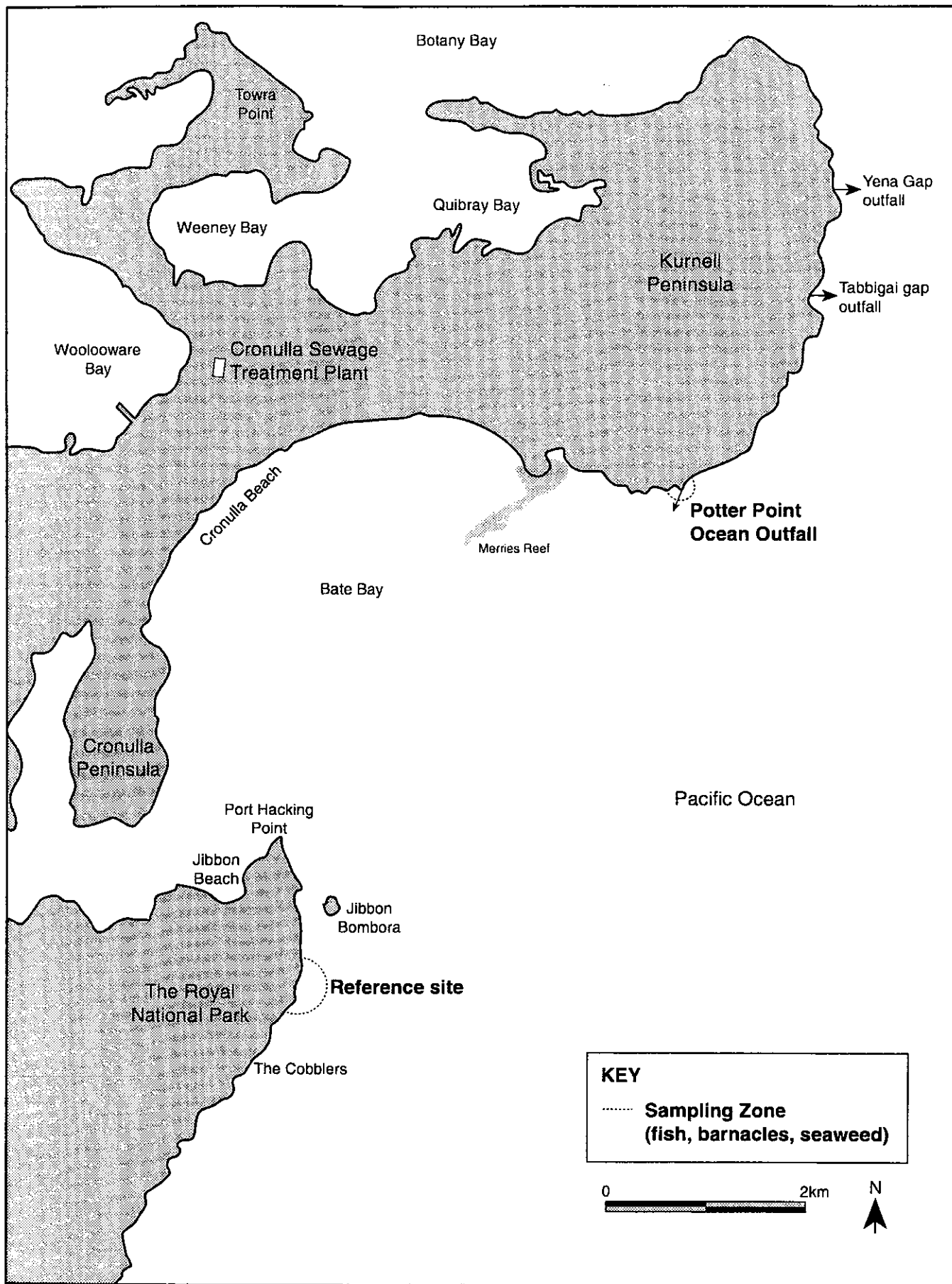


FIGURE 4
 Location of Sampling Zones at Potter Point Ocean Outfall and the Royal National Park

Introduction 1

ANSTO's Health, Safety and Environment Policy commits the Organisation to undertaking its activities in a manner which 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. The Organisation is committed to an on-going process of community consultation on this policy and its implementation.

ANSTO is committed to providing verifiable evidence of the fulfilment of the policy through a program of monitoring and audit. Specifically, the program aims to assure the ANSTO executive and the community that operations at the LHSTC:

- Fully comply with all applicable laws and regulations; and
- Do not result in radiation exposure to staff or the general public in excess of the limits recommended by the International Commission on Radiological Protection (ICRP60), the International Basic Safety Standards (BSS), the National Health and Medical Research Council of Australia (NH&MRC) and the NSW Environment Protection Authority (NSW EPA).

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 during 1998 and assesses the effects of radioactive discharges on both the local population and the environment. The results obtained in earlier surveys have been published regularly and are listed in **Appendix A**.

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

On 5 February 1999, the regulation of ANSTO's operations changed with the establishment of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). As this report covers the calendar year 1998, reference will be made to the regulatory regime applicable at that time. This involved principally the Nuclear Safety Bureau (NSB) and the Australian Radiation Laboratory (ARL).

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 burial ground at Little Forest; and
- accidental airborne releases, or liquid spills which enter the stormwater system.

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

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

The registered dairy herd closest to LHSTC is at Glenfield, approximately 13 kilometres away (NSW Dairy Corporation, 1997). ANSTO has not been aware of any milk suppliers closer than this since 1993. This pathway is therefore not significant and is not considered further.

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

Other potential pathways for the transfer of airborne radioactivity to members of the public include such dietary items as drinking water and vegetable produce. However, these are not considered significant sources of exposure, for the following reasons:

- a) 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
- b) there is little or no commercial food production or processing in the neighbourhood of LHSTC, and
- c) 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 PC-Cream assessment of doses due to ANSTO's airborne effluent releases. See **Section 3.2**.

In addition, ANSTO would be pleased to measure the levels of environmental radioactivity in samples from the local community. Contact the Communications Manager at ANSTO for further information. Levels of integrated external radiation at the LHSTC and in nearby suburban locations were also measured during 1998 using the dosimeters issued by the Australian Radiation Laboratory.

2.2 The Discharge of Low-Level Liquid Effluent Since June 1980 the low-level liquid effluent generated from various operations at the LHSTC has been chemically treated, analysed and recorded to verify compliance with authorised discharge limits before discharge to the Sydney Water Corporation (Sydney Water) sewer. In accordance with the Sydney Water Trade Wastewater Agreement (No. 4423, 1998) the authorised discharge limits were those specified in the former *NSW Radioactive Substances Regulations (1959)*, and 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 eating contaminated fish caught around the Potter Point outfall and ingestion of seawater near the outfall by swimmers and surfers.

Monitoring of the level of radionuclides from the LHSTC near the Potter Point outfall has been undertaken since 1993 and published in ANSTO's *Environmental and Effluent Monitoring at LHSTC* reports (listed in **Appendix A**). The 1998 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.

The monitoring programs at Potter Point confirm that the pre-release treatment of effluents at ANSTO, and 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.

2.3 The Little Forest Burial Ground (LFBG) Between 1960 and 1968 the then Australian Atomic Energy Commission (AAEC) used a small area locally known as Little Forest (see **Figure 1**) for the disposal by burial of solid waste with low levels of radioactivity and (non-radioactive) beryllium oxide that originated predominantly from LHSTC.

The disposal site was selected and wastes disposed of using international guidelines relevant at the time. Near-surface disposal 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 were strictly controlled.

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

Areas adjacent to LFBG have been used by various government agencies and private companies for the disposal of liquid industrial wastes, solid municipal wastes and nightsoil. Some areas were quarried for clay and shale, until 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 readily adsorbed onto the clay subsoil of the LFBG site.

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

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

The radiation levels over the disposal trench area are at 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 cover, or if dissolved radionuclides were transported to the surface by ground water.

Since the 1960s the AAEC and ANSTO have discharged radioactive effluents from LHSTC in compliance with authorisations approved at various times by the NSW Radiological Advisory Council (NSW RAC) in accordance with the NSW Radioactive Substances Regulations (1959), as amended. The discharge limits for both liquid and gaseous discharges were based on a consideration of a conservative set of exposure scenarios and associated pathways, relevant at the time, and were set to ensure that any potential exposures were below the dose limits specified in the NSW Radioactive Substances Act and Regulations.

In 1998 ANSTO complied with:

- any new requirements prescribed by the Nuclear Safety Bureau;
- any provisions of relevant NSW acts and regulations; and in particular
- the provisions of the Sydney Water Trade Wastewater Agreement (1998).

Throughout 1998, the Australian Radiation Laboratory undertook independent audit and verification of ANSTO's effluent and environmental monitoring programs.

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 In 1998 a revised Trade Wastewater Agreement, *Consent to Discharge Trade Wastewater*, was negotiated with Sydney Water under the Water Board Corporatisation Act 1994. Under the terms of this Agreement ANSTO complied with:

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

3.1.1 Radioactivity Concentration Limits - Based on the NSW Radioactive Substances Regulations The NSW Radioactive Substances Regulations (1959) require that the average concentration of each radionuclide (C_i) in the liquid effluent at the point of discharge, must not exceed the Maximum Permissible Concentration (MPC) defined for that radionuclide. Where more than one radionuclide is present, the sum of the average concentrations of all radionuclides (expressed as a fraction of the relevant MPC), termed the concentration quotient, must be no greater than one, ie

$$\text{Equation 1} \quad \sum_i \frac{C_i}{\text{MPC}_i} \leq 1$$

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

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

$$\text{Equation 2} \quad \frac{\alpha}{\text{MPC } ^{226}\text{Ra}} + \frac{\beta}{\text{MPC } ^{90}\text{Sr}} + \frac{{}^3\text{H}}{\text{MPC } ^3\text{H}} \leq 1$$

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

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

Radioisotope	Dose Conversion Factor ⁽¹⁾	Drinking Water Reference Concentration
	mSv/Bq	Bq/L
americium-241	2.0×10^{-4}	0.69
caesium-134	1.9×10^{-5}	7.2
caesium-137	1.3×10^{-5}	10.5
chromium-51	3.8×10^{-9}	3600
cobalt-60	3.4×10^{-6}	40
iodine-131	2.2×10^{-5}	6.2
lead-210	6.9×10^{-4}	0.20
radium-226	2.8×10^{-4}	0.49
radium-228	6.9×10^{-4}	0.20
strontium-90	2.8×10^{-5}	4.9
tritium	1.8×10^{-9}	7600 ⁽²⁾

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

The WHO Guidelines are deemed to apply at the Cronulla Sewage Treatment Plant (CSTP). A conservative dilution factor of 25 is assumed between the ANSTO discharge point and the CSTP (based on previous studies conducted from 1993 to 1996, see **Section 7**). To obtain a concentration limit for monitoring liquid effluent at the ANSTO point of discharge, the above Drinking Water Reference Concentrations for radium-226, strontium-90 and tritium were multiplied by 1000 (converting Bq/L to Bq/m³) and by a factor of 25 (allowing for dilution between ANSTO and the CSTP). The resulting *Activity Concentration Equivalents* are tabulated below.

Concentration Limits at ANSTO Discharge Point based on the WHO Guidelines for Drinking-Water Quality (1993)	
Activity Concentration Equivalents (Bq/m ³)	
radium-226	1.25×10^4
strontium-90	1.25×10^5
tritium	1.95×10^6

The monthly concentration quotient is calculated using the summation formula in equation 2, but the MPC denominators are replaced by the Activity Concentration Equivalents (ACE), ie

$$\text{Equation 4} \quad \frac{\alpha}{\text{ACE } ^{226}\text{Ra}} + \frac{\beta}{\text{ACE } ^{90}\text{Sr}} + \frac{{}^3\text{H}}{\text{ACE } ^3\text{H}} \leq 1$$

3.1.3 Compliance Auditing In 1998, the Australian Radiation Laboratory 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, to assess compliance with their requirements for the acceptance of liquid trade waste. Sydney Water did not raise any non-conformances against ANSTO in 1998. **Section 6.2** presents the results of ANSTO's compliance monitoring of liquid effluent discharges.

3.2 Gaseous Emissions From 1968 until 1988, radioactive emissions from AAEC/ANSTO were subject to a discharge authorisation approved by the NSW RAC which specified the maximum amount of radioactivity that could be discharged from each of the stacks at LHSTC during a given time period.

In 1988, ANSTO proposed to the NSW Radiological Advisory Council (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.

Site dose constraint

In August 1993, the Research Reactor Review Panel recommended that ANSTO should commit itself to emission targets and, in particular, a single-source dose constraint of 0.3 mSv (see **Glossary** for the definition of dose constraint). This recommendation has been adopted by ANSTO. In August 1997 the NSB issued a revised HIFAR Radioactive Airborne Discharge Authorisation specifying four weekly, quarterly and annual notification levels with a HIFAR dose constraint of 0.1 mSv. ARL concurred with this authorisation and also confirmed that a dose constraint of 0.3 mSv was appropriate for the whole site. As indicated above, the site dose constraint previously authorised by the NSW RAC was 0.5 mSv.

In June 1998 the NSB authorised the use of a European computer code, PC-Cream⁽¹⁾ to replace the ANSTO-developed ADDCOR code⁽²⁾, for estimating effective doses due to airborne discharges from the LHSTC site. This internationally-accepted code is considered more appropriate than the now-dated ADDCOR code, and includes the latest ICRP dose conversion factors. Once ANSTO received authorisation to apply the PC-Cream code to the site as a whole, the computer code was used to generate estimated effective doses due to all site discharges in the 1997 and 1998 calendar years. See **Section 6.1**.

PC-Cream 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;
- 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.

Compliance Auditing

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

3.3 Surface Waters The NSW Clean Waters Regulations (1972) as amended, limit the gross alpha and gross beta activity in class C waters to 1.1 and 11.1 Bq/L, respectively. In order to assess ANSTO's compliance with these regulations, sampling points were selected by the NSW Environment Protection Authority (EPA)⁽³⁾ at Strassman, MDP and Bardens Creeks. These creeks, shown on **Figure 2**, receive most of the stormwater running off the LHSTC area. Results of stormwater and surface sampling are discussed in **Sections 5.4 and 5.5** of this report.

¹ Refer to ANSTO Safety and Reliability Report SD/SR/TN 98-7 revision1, August 1998.

² Atmospheric Dispersion and Dosimetry Code for Operators and Regulators. Refer to ANSTO/DR25, 1989.

³ Formerly the State Pollution Control Commission (SPCC)

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 to 2000 keV. The gamma photopeaks in the spectrum are then analysed for significant nuclides and the specific activity calculated. Nuclides detected by this method include cobalt-60 (half-life 5.26 years), caesium-137 (half-life 30.2 years), and iodine-131 (half-life 8.02 days).

Caesium-137: 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). 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 cobalt contained in the steel casings of reactor components. It has a half-life of 5.3 years and is a beta-gamma emitter. This isotope is readily concentrated by both aquatic and terrestrial organisms.

Iodine-131: a fission-product radionuclide with a half-life of 8.02 days. It is biologically important because it can deposit onto pasture and be incorporated into milk. Human consumption of this milk can then lead to iodine-131 uptake by thyroid tissue. Further, inhalation of gaseous iodine-131 can also result in doses to the lung and thyroid. Iodine is more readily concentrated by marine biota than by freshwater organisms.

Tritium (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 more energetic radionuclides (**Section 3.1.2**).

Tritium is widespread in the environment. It is a cosmogenic radionuclide which was also produced as a result of atmospheric nuclear weapons testing (by far the largest contribution). 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 of 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. The gross α and gross β activities are interpreted in terms of the most restrictive isotope as described in **section 3.1.1**. 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 EIS process for the replacement reactor.

4.3.1 *Methods - Environmental Radiochemistry Laboratory*

Australian or International Standard methods for radiological analyses are used, where they are available. Gamma spectrometry, gross alpha, gross beta and tritium analyses of waters are documented and utilise techniques based on those used by the Australian Radiation Laboratory. 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 are counted up to five times. Long counting times (23 hours) are 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.

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.

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 effluent monitoring programs are presented in **Sections 6 & 7** of this report.

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 1998 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**. Methods for gross alpha, gross beta and gamma determinations were updated in 1997. The purpose of this change was to bring the procedures into line with the relevant Australian Standard (AS) or International Standards Organisation (ISO) methods and to enable direct comparison between ANSTO and ARL results. More detailed information on the collection, preparation and analysis of environmental samples is available in **Appendix D**. Environmental survey results for 1998 are presented in **Tables 2 to 18b**.

5.1 Woronora River Routine water samples were collected monthly from the Woronora River at the boat ramp in Jannali Reserve and analysed for tritium. No tritium was detected in these samples during 1998 and none has been detected since July 1980, when discharges of treated liquid effluent from LHSTC to the Woronora River ceased. The data are listed in **Table 2**.

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

Sampling at Forbes Creek was initiated in response to the concerns of some local residents, that occasional overflows from the upstream sewer mains during periods of heavy rainfall may contain radioactivity of LHSTC origin. Tritium is the radionuclide most likely to be detectable under such circumstances.

Tritium was not detected in any of the samples collected during 1998, 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	<i>Girella sp.</i>
green algae (seaweed)	<i>Enteromorpha sp. and Cladophora sp.</i>
surf barnacles	<i>Tesseropera rosea</i>

The approximate quantities of biological material collected in 1998 were:

Location	Total Mass of Material Collected (kg fresh weight)		
	Fish	Green Algae	Barnacles
Potter Point	1.35	1.11	2.66
The Royal National Park	1.47	0.89	0.74

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

The sampling locations at Potter Point and the Royal National Park are shown on **Figure 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 samples collected from Potter Point did not reveal any fission product activity, apart from low levels of iodine-131 in algae.

The short-lived isotope iodine-131 was detected in algal (seaweed) samples from Potter Point at concentrations of 20 to 400 Bq/kg fresh weight (corrected for decay from sampling date). Seaweeds are extremely good environmental indicators, responding rapidly to small changes in pollutant concentrations. It is therefore not surprising that low levels of radionuclides may be detected in these samples.

The levels of iodine-131 found in green algae (seaweed) from Potter Point are of no health significance to humans. The potential radiation dose to members of the general public as a result of ANSTO's discharges to the sewer is very low. It should be noted that ANSTO is not the only source of radionuclides entering the sewer system in the Sutherland Shire, as hospitals using nuclear medicines could also be a source of radionuclides and stormwater can also contain low levels of natural radioactivity from sediments in catchment run-off.

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

5.4 Stormwater Outlets 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.

5.4.1 Stormwater Retention Bunds

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

- Bund A - Opposite building 1;
- Bund B - Opposite the meteorological tower;
- Bund C - MDP - below 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.

Tritium in Stormwater Bunds

In 1998 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 the stormwater bunds at levels well below the WHO drinking water reference concentration of 7800 Bq/L (**Section 3.1.2**). The range of tritium values for bunds A, B & C were 50 to 300, 30 to 360 and <10 to 340 Bq/L respectively.

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

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 1998 (including less-than values) were :

gross alpha < 0.03 Bq/L gross beta 0.80 Bq/L.

These values can be equated with average weekly results for 1998 and are well below the NSW Clean Waters Regulations limits for class C waters: 1.1 Bq/L for gross alpha and 11.1 Bq/L for gross beta activity.

Gamma spectrometry performed on the monthly composite samples revealed traces of caesium-137 in 5 out of 12 months, with no other significant gamma-emitters detected. The average weekly concentration of caesium-137 in MDP Bund C was <0.03 Bq/L, or <0.3% of the WHO reference value for caesium-137 in drinking water. Similar, low levels of caesium-137 have been detected in previous years.

Sediment from Stormwater Bunds

Any sediments which have accumulated in the stormwater bunds are 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 1998 are given in **Table 8**. Gross alpha/beta activities correspond to normal levels for similar local sandy soils. Measurable gamma-emitters included potassium-40, natural ²³⁸U & ²³²Th series progeny and small concentrations of fission products. The low-level activities found do not have any health consequences for humans.

5.4.2 MDP+60m

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

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

Tritium in Water from MDP+60m

Tritium results for the weekly MDP+60m water samples are shown in **Table 9a** and varied from <20 to 320 Bq/L. The average tritium concentration of weekly samples for the year was <92 Bq/L, which is less than 2% of the WHO drinking water reference concentration.

Radioactivity in MDP+60m Monthly Composite

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

Traces of caesium-137, cobalt-60 and chromium-51 at low levels were occasionally identified in monthly composite water samples from MDP+60m, by sensitive gamma spectrometry techniques. The maximum caesium-137 concentration in 1998 was 0.025 Bq/L, which represents 0.24% of the WHO drinking water reference concentration. The traces of chromium-51 and cobalt-60 detected were negligible, at 0.002% and 0.04% of their respective WHO drinking water reference concentrations.

Stormwater Summary

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

5.5 Creeks Draining LHSTC SPCC Sampling Points

Stormwater from the LHSTC flows into three small local streams, which are classified as class 'C', waters under the NSW Clean Waters Regulations (1972). In 1975, the NSW EPA, required that the stormwater be sampled periodically at selected locations, in order to demonstrate compliance with the activity limits specified in the NSW Clean Waters Regulations (1972). Sampling points on Strassman Creek, Bardens Creek and MDP Creek (**Figure 2**) were sampled and analysed for gross alpha and gross beta activity.

In 1998, gross alpha and gross beta analyses were performed using methods 9696 & 9697 of the International Organisation for Standardisation. The data are presented in **Table 10**. The gross beta results include the contribution of natural potassium-40 activity. All results were well below the NSW Clean Waters Regulations limits for gross alpha and gross beta activity. 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.

Samples of water were also collected from the sampling weir on Bardens Creek at weekly intervals during 1998, for tritium analysis. The results are shown in **Table 11**. The highest value recorded during the year was 970 Bq/L, which is less than 13 % of the WHO reference concentration for tritium in drinking water (**Section 3.1.2**). The average weekly concentration at this location was less than 110 Bq/L, or < 2% of the reference concentration. It should be noted that water from Bardens Creek is not part of any known drinking water supply.

5.6 Effluent Discharge Pipeline The ANSTO liquid effluent disposal pipeline, which runs above ground for much of its length, is shown on **Figure 2**. Surveys of the dose rates along this pipeline were carried out in 1998, and the results are summarised in **Table 12**. These surveys were performed as part of the regular program of inspection and maintenance of the pipeline in order to detect past or present leaks. No such problems were detected in 1998.

The dose rates recorded along the pipeline in April 1998 with an Eberline PRM-7 field dose-rate meter, were similar to past readings. The second survey in September 1998 was carried out with another monitor (of the same model) which had a slightly different sensitivity and this is reflected in the increased range of the background readings. All dose rates recorded were less than 0.15 $\mu\text{Sv}/\text{hour}$ and are principally due to natural background radiation.

5.7 Little Forest Burial Ground (LFBG) Results of sampling at the LFBG are given in **Tables 13, 14, 15, and 16**. The locations of the sampling points and the burial trenches are shown in **Figure 3**.

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, 1998 ranged from 0.10 to 0.15 $\mu\text{Sv}/\text{hour}$, consistent with normal background readings. Two localised points, # 5 & #6 near the centre of the trenches which have shown slightly elevated readings in the past, were also at background levels in 1998.

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 1998 therefore no soil samples were collected. During the year three trench locations were top-dressed with clay/shale of local origin.

¹ Formerly the State Pollution Control Commission (SPCC)

5.7.3 Groundwater Monitoring at LFBG

Groundwaters from 15 monitoring bores located both inside and outside the fenced LFBG area were collected in June and November 1998 and analysed for tritium, gross alpha, gross beta and gamma activities. Results are listed in **Table 14**.

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

Gamma-emitters in Groundwaters

No artificial radionuclides were detected in any bores other than MB16, in the centre of the trench area, which contained traces of cobalt-60 and caesium-137. The concentrations of both radionuclides were less than 1% of the relevant adult drinking water reference concentrations tabulated in **Section 3.1.2**.

Gross alpha/beta activity in Groundwaters

The levels of gross alpha and gross beta activity in groundwaters from LFBG not only comply with the Clean Waters Act requirements for class C waters, they are also very close to the levels considered safe for drinking water in Australia. The results show a reduction in gross alpha and gross beta activities when compared to pre-1996 values, this is due to improved sampling methods implemented in 1996, which exclude sediment from the water samples.

Tritium in Groundwaters

For bores inside the fenced area, tritium concentrations in 1998 were similar to previous measurements, with detectable tritium levels in eight bores: BHF, BH10, OS2, OS3, MB13, MB16, MB17 and MB18. Bore MB16, being in the centre of the trenches, had the highest tritium concentration at 7010 Bq/L, 90% of the WHO recommended level for drinking water.

Tritium concentrations in the seven remaining bores, including the three which are outside the fenced LFBG area, remain at background levels.

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 are negligible. Built to United States Environmental Protection Authority specifications, the sampler was commissioned in October 1997 to replace the previous solar-powered monitoring station (which was vandalised and stolen in 1996). The Ecotech sampler is capable of collecting greater quantities of air than the previous system and is therefore more accurate.

The air sampling flow rate is set at 60 m³ per hour and airborne particulates are progressively accumulated over a period of three months on a cellulose fibre filter paper. When operated as above, the high-volume sampler will collect approximately 1440 cubic metres of air per quarter, and 5760 m³ per annum. This is about twelve times greater than the average annual volume recorded using the previous system. The particulate sampling method described above is conservative, since a size-selective inlet is not used and larger particles in excess of respirable size may also be collected. The particles collected at LFBG would be up to about 50 microns equivalent aerodynamic diameter (EAD). Particles below 10 microns EAD are respirable and hence considered a potential health hazard. Such particulate matter is generated by industrial processes, combustion of fuels, burning of vegetation and incineration. These particles are also present in motor vehicle emissions, wind blown dust and salt air (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.

Results of Airborne Particulate Monitoring

The results for airborne particulate monitoring at LFBG in 1998 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. No beryllium or plutonium concentrations were detected on the analysed portions in 1998.

To estimate the amount of airborne particulates being generated at the LFBG, some filters were dried and weighed prior to use and again at the conclusion of sampling. The particulate matter on the filters used for the July - Sept. 1998 and Oct. - Dec. 1998 sampling periods weighed 0.045 and 0.053 grams respectively. The airborne particulate concentrations during sampling from July to December 1998 were less than 3.5×10^{-5} grams per cubic metre of air, which is extremely low.

5.7.6 Wind Speeds at LFBG

The wind speed threshold for increased resuspension of dust particles from the ground, in temperate Australian conditions is normally considered to be about 5 to 6 metres per second (Clark, 1998 personal communication). However, this will depend on local conditions such as soil moisture, the age of the particles and their bonding to the ground surface, vegetation cover and local turbulence amongst other factors. 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.

In 1998, during periods of air sampling at the LFBG, the average wind speed was 3.3 metres per second and data ranged from 0.8 to 8.4 metres per second. This information was obtained from 15-minute averages of wind speed data recorded at the 10 metre high ANSTO meteorological tower.

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 were sufficient to generate particulates from an exposed surface (G. Clark, personal communication, July 1998).

LFBG Summary

The LFBG is a stable and well-grassed area, which rarely experiences winds capable of significant dust generation. The levels of suspended particulates were determined for the last six months in 1998 and the results indicate that very little resuspension of dust particles occurred. 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 Ambient Iodine-131 in Air Four (4) continuous air sampling stations are situated along the eastern fence boundary of the site (where suburban residences are closest) to monitor concentrations of ambient iodine-131 in air. The locations of these samplers are shown on **Figure 2**. Iodine-131 is the nuclide of interest since it could potentially be incorporated into the food chain. Noble gas emissions cannot be detected by 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 m³ per day. Filters are replaced and analysed weekly, with air flow rates through the filters being checked at the same time. Calculations of iodine-131 activity give maximum levels of activity using a conservative set of assumptions. Analysis is via gamma spectrometry of the Maypacks (see **Appendix D** for further details).

No iodine-131 was detected in ambient air at the site boundary during 1998, all results were below the detectable level of 0.0025 Bq/m³ (**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/m³. Since the fifty-two

measurements in 1998 showed no detectable iodine-131, the average annual dose to the public from iodine-131 is clearly far less than 0.01 mSv⁽¹⁾.

5.9 Meteorological Monitoring In common with many other nuclear facilities, ANSTO undertakes an extensive program of meteorological measurements. The prime reason for such a program is to allow estimates to be made of the downwind concentration of any airborne pollutants, particularly radionuclides, released from the site through routine operations or under accident conditions. The data collected from this program provide the necessary input to the atmospheric dispersion model called PC-Cream⁽²⁾ which is used to compute the effective dose to an individual due to the routine airborne or accidental release of radionuclides from the LHSTC.

In 1993, three additional meteorological stations were installed to investigate the influence of local complex terrain on wind flow, dispersion patterns and temperatures (Clark, 1997). The stations are located at the Lucas Heights Community School; Boys Town School (Engadine) and at the "Shackels Estate" in the Woronora River valley (Figure 1). Due to repeated vandalism, the meteorological station at the Lucas Heights Community School was removed in September 1998.

The on-site meteorological tower and associated laboratory are shown on Figure 2.

Wind Direction

Annual average wind speeds recorded at Lucas Heights from 1991 to 1996 were approximately 2.5 metres per second (Clark, 1997). The winds that predominate at Lucas Heights during summer and winter are shown in the table below.

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

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

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

Rainfall

The total rainfall at Lucas Heights in 1998 was 1207 mm, recorded on 129 rainy days. The wettest month was May, with 203.7 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 1998 was July with an average midday temperature of 14.4 °C while the warmest month was December, when the average midday temperature was 24.4 °C.

The temperature extremes recorded were:

Minimum: 2.8 °C in July; Maximum: 40.2 °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.

¹ Based on the Committed Effective Dose per Unit Activity given in the International Basic Safety Standards (1996), Safety Series No 115.

² Refer to ANSTO Safety and Reliability Report SD/SR/TN98-7 revision 1, August 1998.

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 1998 with both ANSTO and ARL thermoluminescent dosimeters (TLD).

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

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

Figure 2 shows the locations of dosimeters 1 to 15.

Results

Table 18a shows the integrated annual absorbed dose to air, in millisieverts, as monitored by the ARL dosimeters for the calendar year 1998, and compares these figures with results for 1994 through to 1997. Measurements were made over quarterly monitoring periods, the dosimeters were returned to ARL for measurement, and the readings were reported to ANSTO as annual absorbed dose to air in terms of milligray. The absorbed dose was then converted to effective dose (in millisieverts) using the conservative conversion factor of one⁽¹⁾.

The 1998 annual doses measured at or within the LHSTC perimeter fence, had a minimum of 0.7 mSv and a maximum of 3.3 mSv. The 1998 annual absorbed dose to air due to environmental radiation measured outside several homes in the vicinity of the LHSTC was around 0.9 mSv. When converted to an hourly rate, this figure corresponds with the average hourly absorbed dose rate to air from terrestrial gamma radiation, recorded in Australian capital cities in surveys carried out by the ARL and reported by UNSCEAR (1993). This means that the external gamma dose rates at residences near the LHSTC are at normal background levels. The annual doses measured at these locations have remained constant (within measurement tolerances) since the introduction of TLD monitoring in 1994.

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

The movement of stored radioactive materials affected the pattern of doses in the HIFAR fenced area during 1998. As a result of the relocation of the material, the dose at location 2 on the inner perimeter fence (closest to the building 59 extension) was elevated when compared with the pre-1997 measurements. Building 59 is a storage facility for low level radioactive wastes. Safety Division conducted a comprehensive dose rate survey in the Building 59 vicinity, both inside and outside the perimeter fence, as part of the analysis of environmental and worker doses. The results of the dose rate survey, together with a consideration of occupancy factors, indicate that there is no justification for further shielding of the building. However, consideration is being given to reorganisation of materials within the store and additional local shielding for specific materials. This location is about 1.8 kilometres away from any residential areas and there is no public occupancy of the area.

¹ UNSCEAR (1993) use conversion factors of 0.72 Sv per Gy for adults, 0.80 for children and 0.93 for infants.

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 handling, treatment, routine monitoring and authorised discharge of liquid effluent arising from operations at LHSTC. Descriptions of the effluent sampling and analysis procedures are given in the following sections. For more information on stack sampling procedures, see **Appendix E**.

6.1 Airborne Effluent Stack Discharges

The authorised airborne effluent discharges from LHSTC stacks are monitored weekly by ANSTO's Safety Division. Samples of effluent airstreams are analysed for gamma emitters, noble gases, tritium, and gross alpha/beta activity. The locations of these discharge stacks around the site are shown on **Figure 2**. **Appendix B** summarises the types of stack discharges that occur at LHSTC and comments on their causes.

Stack Sampling

During 1998, 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.

Results

Table 19a, 19b, 19c and 19d presents the 1998 airborne emission data for the individual stack release points on a quarterly basis.

The airborne effluent stack discharge data for the 1997 and 1998 calendar years were used to estimate possible doses to members of the public due to airborne releases from the site in 1997 and 1998 (see **Section 8.1**). The 1997 data is included in this report because the PC-Cream code was not formally approved for site-wide use at the time of publication of the report for 1997 (ANSTO/E-732).

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.

6.2 Low-Level Liquid Effluent Discharges

Liquid effluent treatment and discharge

The Waste Operations group at ANSTO is responsible for the handling, treatment, routine 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**.

To facilitate treatment, waste waters are segregated into 3 categories:

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

The 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. Finally, groundwater seeping into the sump in the vicinity of building 27 (the intermediate waste and spent fuel storage facility) is pumped into the holding tanks. The levels of gamma emitting isotopes and tritium in the groundwater seepage are monitored monthly.

Treated effluent is transferred to holding tanks where levels of radioactivity are checked prior to discharge to the sewer. Proportional samples from the discharge pipeline are collected during 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 which make up the monthly composite).

Liquid Effluent Results

Groundwater seepage from the area below Building 27 was analysed monthly in 1998 (Table 20). No significant gamma activity was detected and tritium levels were well below the WHO drinking water guideline value 7800 Bq/L).

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 equations 2 and 4 (Sections 3.1.1 and 3.1.2). All quotients were below the limit (ie <1), demonstrating compliance with the Sydney Water Trade Wastewater Agreement.

In 1998 the analytical methods for gross alpha and gross beta determinations were changed from gas proportional counting to liquid scintillation analysis. These changes were made to enable more rapid analyses for operational reasons. Procedures were subsequently changed in July 1998 to improve alpha detection limits. The concentrations of alpha emitters were below the detection limits and, for this reason, quotients are reported as less than values.

Liquid Effluent Compliance

Former NSW Radioactive Substances Regulations (1959):

The monthly radionuclide concentration quotients ranged from <0.09 to <0.94 and the average quotient was <0.45, representing less than 45% of the limit.

WHO Guidelines for Drinking-Water Quality:

The average monthly quotient term (based on the WHO Activity Concentration Equivalents at the ANSTO discharge point) for 1998 was <0.39. This represents less than 39% of the limit. Individual monthly quotients ranged from <0.08 to <0.79.

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 minimum, maximum and average values recorded from 1995 to 1998. The standards for acceptance of the trade waste are also listed against each component. All discharges in 1998 complied with the relevant standards for acceptance of trade wastes to the sewer, as required by Sydney Water.

Advanced primary treated effluent from the Cronulla Sewage Treatment Plant is discharged from a submerged cliff face outfall at Potter Point, located at the northern end of Bate Bay on the Southern Sydney coastline, NSW (**Figure 4**).

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

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

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

To satisfy objectives (i) and (ii) above, a routine effluent release was monitored during 1998. As in previous investigations, tritium was used to monitor the sewage plume since it is usually present in the ANSTO discharges. Objective (iii) was met by sampling biota at Potter Point twice during the year (**Section 5.3**).

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 from a knowledge of:

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

7.1 December 1998 Effluent Monitoring The tritium levels offshore in the immediate vicinity of Potter Point were investigated on 3 December 1998. The contents of a holding tank at Lucas Heights were released between 21:00 hours on 2 December 1998 and 03:00 hours on the following morning. The total volume released over six hours was 410 kilolitres, with an average tritium concentration of 3218 Bq/L.

Effluent Transit Time to Cronulla STP

An automatic sampler was used to collect hourly samples of effluent near the outflow of the Cronulla STP. The tritium concentration of the effluent varies as it passes through the treatment plant. The interval between the mid-point of the effluent release from Lucas Heights and the time at which the maximum tritium concentration was observed at the STP, was approximately 12 hours. This is consistent with effluent transit times obtained in previous studies, ranging from 9.6 to 11.8 hours.

Offshore sampling

On exit from the Cronulla STP the treated sewage travels via a pipeline to the Potter Point outfall where it enters the ocean (this takes approximately one hour). The ANSTO Environment Division research vessel *Imara* conducted an hourly water sampling program from 10:00 to 16:00 hours on 3 December 1998. Two-litre samples of water were taken from the visible effluent plume moving away to the south of the outfall, at depths of 0.5, 1.0 and 2 metres.

These samples were taken at five stations that were marked by buoys placed in position before sampling commenced and accurately fixed using the differential global positioning system available on board the vessel. The first sampling station was located 50 metres from the ocean outfall. The remaining stations 2, 3, 4, & 5 were positioned at 50 metre intervals within the sewage plume. Station 5 was 250 metres from the outfall.

Tritium Results

The water samples were analysed for tritium concentration by liquid scintillation counting. Tritium was detected in eight of fourteen samples taken from station 1 at 0.5 and 1 metre depths. No tritium was detected in the seven samples from station 1 at 2 metres depth. The maximum tritium concentration at the outfall (station 1) was 6.2 Bq/L at 0.5 metre depth, collected about 16 hours after the release began. This is 0.1% of the WHO reference value for tritium in drinking water. No tritium was found in any samples from stations 2 to 5, all were less than the limit of detection for tritium (5 Bq/L).

The average tritium concentration in the effluent released from LHSTC on 2 December 1998 was 3218 Bq/L and the highest concentration in samples taken the next day at the outflow of the Cronulla STP was 110 Bq/L. The minimum in-line dilution ratio was therefore 29:1. This is consistent with previously observed values for overnight releases, ie outside normal business hours, which were 26.9, 21.5, 31.7 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 higher dilution factors for daytime releases.

Potential Radiation Exposure to Members of the Public

8

The principal sources of potential radiation exposure to members of the public from routine operations at LHSTC are from airborne emissions and low level liquid effluent discharges to the sewer. These sources comply with discharge authorisations given previously by the NSW Radiological Advisory Council or concentration limits specified in the Trade Waste Agreement with Sydney Water. The authorised discharge limits are based on limiting the doses to hypothetical critical group members to levels well below the public dose limits, and below the 0.3 mSv site dose constraint.

8.1 Airborne Emissions As indicated in **Section 3.2**, the PC-Cream atmospheric transport, dispersion and dosimetry computer code was used to evaluate potential doses to members of the public at various receptor locations, based on measured stack discharges and local meteorological data. **Tables 23a & 23b** give summaries of the estimated effective doses due to airborne discharges from LHSTC in 1998 and 1997, at specified locations and distances from the reactor. The 1997 data is included in this report because the PC-Cream model was not approved for site-wide use at the time of publication of the 1997 report (ANSTO/E-732).

The results show that the potential effective doses to critical group members of the public within the 1.6 km radius ANSTO buffer zone, were estimated to be less than 0.010 mSv per year in 1997 and 1998. 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 authorised by the NSB. For members of the general public residing at the 1.6 km radius ANSTO buffer zone boundary and beyond, the most exposed individual was also estimated to receive less than 0.010 mSv/year.

Iodine-131 emissions from the LHSTC were also monitored at the perimeter fence. No ambient iodine levels were detected in 1998. Assuming continuous exposure to the iodine-131 minimum detectable concentration of 0.0025 Bq/m³, 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 represents 1% of the NH&MRC recommended annual dose limit of 1 mSv and about 3% of the site dose constraint adopted by ANSTO, and was calculated in an extremely conservative manner. This is consistent with the results obtained from the PC-Cream model.

Table 24, taken from UNSCEAR (1993), shows the average annual effective doses to adults from the various natural sources of radiation which result in an estimated total annual dose of 2.4 mSv. This figure will vary with local geological conditions and with height above sea level and is generally accepted to range from 1.8 to 2.2 mSv per year in Australia.

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

8.2 Low-Level Liquid Effluent Low-level liquid effluent is chemically treated and analysed before controlled discharge to the Sydney Water sewer. Prior to 1980, 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 1998 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 levels of iodine-131 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 recreating in the ocean in the vicinity of the outfall or ingesting seafood from the area.

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

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

A slightly elevated external gamma radiation reading of 3.3 mSv/year was registered at LHSTC on the southern sector of the perimeter fence. This area was affected by the relocation of nuclear material to the new storage facility in building 59. 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.

8.4 Little Forest Burial Ground The 1998 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 inside the fenced area. All bores were below drinking water guideline levels for tritium and no tritium was detected outside the fenced area.

Very low levels of cobalt-60 and caesium-137 were detected in MB16, which is in the centre of the trenches. The other borewaters contained radioactivity of natural origin.

The majority of gross alpha and gross beta activities measured in LFBG groundwaters were below the NH & MRC Australian drinking water guideline levels (0.1 and 0.5 Bq/L respectively).

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

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. The airborne particulate concentrations measured during sampling from July to December 1998 were extremely low.

Based on these and previous surveys, it is concluded that possible radiation exposure to members of the general public via the inhalation pathway is negligible.

External radiation readings over the trenches are consistent with normal background levels. Radiation readings around the LFBG site boundary fence are all at background levels, confirming that possible doses to members of the public from external radiation can also be regarded as negligible.

Acknowledgements 9

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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) and airborne effluent release data (Tables 19a to 19d, 23a & 23b) were supplied by Safety Division.

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

References 10

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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 (a helium-4 nucleus). Although alpha particles are normally highly energetic, they travel only a few centimetres in air and are stopped by a sheet of paper or outer layer of dead skin.

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

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

becquerel (Bq): Unit of radioactivity, equal to one radioactive disintegration per second. This SI unit may be used instead of the curie (Ci): ie
1 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.

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

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

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

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

dose limits: The maximum radiation dose that a person may receive over a stated period of time. Internationally recommended limits adopted by Australia are that radiation workers should not accumulate more than 20 mSv per year. Members of the public should not receive more than 1 mSv/ year (NH&MRC 1995).

effective dose: A physical quantity used in the measurement of ionising radiation dose to humans, taking into account the harmfulness of different types of radiation and the susceptibility to harm of different organs of the body. The effective dose is the sum of weighted equivalent doses to all organs and tissues of the body, where the equivalent dose to each organ and tissue is multiplied by the weighting factor for that organ or tissue. The unit of effective dose is joules per kilogram, termed the sievert (Sv), or more commonly the millisievert (mSv) (one-thousandth of one sievert).

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

equivalent dose: A weighted radiation dose to an organ or tissue, which is the product of absorbed dose in the organ or tissue and the radiation weighting factor (determined by the type and energy of the radiation to which the organ or tissue is exposed). This measurement enables the dose received by exposed persons to be expressed on a scale common to all ionising radiation. The unit of equivalent dose is joules per kilogram, termed the sievert (Sv). Dose is most commonly expressed as millisieverts (mSv).

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

radioactivity: The property of certain nuclides of spontaneously emitting particles or gamma radiation, or of emitting x-radiation following orbital electron capture, or of undergoing spontaneous fission. The SI (International System) unit of radioactivity is the becquerel (Bq). One becquerel is equal to one nuclear disintegration per second. This is a direct measure of the amount of radioactivity in a sample.

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

sievert: The unit of measurement of dose, effective dose or equivalent dose. It is equal to the absorbed dose (in grays) multiplied by a factor related to a particular part of the body. It is the unit used to assess the effects of ionising radiation on living cells. Usually measured in millisieverts, the whole-body dose that every person receives from natural background radiation in one year is about 2.4 millisieverts. Replaces the rem: $1 \text{ Sv} = 100 \text{ rem}$.

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

Radioactive Nuclide	Half-life	Stack	Form of Release	Comment
Iodine-131	8 days	All	Vapour	All stacks are continuously sampled for iodine-131, even though only a few are routinely releasing it. This is partly because of the importance of iodine in any accidental release of mixed fission products and partly because it has sometimes been used in tracer experiments, so that small amounts might occasionally appear in any stack effluent.
Strontium-90	29 years	All	Particulate	The same sampler that measures the iodine release discharges, also measures the particulate activity, both alpha and beta. The filter paper which traps the airborne particles is counted the day after its removal from the stack and again after a delay of 4 weeks to allow the short-lived alpha and beta activity to decay. Any long-lived beta activity on the filters is assumed to be strontium-90, even though this nuclide is not a likely candidate. Note that all the exhaust gases have passed through high efficiency particulate air filters which are better than 99.97% efficient for particle sizes > 0.3 microns.
Argon-41	1.8 hours	HIFAR	Gas	Air is used to cool some of the irradiation rigs in HIFAR. The naturally occurring argon-40 in air becomes activated in passing through the reactor by the absorption of a neutron to form radioactive argon-41 which decays to stable potassium-41. The argon-41 does not deposit on any surface or react with any known substance, since it is a noble gas. It is a beta-gamma emitter which is easy to detect electronically and by film badges.
Tritium	12 years	HIFAR	WaterVapour	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.
Tritium	12 years	Bld 20	WaterVapour	Bld 20 is the decontamination centre and occasionally handles coolant pumps removed from the reactor for maintenance.
Tritium	12 years	Bld 57	WaterVapour	Bld 57 is where the spent resin beds, used to purify the HIFAR coolant water, are regenerated or replaced. Most of the tritiated water on the resin beds is trapped before the drying gas is discharged to the stack.
Mercury-197 Mercury-203 (other activity)	64 hours	HIFAR	Vapour	Slight traces of mercury vapour in the air within the HIFAR containment are activated in passing through the HIFAR reactor. The mercury probably comes from a thermometer dropped at some time in the containment building.
Arsenic-76 (other activity)	26 hours	HIFAR	Arsene Vapour	Very slight traces of arsenic vapour in the air within the HIFAR containment are activated in passing through the HIFAR reactor. The arsenic vapour is being slowly emitted from wood, treated with preservative, which was used a few years ago, when renewing the thermal cladding of the containment building.

Radioactive Nuclide	Half-life	Stack	Form of Release	Comment
Iodine-131	8 days	HIFAR	Vapour	Even though there are, at most, only traces of iodine-131 in the exhaust from HIFAR under normal operation, the effluent is continuously sampled for iodine, since it would be the most important activity released in a serious accident to the reactor.
Xenon-133 Xenon-135 Xenon-135 Krypton-87 Krypton-85m Krypton-88 (Noble gases)	5.3 days 9.2 hrs 15 mins 76 mins 4.5 hrs 2.8 hrs	Bld 54	Gas	These are all fission product noble gases. The radio-nuclide most often used as a diagnostic tracer in nuclear medicine is technetium-99m, extracted from fresh fission products. Small uranium targets are irradiated in HIFAR for a few days before they are dissolved in nitric acid in a fully enclosed apparatus in one of the heavily shielded "Hot Cells" in Bld 54. The noble gases that are released during dissolution are delayed on a large charcoal bed in the next cell. When the targets are completely dissolved the charcoal bed is isolated and the noble gases allowed to decay. However, additional noble gases are formed in the nitric acid solution, from radioactive gases released from the apparatus as the liquid is manipulated into different parts of the equipment by means of vacuum lines. The exhaust gases from the vacuum lines pass through small charcoal beds to trap most of the iodine-131. About 90% of the noble gases are delayed during dissolution leaving only 10% to be released during processing.
Iodine-131	8 days	Bld 54	Organic Iodine Vapour	Iodine-131 is also released during technetium-99m extraction from fresh fission products. Iodine is very volatile even at room temperature and about 3% escapes from the enclosed apparatus, despite efforts to contain it. To prevent this quantity of iodine being released to the atmosphere, the exhaust from the hot cells passes through sixteen beds filled with a specially impregnated charcoal, which was developed in England to trap all forms of airborne iodine, even at high humidity. The beds are tested regularly and are replaced as necessary. The most penetrating form of airborne radio-iodine has been found to be the vapour of an organic compound, methyl iodide, formed when the extremely dilute radioactive iodine reacts with traces of organic vapours.
Iodine-131	8 days	Bld 23		Iodine-131 is an important medical isotope in its own right, being used in the treatment of thyroid cancer. It is produced by the irradiation of a tellurium target in HIFAR, before being processed in a small shielded hot cell in Bld 23. The exhaust from the group of cells passes through three charcoal beds similar to the ones in Bld 54.

APPENDIX C: SYMBOLS AND PREFIXES

Symbol	Name	Half-life (years)
α	alpha	
β	beta	
γ	gamma	
²⁴¹ Am	americium-241	432.2 years
⁷ Be	beryllium-753.	3 days
¹³⁷ Cs	caesium-137	30.14 years
¹³⁴ Cs	caesium-134	2.06 years
¹⁴⁴ Ce	cerium-144	284.9 days
⁵¹ Cr	chromium-51	27.7 days
⁶⁰ Co	cobalt-60	5.3 years
¹³¹ I	iodine-131	8.02 days
K	stable potassium	
⁴⁰ K	potassium-40	1.3 x 10 ⁹ years
²⁴⁰ Pu	plutonium-240	6.56 x 10 ³ years
¹⁰³ Ru	ruthenium-103	39.25 days
¹⁰⁶ Ru	ruthenium-106	371.6 days
⁹⁰ Sr	strontium-90	28.6 years
²³² Th	thorium-232	1.4 x 10 ¹⁰ years
³ H	tritium	12.3 years
²³⁸ U	uranium-238	4.5 x 10 ⁹ years

SI units

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

Multiples and submultiples of SI units

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

APPENDIX D ENVIRONMENTAL SAMPLE COLLECTION AND ANALYTICAL PROCEDURES

Sample Collection: *Potter Point Biological Samples*

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

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

All samples were oven-dried at 70 °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 °C, then passed through a coarse sieve to remove large stones and organic matter. The dry weight was recorded, then the sample ignited at 450 °C in a muffle furnace, cooled and re-weighed. The whole, ashed sample was subsampled for gamma spectrometry and gross beta counting. The remainder of the ashed sample was sieved to yield a fraction with particle sizes ranging from 125 to 250 microns for the gross alpha analysis.

Sediment samples 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).

Groundwaters

Groundwaters from bores at Little Forest Burial Ground were collected by first pumping out the contents of each bore, then allowing all the bores to recharge with fresh groundwater over a period of at least two days. The samples were then collected by pumping 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 m³ 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 m³ 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 m³ per

quarter. 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 - ARL dosimeters

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

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

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

Analysis Methods: *Tritium in waters*

Water samples to be analysed for tritium were prepared by distillation according to the International Organization for Standardization (ISO) standard method 9698:1989(E). Aliquots of five millilitres (one millilitre in previous years) were taken from the distilled samples and combined with 11 mL of Ultima Gold scintillant cocktail in polyethylene counting vials. The samples were counted in a Packard Tri-carb Liquid Scintillation Analyser, model 2700TR. The first set of counts are discarded in order to allow the samples several hours to equilibrate in the dark. Three tritium standards (prepared monthly using a certified Amersham tritium solution) and a distilled water blank were counted with the samples, to check the operation and background radioactivity of the counter. A series of quenched standards were counted to determine the relationship between the spectral index of the external standard and the counting efficiency. Sample activity was corrected for chemical quenching. Total counting time was 100 minutes per vial, comprising five 20-minute counts. Results were calculated in terms of Bq/litre along with a minimum detectable activity (at 95% confidence level).

Gross Alpha/Beta Activity in Soils

Soils/sediments were counted for gross beta activity in a Geiger-Müller tube with a 2-inch diameter end-window. Alpha counting of these samples was done on a fraction with a grain size of 125 to 250 microns, in an AERE type alpha-drawer assembly (a zinc sulphide scintillating screen monitored by a photomultiplier tube). Beta and alpha activities were assumed to have energies similar to potassium-40 and natural uranium respectively. Analytical grade potassium chloride was used to standardise the detector for beta activity because of its natural potassium-40 content. A sand specially coated with uranyl nitrate, and of the same particle size as the sample, was used to standardise the alpha detector.

Gross Alpha/Beta Activity in Waters - changeover to ISO methods

Most water samples were screened for gross alpha/beta activities to determine whether further tests for individual radionuclides were necessary. All of these water samples for 1998 were analysed using ISO methods 9696 & 9697(1992).

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

ISO 9696 & 9697 (1992) - planchette thick source methods

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

Standard sources of 100 mg thickness were used to calibrate the Canberra 2400 thin-window gas-flow proportional alpha/beta counting system. The 100 mg standard sources were prepared as 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 repeatability of results; ability to store dry residues for future reference; unfiltered samples can be used; acidified samples can be used on stainless steel planchettes which have lower backgrounds than aluminium planchettes. Disadvantages: long preparation times and risk of losing samples through increased handling.

ARL gel method for preparation of gamma sources

All water samples which were concentrated for gamma spectrometry were prepared by the following method. Sample volumes ranging from two to twelve litres were evaporated on a hotplate to about 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 ARL. Results are expressed in Bq/litre. The building 27 sump sample is not concentrated prior to counting which allows a faster determination for short-lived radionuclides.

Gamma spectrometry - water, soils, vegetation, fish, algae, barnacles, maypacks

Gamma spectra are obtained by placing prepared samples onto a high-purity germanium (HPGe) low-background detector, and acquiring counts over a 23 hour period. A multi-channel analyser sorts the spectra according to the energy of the gamma photons. Peak areas in the sample spectra are calculated using an Ortec software package, Maestro II. Background spectra are acquired with no sample present to determine the radioactivity due to the environment and detector components, as distinct from the sample activity. Peaks at certain energies in the spectrum are used to identify the isotope and the amount present in the sample. A spectrum report is printed for each sample, showing the sample description, the peaks identified, gross and net areas of the peaks and associated counting errors.

The gamma detector energy spectrum is calibrated periodically using certified point sources. The counting efficiency of the detector is determined over a range of energies using several gamma sources, prepared from IAEA reference materials. These standard reference materials have a similar matrix to the types of samples usually encountered and are prepared in the same geometry. Background spectra are acquired with no sample present and are counted for the same length of time as the samples. Prepared samples for gamma spectrometry are presented in a uniform geometry, ie packed into petri dishes of 65mm diameter. The types of samples counted are mainly concentrated water samples set in agar gel, ashed vegetation or biota; dried/ashed sediments or powdered material.

Marinelli beakers are also used for direct counting of unconcentrated liquid samples. They are plastic containers which fit over and around the detector and contain 500 mL of sample. Calibration of the detector efficiency is done using a Marinelli beaker filled with 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 its 1460 keV peak in the gamma spectrum of the sample, or by chemical analysis of the sample's potassium content and a subsequent calculation of the potassium-40 activity. The latter method is more accurate. The specific activity of potassium is 27.6 Bq of potassium-40 per gram of stable potassium (Australian Drinking Water Guidelines, 1996).

Air samples - Ambient Iodine-131

One set of Maypacks are set aside each week in case random independent checking is required by officers of the ARL. The other set is analysed at ANSTO, by placing the four cartridges simultaneously under a large (8x4 inch) sodium-iodide gamma detector and counting for 5 hours. If an iodine-131 peak is detected then the filters are analysed individually using a high-purity germanium gamma detector, to determine which filters are the source of the activity.

Results are reported in units of iodine-131 activity per volume of air sampled (Bq/m³). The results are calculated in an extremely conservative manner, using the assumptions that:

- all the activity was released on the first day of the seven-day sampling period, ie any iodine-131 results are corrected for decay (due to the 8 day half-life) back to the first day of the sampling period.
- all the measured activity was released at one point (there are actually four locations being measured).

APPENDIX E : AIRBORNE EFFLUENT SAMPLE COLLECTION AND ANALYSIS

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

Sampling for gases, vapours and particulates

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

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

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

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

Sampling for Tritiated Water

Tritiated water in the airborne effluent is sampled using a tritium bubbler.

A proportion of the stack airstream is drawn through a series of four Dreschel bottles filled with 200 mL of demineralised water, thus trapping the tritiated water with an efficiency of about 99%. The flow rate is limited to 1 litre per minute by a Millipore critical orifice. The four samples are transferred to a one litre flask, topped-up to 1 litre, and a 1 mL subsample taken for testing. A liquid scintillation counter is then used to measure the tritium level in the sample.

Sampling for Noble Gases

Noble gases are measured in situ by a gamma spectrometer. As the effluent passes through a 250 mL sampling flask at 4 litres per minute, a gamma spectrometer with a NaI detector is used to count the noble gas activity.

TABLE 1
ENVIRONMENTAL MONITORING SCHEDULE, 1998

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

Notes:

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

Continued next page...

TABLE 1 Continued...

SAMPLE	STATION	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Ground water	Little Forest Burial Ground.	Twice yearly.	Bores are pumped dry & allowed to refill. Seven litres sampled from the centre of the bore, avoiding the sediment.	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. Direct gamma spectrometry on 500mL in Marinelli beaker. Remainder acidified & stored.
Airborne particulates	Little Forest Burial Ground: trench area.	Quarterly: particulates are accumulated for ~ 4 hours every 2 weeks over three months.	Airborne particulates collected on a filter paper using mobile <i>Ecotech</i> high-volume air sampler.	Each quarterly sample divided into four equal parts: one analysed for beryllium by ICPMS, another put aside for a yearly composite, analysed for $^{239/240}\text{Pu}$. 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.
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	STATION	FREQUENCY	COLLECTION DETAILS	SAMPLE PREPARATION & ANALYSIS
Marine Biological Samples	Potter Point Ocean Outfall	Twice yearly.	Barnacles, algae & fish, near the outfall.	Gamma spectrometry of dried, homogenised samples.
	The Royal National Park.	Twice yearly.	Barnacles, algae & fish .	As above.
Gamma Dose Rate Survey	Effluent discharge pipeline.	Twice yearly.	Pipe joints and ground surveyed using Eberline PRM-7 dose-rate meter. Soil sampled if >3 times the background dose.	If collected, soils are sieved and ashed, then counted for α, β, γ activity.
	Little Forest Burial Ground.	Yearly.	Burial trenches are surveyed using a field dose-rate monitor. Soil is sampled if >3 times background.	As above.
External Gamma Radiation	LHSTC perimeter: 15 sites; 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, 1998

Date	Tritium ⁽²⁾ (Bq/L)
6-1-98	< 10 ⁽³⁾
13-2-98	< 10
3-3-98	< 10
1-4-98	< 10
6-5-98	< 10
2-6-98	< 20
8-7-98	< 10
4-8-98	< 20
1-9-98	< 10
13-10-98	< 20
3-11-98	< 10
1-12-98	< 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, 1998

Date	Tritium ⁽²⁾ (Bq/L)
6-1-98	< 10
13-2-98	< 10
3-3-98	< 10
1-4-98	< 10
6-5-98	< 10
2-6-98	< 20
8-7-98	< 10
4-8-98	< 10
1-9-98	< 10
13-10-98	< 10
3-11-98	< 10
1-12-98	< 10

Notes:

1. Refer to **Figure 1** for 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, 1998

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	20-3-98	N.D.	N.D.	140 ± 10	N.D.	N.D.	N.D.
	20-3-98	N.D.	N.D.	140 ± 10	N.D.	N.D.	N.D.
	26-10-98	N.D.	N.D.	140 ± 10	N.D.	N.D.	N.D.
	26-10-98	N.D.	N.D.	130 ± 10	N.D.	N.D.	N.D.
The Royal National Park Reference site	3-4-98	N.D.	N.D.	130 ± 10	N.D.	N.D.	N.D.
	3-4-98	N.D.	N.D.	130 ± 10	N.D.	N.D.	N.D.
	23-12-98	N.D.	N.D.	130 ± 10	N.D.	N.D.	N.D.
	23-12-98	N.D.	N.D.	120 ± 10	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**, ⁷Be and ⁴⁰K are all of natural origin.

TABLE 5
RADIOACTIVITY IN ALGAE FROM POTTER POINT
OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1998

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	23-3-98	✓	11 ± 3	140 ± 30	N.D.	N.D.	26 ± 5
	23-3-98	✓	14 ± 2	130 ± 10	N.D.	N.D.	20 ± 2
	26-10-98	✓	11 ± 2	110 ± 10	N.D.	N.D.	350 ± 30
	26-10-98	✓	13 ± 2	100 ± 10	N.D.	N.D.	400 ± 40
The Royal National Park Reference site	22-4-98	✓	8 ± 1	120 ± 10	N.D.	N.D.	N.D.
	22-4-98	✓	11 ± 1	110 ± 10	N.D.	N.D.	N.D.

TABLE 6
RADIOACTIVITY IN BARNACLES FROM POTTER POINT
OCEAN OUTFALL AND THE ROYAL NATIONAL PARK, 1998

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	23-3-98	N.D.	N.D.	30 ± 10	N.D.	N.D.	N.D.
	23-3-98	N.D.	N.D.	30 ± 10	N.D.	N.D.	N.D.
	26-10-98	✓	N.D.	< 10	N.D.	N.D.	N.D.
	26-10-98	✓	N.D.	< 10	N.D.	N.D.	N.D.
The Royal National Park Reference site	22-4-98	✓	N.D.	20 ± 10	N.D.	N.D.	N.D.
	22-4-98	✓	N.D.	30 ± 10	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**, ⁷Be and ⁴⁰K are all of natural origin.

TABLE 7a
TRITIUM IN MONTHLY WATER SAMPLES FROM
STORMWATER BUNDS, 1998

Date	Tritium ⁽¹⁾ (Bq/L)	
	BUND A ⁽²⁾ Behind Building 1	BUND B Opposite Meteorological Tower
12-1-98	150 ± 20	70 ± 10
13-2-98	300 ± 20	360 ± 20
16-3-98	160 ± 10	60 ± 10
21-4-98	90 ± 10	110 ± 10
27-5-98	70 ± 20	30 ± 20
23-6-98	140 ± 10	70 ± 10
27-7-98	80 ± 10	80 ± 10
10-8-98	50 ± 10	60 ± 10
22-9-98	50 ± 10	140 ± 10
27-10-98	150 ± 30	70 ± 20
20-11-98	200 ± 10	40 ± 10
16-12-98	100 ± 10	120 ± 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⁾ 1998

Date	Tritium ^(2,3) Bq/L	Date	Tritium Bq/L
6-1-98	40 ± 10	8-7-98	80 ± 10
13-1-98	90 ± 10	14-7-98	60 ± 10
20-1-98	40 ± 20	21-7-98	< 30
27-1-98	150 ± 20	28-7-98	30 ± 10
3-2-98	100 ± 10	4-8-98	80 ± 20
10-2-98	210 ± 20	10-8-98	30 ± 10
16-2-98	140 ± 10	19-8-98	< 30
24-2-98	100 ± 10	25-8-98	150 ± 10
3-3-98	110 ± 10	1-9-98	60 ± 10
10-3-98	110 ± 10	8-9-98	70 ± 10
17-3-98	140 ± 10	15-9-98	70 ± 10
24-3-98	90 ± 20	22-9-98	100 ± 10
1-4-98	60 ± 10	29-9-98	90 ± 10
7-4-98	120 ± 10	6-10-98	110 ± 10
14-4-98	340 ± 20	13-10-98	90 ± 10
21-4-98	230 ± 10	20-10-98	90 ± 10
28-4-98	< 10 ⁽⁴⁾	27-10-98	< 10
6-5-98	40 ± 10	3-11-98	40 ± 10
12-5-98	90 ± 20	10-11-98	60 ± 10
19-5-98	< 20	17-11-98	80 ± 10
26-5-98	< 30	24-11-98	120 ± 10
2-6-98	30 ± 20	1-12-98	140 ± 10
9-6-98	70 ± 10	8-12-98	30 ± 10
16-6-98	< 20	15-12-98	40 ± 10
23-6-98	40 ± 20	22-12-98	120 ± 10
1-7-98	50 ± 10	30-12-98	80 ± 10

Notes:

1. Refer to **Figure 2** for the location of this sampling point.
2. The average tritium level during 1998 was about 90 Bq/L, which is less than 2% 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, 1998

Monthly Composite ⁽¹⁾	RADIOACTIVITY (Bq/L)			
	Gross α ⁽²⁾	Gross β ⁽⁴⁾	Gamma emitters	
			¹³⁷ Cs ⁽⁵⁾	⁴⁰ K
January	< 0.03 ⁽³⁾	0.99 ± 0.02	0.055 ± 0.013	< 0.5
February	0.05 ± 0.01	1.16 ± 0.02	0.065 ± 0.014	0.5 ± 0.1
March	0.06 ± 0.02	1.20 ± 0.02	0.064 ± 0.013	< 0.4
April	0.03 ± 0.01	0.47 ± 0.02	0.049 ± 0.013	< 0.3
May	0.05 ± 0.01	0.48 ± 0.01	N.D. ⁽⁶⁾	0.4 ± 0.2
June	0.02 ± 0.01	0.37 ± 0.01	N.D.	< 0.04
July	0.06 ± 0.02	0.92 ± 0.02	N.D.	< 0.4
August	< 0.02	1.23 ± 0.02	N.D.	< 0.4
September	< 0.03	0.49 ± 0.01	N.D.	N.D.
October	0.03 ± 0.01	0.59 ± 0.01	N.D.	N.D.
November	< 0.03	0.86 ± 0.02	N.D.	N.D.
December	0.02 ± 0.01	0.72 ± 0.02	0.034 ± 0.011	< 0.3

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 ¹³⁷Cs in MDP Bund C in 1998 was < 0.03 Bq/L, which is < 0.3 % of the WHO reference value for ¹³⁷Cs in drinking water (10.5 Bq/L).
6. "N.D": the radionuclide was not detected.

TABLE 8
RADIOACTIVITY IN SEDIMENT FROM STORMWATER BUNDS, 1998

Location ⁽¹⁾	Date	RADIOACTIVITY in SEDIMENT (Bq/g DW) ⁽²⁾			
		Gross α	Gross β	Gamma Emitters	⁴⁰ K
BUND A: Behind Building 1	3-9-98	0.31 ± 0.06	0.33 ± 0.02	⁷ Be = 0.033 ± 0.005 ¹³⁷ Cs = 0.009 ± 0.001	0.36 ± 0.04
BUND B: Opposite Meteorological Tower	3-9-98	0.30 ± 0.07	0.22 ± 0.02	⁷ Be = 0.040 ± 0.006 ¹³⁷ Cs = 0.003 ± 0.001 ⁶⁰ Co < 0.003 ⁽³⁾	0.12 ± 0.02
BUND C: MDP (on Stormwater Outlet No.1)	11-7-98	0.41 ± 0.10	0.76 ± 0.04	²⁴¹ Am = 0.005 ± 0.001 ¹⁴⁴ Ce = 0.034 ± 0.005 ⁷ Be = 0.066 ± 0.009 ¹⁰³ Ru = 0.129 ± 0.014 ¹⁰⁶ Ru = 2.81 ± 0.28 ⁶⁰ Co = 0.025 ± 0.003 ¹³⁷ Cs = 0.120 ± 0.011	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⁾ 1998

Date	Tritium ^(2,3) Bq/L	Date	Tritium Bq/L
6-1-98	30 ± 10	8-7-98	90 ± 10
13-1-98	120 ± 10	14-7-98	40 ± 10
20-1-98	90 ± 10	21-7-98	< 30
27-1-98	140 ± 10	28-7-98	50 ± 10
3-2-98	150 ± 30	4-8-98	70 ± 10
10-2-98	130 ± 20	10-8-98	30 ± 10
16-2-98	130 ± 10	19-8-98	< 30
24-2-98	150 ± 20	25-8-98	50 ± 10
3-3-98	130 ± 10	1-9-98	70 ± 10
10-3-98	140 ± 10	8-9-98	70 ± 10
17-3-98	150 ± 20	15-9-98	80 ± 10
24-3-98	130 ± 20	22-9-98	100 ± 10
1-4-98	140 ± 10	29-9-98	110 ± 20
7-4-98	170 ± 20	6-10-98	110 ± 20
14-4-98	320 ± 20	13-10-98	100 ± 10
21-4-98	120 ± 10	20-10-98	110 ± 30
28-4-98	140 ± 10	27-10-98	< 20
6-5-98	40 ± 10	3-11-98	90 ± 10
12-5-98	110 ± 20	10-11-98	60 ± 10
19-5-98	< 20 ⁽⁴⁾	17-11-98	100 ± 10
26-5-98	70 ± 20	24-11-98	100 ± 10
2-6-98	30 ± 20	1-12-98	110 ± 10
9-6-98	120 ± 10	8-12-98	40 ± 10
16-6-98	30 ± 10	15-12-98	30 ± 10
23-6-98	40 ± 20	22-12-98	110 ± 20
1-7-98	60 ± 10	30-12-98	80 ± 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 1998 was < 92 Bq/L, representing < 2 % 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, 1998

Monthly Composite ⁽¹⁾	RADIOACTIVITY (Bq/L)			
	Gross α ⁽²⁾	Gross β	Gamma emitters	
			¹³⁷ Cs ⁽⁴⁾	⁴⁰ K
January	< 0.02 ⁽³⁾	0.42 ± 0.02	¹³⁷ Cs = 0.021 ± 0.004	< 0.11
February	< 0.01	0.25 ± 0.01	¹³⁷ Cs = 0.025 ± 0.004	< 0.13
March	0.03 ± 0.01	0.46 ± 0.01	¹³⁷ Cs = 0.021 ± 0.004	0.15 ± 0.04
April	0.03 ± 0.01	0.73 ± 0.01	¹³⁷ Cs = 0.022 ± 0.003 ⁶⁰ Co = 0.016 ± 0.004	0.08 ± 0.03
May	0.05 ± 0.01	0.49 ± 0.01	N.D	< 0.22
June	0.03 ± 0.01	0.40 ± 0.01	N.D	< 0.21
July	< 0.03	0.54 ± 0.01	⁵¹ Cr = 0.069 ± 0.026 ¹³⁷ Cs = 0.015 ± 0.003 ⁶⁰ Co = 0.013 ± 0.003	< 0.03
August	< 0.04	0.40 ± 0.01	N.D	< 0.10
September	< 0.03	0.47 ± 0.01	N.D	N.D
October	0.03 ± 0.01	0.48 ± 0.01	¹³⁷ Cs = 0.011 ± 0.005	0.23 ± 0.09
November	< 0.02	0.52 ± 0.01	¹³⁷ Cs = 0.020 ± 0.004	0.11 ± 0.04
December	< 0.03	0.51 ± 0.01	¹³⁷ Cs = 0.016 ± 0.004	< 0.02

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 ¹³⁷Cs concentration measured in 1998 was less than 0.25 % of the WHO reference value for ¹³⁷Cs in drinking water (10.5 Bq/L), see **Section 3.1.2**. The ⁵¹Cr and ⁶⁰Co concentrations were also a small percentage (< 0.05 %) of the levels allowable in drinking water.

TABLE 10
RADIOACTIVITY IN WATER FROM SPCC⁽¹⁾ SAMPLING POINTS, 1998

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
14-1-98	< 0.03 ⁽³⁾	0.09 ± 0.01	< 0.02	0.06 ± 0.01	< 0.02	0.41 ± 0.01
19-2-98	< 0.01	0.05 ± 0.01	< 0.01	0.05 ± 0.01	< 0.01	0.07 ± 0.01
16-3-98	< 0.02	0.08 ± 0.01	< 0.01	0.07 ± 0.01	< 0.02	0.39 ± 0.01
28-4-98	< 0.02	0.07 ± 0.01	< 0.03	0.05 ± 0.01	< 0.01	0.44 ± 0.01
28-5-98	< 0.03	0.08 ± 0.01	< 0.02	0.06 ± 0.01	< 0.03	0.31 ± 0.01
26-6-98	< 0.02	0.08 ± 0.01	0.03 ± 0.01	0.10 ± 0.01	< 0.02	0.32 ± 0.01
31-7-98	< 0.02	< 0.03	< 0.01	0.04 ± 0.01	< 0.02	0.33 ± 0.01
28-8-98	< 0.02	0.05 ± 0.01	< 0.03	0.06 ± 0.01	< 0.01	0.16 ± 0.01
30-9-98	< 0.03	0.05 ± 0.01	< 0.03	0.10 ± 0.01	< 0.01	0.34 ± 0.01
29-10-98	< 0.02	< 0.01	0.03 ± 0.01	0.03 ± 0.01	< 0.01	0.03 ± 0.01
20-11-98	< 0.01	< 0.01	< 0.02	< 0.03	< 0.02	0.24 ± 0.01
15-12-98	< 0.03	0.04 ± 0.01	< 0.02	0.08 ± 0.01	< 0.03	0.24 ± 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), 1998

Date	Tritium ⁽²⁾ Bq/L	Date	Tritium Bq/L
6-1-98	100 ± 10	8-7-98	350 ± 10
13-1-98	150 ± 20	14-7-98	60 ± 10
20-1-98	90 ± 20	21-7-98	70 ± 10
27-1-98	50 ± 20	28-7-98	60 ± 10
3-2-98	60 ± 20	4-8-98	30 ± 20
10-2-98	800 ± 30	10-8-98	30 ± 10
16-2-98	80 ± 10	19-8-98	< 20
24-2-98	80 ± 10	25-8-98	20 ± 10
3-3-98	50 ± 10	1-9-98	30 ± 10
10-3-98	40 ± 10	8-9-98	20 ± 10
17-3-98	50 ± 10	15-9-98	20 ± 10
24-3-98	< 10 ⁽³⁾	22-9-98	30 ± 10
1-4-98	< 10	29-9-98	40 ± 10
7-4-98	40 ± 10	6-10-98	30 ± 10
14-4-98	30 ± 10	13-10-98	180 ± 20
21-4-98	70 ± 10	20-10-98	970 ± 90
28-4-98	30 ± 10	27-10-98	70 ± 30
6-5-98	60 ± 20	3-11-98	60 ± 10
12-5-98	20 ± 10	10-11-98	70 ± 10
19-5-98	< 30	17-11-98	50 ± 10
26-5-98	< 40	24-11-98	270 ± 10
2-6-98	90 ± 40	1-12-98	60 ± 10
9-6-98	50 ± 10	8-12-98	100 ± 10
16-6-98	< 10	15-12-98	230 ± 10
23-6-98	40 ± 10	22-12-98	560 ± 10
1-7-98	40 ± 10	30-12-98	180 ± 10

Notes:

1. See **Figure 2** for the location of this sampling point.
2. The average weekly tritium concentration at Bardens Creek weir during 1998 was less than 110 Bq/L, which is <2 % 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 ⁽¹⁾, 1998

Date	Location ⁽²⁾	Doserate ($\mu\text{Sv}/\text{hour}$)		Background Doserate ($\mu\text{Sv}/\text{hour}$)
		Ground Below Joint	Pipe Joint	
28-4-98	Joints No.1-22	0.05 – 0.08	0.05 – 0.07	0.05 – 0.08
14-9-98	Joints No.1-22	0.07 – 0.12	0.07 – 0.13	0.07 – 0.15

Notes:

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

TABLE 13
GAMMA SURVEY - BURIAL TRENCHES
LITTLE FOREST BURIAL GROUND, 1998

Date	Location ^(1,2)	Doserate ($\mu\text{Sv}/\text{hour}$)
9 December 1998	Background reading (outside LFBG fence)	0.10 – 0.15
	Readings over all trenches	0.10 – 0.15
	Point #5	0.10 – 0.15
	Point #6	0.10 – 0.15

Notes:

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

TABLE 14
RADIOACTIVITY IN GROUNDWATER FROM LITTLE FOREST
BURIAL GROUND, 1998

Bore ⁽¹⁾	Date Sampled	RADIOACTIVITY ⁽²⁾ Bq/L				
		³ H	Gross α	Gross β	Gamma Emitters	
					Other	⁴⁰ K
BHF	25-5-98	70 ± 20	0.04 ± 0.01	0.09 ± 0.01	N.D.	< 0.2
BH10	"	150 ± 20	0.05 ± 0.01	0.05 ± 0.01	N.D.	< 0.6
OS2	"	730 ± 30	0.06 ± 0.01	0.09 ± 0.01	N.D.	< 0.2
OS3	"	240 ± 30	0.04 ± 0.01	0.29 ± 0.01	N.D.	< 0.4
MB11	"	< 10 ⁽³⁾	< 0.03	< 0.03	N.D.	< 0.4
MB12	"	< 50	< 0.01	< 0.03	N.D.	< 0.5
MB13	"	910 ± 20	0.03 ± 0.01	0.07 ± 0.01	N.D.	< 0.3
MB14	"	< 10	< 0.03	0.07 ± 0.01	N.D.	< 0.5
MB15	"	< 20	0.06 ± 0.01	0.10 ± 0.01	N.D.	< 0.2
MB16 ⁽⁴⁾	"	1940 ± 30	0.14 ± 0.01	0.32 ± 0.01	⁶⁰ Co = 0.08 ± 0.01 ¹³⁷ Cs = 0.04 ± 0.01	< 0.2
MB17	"	310 ± 20	0.07 ± 0.01	0.07 ± 0.01	N.D.	< 0.2
MB18	"	90 ± 30	0.04 ± 0.01	0.08 ± 0.01	N.D.	< 0.2
MB19 ⁽⁵⁾	"	< 10	< 0.05	0.13 ± 0.01	N.D.	< 0.4
MB20	"	< 30	0.06 ± 0.01	0.28 ± 0.01	N.D.	< 0.4
MB21	"	< 10	0.05 ± 0.01	0.14 ± 0.01	N.D.	< 0.5
BHF	28-9-98	150 ± 20	0.04 ± 0.01	0.07 ± 0.01	N.D.	N.D.
BH10	"	4810 ± 50	0.14 ± 0.06	0.09 ± 0.04	N.D.	< 0.3
OS2	"	1410 ± 40	0.06 ± 0.01	0.11 ± 0.01	N.D.	< 0.3
OS3	"	750 ± 20	0.04 ± 0.01	0.30 ± 0.01	N.D.	N.D.
MB11	"	< 10	< 0.03	0.05 ± 0.02	N.D.	< 0.6
MB12	"	< 30	< 0.03	0.07 ± 0.01	N.D.	< 0.3
MB13	"	1740 ± 60	< 0.02	0.10 ± 0.01	N.D.	< 0.4
MB14	"	< 10	< 0.05	0.12 ± 0.01	N.D.	N.D.
MB15	"	< 10	0.03 ± 0.01	0.10 ± 0.01	N.D.	< 0.3
MB16	"	7010 ± 70	0.22 ± 0.02	0.32 ± 0.01	⁶⁰ Co = 0.17 ± 0.04	N.D.
MB17	"	1880 ± 40	0.05 ± 0.02	0.11 ± 0.02	N.D.	< 0.3
MB18	"	< 20	0.04 ± 0.01	0.09 ± 0.01	N.D.	< 0.4
MB19	"	< 10	< 0.06	0.20 ± 0.02	N.D.	< 0.2
MB20	"	< 20	0.10 ± 0.02	0.35 ± 0.02	N.D.	< 0.4
MB21	"	< 20	0.04 ± 0.01	0.13 ± 0.01	N.D.	< 0.3

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 ⁶⁰Co and ¹³⁷Cs 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.

TABLE 15
RADIOACTIVITY IN CREEKS RECEIVING RUNOFF FROM THE
LITTLE FOREST BURIAL GROUND AREA, 1998

Sample Location	Date	RADIOACTIVITY in SEDIMENT (Bq/g DW)			
		Gross α	Gross β	γ -emitters	
Mill Creek	16-12-98	0.70 \pm 0.08	0.11 \pm 0.02	^{40}K = 0.06 \pm 0.01 U & Th series	
Bardens Creek	16-12-98	0.42 \pm 0.07	0.08 \pm 0.02	^{40}K = 0.06 \pm 0.01 U & Th series	
Sample Location	Date	RADIOACTIVITY in WATER (Bq/L)			
		Gross α	Gross β	γ -emitters	Tritium
Mill Creek	16-12-98	0.05 \pm 0.01	0.19 \pm 0.01	^{40}K < 0.7	< 10
Bardens Creek	16-12-98	< 0.03	0.15 \pm 0.01	^{40}K < 0.4	< 10

Notes:

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

TABLE 16
PARTICULATES IN AIR AT LITTLE FOREST BURIAL GROUND, 1998

Sampling Period ^(1, 2)	Average Windspeed ⁽³⁾ (m.s ⁻¹)	Equivalent Volume ⁽⁴⁾ (m ³)	Beryllium ⁽⁵⁾		^{239/240} Plutonium ⁽⁶⁾	
			μg (total)	$\mu\text{g m}^{-3}$	Bq (total)	Bq m ⁻³
Jan – Mar	3.9	386.2	< 0.10	< 2.6 $\times 10^{-4}$	-	-
Apr – Jun	2.5	361.1	< 0.10	< 2.8 $\times 10^{-4}$	-	-
July – Sept	2.5	333.1	< 0.10	< 3.0 $\times 10^{-4}$	-	-
Oct – Dec	4.3	421.9	< 0.10	< 2.4 $\times 10^{-4}$	-	-
1998 Composite	3.3	1502.3	-	-	< 0.001	< 6.6 $\times 10^{-7}$

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 $\mu\text{g m}^{-3}$ 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/m³ 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, 1998

Sampled during the week ending:	Iodine-131 Air Concentration Bq / m ³	Sampled during the week ending:	Iodine-131 Air Concentration Bq / m ³
6-1-98	< 0.0025	8-7-98	< 0.0025
13-1-98	< 0.0025	14-7-98	< 0.0025
20-1-98	< 0.0025	21-7-98	< 0.0025
27-1-98	< 0.0025	28-7-98	< 0.0025
3-2-98	< 0.0025	4-8-98	< 0.0025
10-2-98	< 0.0025	10-8-98	< 0.0025
16-2-98	< 0.0025	19-8-98	< 0.0025
24-2-98	< 0.0025	25-8-98	< 0.0025
3-3-98	< 0.0025	1-9-98	< 0.0025
10-3-98	< 0.0025	8-9-98	< 0.0025
17-3-98	< 0.0025	15-9-98	< 0.0025
24-3-98	< 0.0025	22-9-98	< 0.0025
1-4-98	< 0.0025	29-9-98	< 0.0025
7-4-98	< 0.0025	6-10-98	< 0.0025
14-4-98	< 0.0025	13-10-98	< 0.0025
21-4-98	< 0.0025	20-10-98	< 0.0025
28-4-98	< 0.0025	27-10-98	< 0.0025
6-5-98	< 0.0025	3-11-98	< 0.0025
12-5-98	< 0.0025	10-11-98	< 0.0025
19-5-98	< 0.0025	17-11-98	< 0.0025
26-5-98	< 0.0025	24-11-98	< 0.0025
2-6-98	< 0.0025	1-12-98	< 0.0025
9-6-98	< 0.0025	8-12-98	< 0.0025
16-6-98	< 0.0025	15-12-98	< 0.0025
23-6-98	< 0.0025	22-12-98	< 0.0025
1-7-98	< 0.0025	30-12-98	< 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 the minimum detectable concentration of 0.0025 Bq/m³ would receive an effective dose of less than 0.01 mSv per year (IAEA, 1994).

TABLE 18a
EXTERNAL GAMMA RADIATION AT LHSTC
(ARL Dosimeter Results) 1994 to 1998

Dosimeter Location: on-site ⁽¹⁾	Effective Dose ⁽²⁾ ARL Dosimeters ⁽³⁾ (mSv / year)				
	1994	1995	1996	1997	1998
1 Hifar fence - south east	1.0 ± 0.1	1.2 ± 0.3	0.8 ± 0.3	0.9 ± 0.4	1.0 ± 0.4
2 Hifar fence - south	2.2 ± 0.4	2.4 ± 0.5	2.2 ± 0.3	3.3 ± 0.5	3.3 ± 0.5
3 Perimeter fence - west	1.2 ± 0.2	1.4 ± 0.3	1.0 ± 0.4	1.2 ± 0.5	1.3 ± 0.5
4 Hifar fence - west	1.5 ± 0.7	1.5 ± 0.5	2.1 ± 0.3	1.5 ± 0.6	1.2 ± 0.5
5 Hifar fence - north west	1.4 ± 0.7	1.2 ± 0.4	3.0 ± 0.5	1.2 ± 0.5	0.9 ± 0.4
6 Perimeter fence - north A	0.9 ± 0.3	1.0 ± 0.4	0.8 ± 0.3	0.9 ± 0.4	0.8 ± 0.4
7 Internal fence - north	0.9 ± 0.3	1.1 ± 0.5	0.8 ± 0.3	1.1 ± 0.4	0.8 ± 0.4
8 Perimeter fence - north B	0.9 ± 0.2	1.2 ± 0.7	0.7 ± 0.3	1.0 ± 0.4	0.8 ± 0.4
9 Perimeter fence - north east	0.9 ± 0.2	1.0 ± 0.4	0.7 ± 0.3	0.8 ± 0.3	0.8 ± 0.3
10 Perimeter fence - east	1.0 ± 0.3	1.2 ± 0.3	0.7 ± 0.3	0.9 ± 0.4	0.8 ± 0.4
11 Perimeter fence - south east	1.0 ± 0.3	1.0 ± 0.3	0.5 ± 0.2	0.9 ± 0.3	0.9 ± 0.4
12 Corner of Curie and Roentgen Streets	1.2 ± 0.4	1.2 ± 0.5	0.8 ± 0.3	1.2 ± 0.5	0.8 ± 0.4
13 Perimeter fence - south	0.8 ± 0.2	0.9 ± 0.4	0.6 ± 0.2	0.7 ± 0.3	0.8 ± 0.4
14 Hifar fence - east	1.0 ± 0.2	1.1 ± 0.4	0.8 ± 0.3	1.0 ± 0.4	1.1 ± 0.5
15 Hifar fence - north east	1.1 ± 0.3	1.2 ± 0.4	0.9 ± 0.4	1.1 ± 0.5	1.0 ± 0.4
Dosimeter Location: off-site	1994	1995	1996	1997	1998
16 Private house - Lucas Heights	0.9 ± 0.2	0.9 ± 0.3	0.7 ± 0.3	0.8 ± 0.3	0.9 ± 0.4
17 Private house - Engadine	0.8 ± 0.1	1.0 ± 0.4	0.8 ± 0.3	1.1 ± 0.4	0.9 ± 0.4
18 Private house - Woronora	0.9 ± 0.2	1.1 ± 0.5	0.7 ± 0.3	0.9 ± 0.4	0.9 ± 0.4

- 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 ARL dosimeters are the same as those usually used for personal monitoring, consisting of calcium sulphate thermoluminescent material with three filtered areas and an open window. The uncertainties (at the 95% confidence level) have been estimated from the standard deviation of the results for several dosimeters placed at the same location

TABLE 18b
EXTERNAL GAMMA RADIATION AT LHSTC,
Comparison of ARL and ANSTO Results, 1998

Dosimeter Location: on-site ⁽¹⁾		Thermoluminescent Dosimeter Results 1998	
		Effective Dose ⁽²⁾ (mSv / year)	
		ARL ⁽³⁾	ANSTO ⁽⁴⁾
1	Hifar fence - south east	1.0 ± 0.4	1.1 ± 0.1
2	Hifar fence - south	3.3 ± 0.5	3.3 ± 0.1
3	Perimeter fence - west	1.3 ± 0.5	1.3 ± 0.1
4	Hifar fence - west	1.2 ± 0.5	1.5 ± 0.1
5	Hifar fence - north west	0.9 ± 0.4	1.3 ± 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	0.8 ± 0.4	1.0 ± 0.1
9	Perimeter fence - north east	0.8 ± 0.3	0.9 ± 0.1
10	Perimeter fence - east	0.8 ± 0.4	1.0 ± 0.1
11	Perimeter fence - south east	0.9 ± 0.4	1.0 ± 0.1
12	Corner of Curie and Roentgen St	0.8 ± 0.4	1.2 ± 0.1
13	Perimeter fence - south	0.8 ± 0.4	0.8 ± 0.1
14	Hifar fence - east	1.1 ± 0.5	1.1 ± 0.1
15	Hifar fence - north east	1.0 ± 0.4	1.2 ± 0.1
Dosimeter Location: off-site		ARL	ANSTO
16	Private house - Lucas Heights	0.9 ± 0.4	0.9 ± 0.1
17	Private house - Engadine	0.9 ± 0.4	1.3 ± 0.1
18	Private house - Woronora	0.9 ± 0.4	1.0 ± 0.1

Notes:

1. Refer to **Figure 2** for the locations of thermoluminescent 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 ARL dosimeters are the same as those usually used for personal monitoring, consisting of calcium sulphate thermoluminescent material with three filtered areas and an open window. The ANSTO environmental dosimeters contain lithium fluoride and calcium fluoride thermoluminescent materials with energy compensation filters.
4. The uncertainties 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.

TABLE 19a
AIRBORNE RADIOACTIVITY DISCHARGES FROM INDIVIDUAL DISCHARGE POINTS
January – March 1998

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.	0.82						
15A	N.D.	26	1.4	560	30	Hg-197 22	Hg-203 3.0	As-76 49	Br-82 2.1
15M	N.D.	N.D.	0.40	91	N.D.				
19S	N.D.	N.D.	1.8						
19D	N.D.	N.D.	0.05						
20	N.D.	44	3.7	1.5					
21A	N.D.	N.D.	0.36						
21B	N.D.	N.D.	0.05						
23A	N.D.	570	3200			Hg-197 N.D.	Hg-203 N.D.		
23B	N.D.	N.D.	1.1						
41A	N.D.	N.D.	2.1						
41B	N.D.	N.D.	3.8						
54 Hotcells	N.D.	N.D.	2300		190	I-132 11 000	I-133 470		
56	N.D.	N.D.	1.8						
57	N.D.	N.D.	0.72	83					

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
April – June 1998

STACK ⁽¹⁾	Alpha (kBq)	Beta ⁽²⁾ (kBq)	Iodine-131 (MBq)	Tritium (GBq)	Noble Gases ⁽³⁾ (TBq)	Other Nuclides (MBq)			
						Hg-197 23	Hg-203 1.2	As-76 39	Br-82 1.3
3	N.D. ⁽⁴⁾	N.D.	0.30						
15A	N.D.	24	1.2	350	33	Hg-197 23	Hg-203 1.2	As-76 39	Br-82 1.3
15M	N.D.	N.D.	0.18	170	N.D.				
19S	N.D.	N.D.	0.56						
19D	N.D.	N.D.	0.02						
20	N.D.	31	2.0	1.2					
21A	N.D.	N.D.	0.12						
21B	N.D.	N.D.	0.01						
23A	N.D.	1600	2000			Hg-197 N.D.	Hg-203 N.D.		
23B	N.D.	N.D.	0.51						
41A	N.D.	N.D.	0.79						
41B	N.D.	N.D.	7.8						
54 Hotcells	N.D.	N.D.	1500		140	I-132 8300	I-133 210		
56	N.D.	N.D.	1.1						
57	N.D.	N.D.	0.81	0.71					

- 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
July – September 1998

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.	1.2						
15A	N.D.	49	2.5	410	36	Hg-197 28	Hg-203 2.4	As-76 71	Br-82 1.2
15M	N.D.	N.D.	1.0	33	N.D.				
19S	N.D.	N.D.	13						
19D	N.D.	N.D.	0.33						
20	N.D.	61	3.4	1.1					
21A	N.D.	N.D.	0.44						
21B	N.D.	N.D.	0.20						
23A	N.D.	1200	2700			Hg-197 N.D.	Hg-203 N.D.		
23B	N.D.	N.D.	4.7						
41A	N.D.	N.D.	3.0						
41B	N.D.	N.D.	1.4						
54 Hotcells	N.D.	N.D.	3300		160	I-132 19000	I-133 400		
56	N.D.	N.D.	11						
57	N.D.	N.D.	1.2	28					

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
October – December 1998

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.	1.1						
15A	N.D.	110	1.6	380	43	Hg-197 51	Hg-203 2.5	As-76 51	Br-82 2.2
15M	N.D.	N.D.	0.79	45	0.02				
19S	N.D.	N.D.	3.6						
19D	N.D.	N.D.	0.17						
20	N.D.	N.D.	1.1	3.3					
21A	N.D.	N.D.	0.14						
21B	N.D.	N.D.	0.09						
23A	N.D.	1900	2700			Hg-197 N.D.	Hg-203 N.D.		
23B	N.D.	N.D.	0.97						
41A	N.D.	N.D.	9.3						
41B	N.D.	N.D.	1.6						
54 Hotcells	N.D.	N.D.	3100		240	I-132 19000	I-133 520		
56	N.D.	N.D.	2.9						
57	N.D.	N.D.	0.41	6.8					

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⁾, 1998

Date Sampled	RADIOACTIVITY (Bq/L)	
	Gamma-emitters ⁽²⁾	Tritium ⁽³⁾
12-1-98	⁴⁰ K < 1.6 ⁽⁴⁾	440 ± 10
20-2-98	⁴⁰ K < 2.4	440 ± 20
10-3-98	⁴⁰ K < 2.2	470 ± 20
14-4-98	⁴⁰ K < 1.5	360 ± 20
27-5-98	⁴⁰ K < 1.8	330 ± 10
30-6-98	⁴⁰ K < 2.0	280 ± 10
27-7-98	⁴⁰ K < 2.4	310 ± 10
31-8-98	⁴⁰ K < 2.4	430 ± 20
1-10-98	⁴⁰ K < 2.2	650 ± 20
29-10-98	⁴⁰ K < 1.5	470 ± 20
4-12-98	⁴⁰ K < 2.1	470 ± 30
22-12-98	⁴⁰ K < 2.1	510 ± 20

Notes:

1. See **Figure 2** for the location of building 27 sump. 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. The average tritium levels in groundwater near building 27 in 1998 were below 370 Bq/L, less than 5% of the WHO reference concentration for tritium in drinking water (7800 Bq/L).
4. Results quoted as "less than" figures were below the minimum detectable activity (stated with 95 % confidence).

TABLE 21
RADIOACTIVITY IN LIQUID EFFLUENT DISCHARGED TO
THE SYDNEY WATER SEWER, 1998

MONTH	TOTAL VOLUME Discharged m ³	AVERAGE CONCENTRATION IN DISCHARGES			Average MONTHLY Concentration QUOTIENT ^(4,5)	
		ALPHA ^(1,2) Bq/m ³	BETA ⁽³⁾ Bq/m ³	TRITIUM Bq/m ³	Former 1959 Radioactive Substances Regulations	WHO Guidelines for Drinking Water
January	5909	< 2.74 x 10 ³	4.77 x 10 ⁴	5.25 x 10 ⁶	< 0.75	< 0.62
February	5183	< 3.00 x 10 ³	6.33 x 10 ⁴	8.25 x 10 ⁶	< 0.94	< 0.79
March	8772	< 2.41 x 10 ³	5.98 x 10 ⁴	1.25 x 10 ⁷	< 0.84	< 0.73
April	7175	< 2.93 x 10 ³	2.25 x 10 ⁴	1.74 x 10 ⁷	< 0.52	< 0.50
May	9296	< 3.17 x 10 ³	2.23 x 10 ⁴	4.07 x 10 ⁶	< 0.54	< 0.45
June	7789	< 3.15 x 10 ³	2.18 x 10 ⁴	8.55 x 10 ⁶	< 0.54	< 0.47
July	9114	< 2.74 x 10 ³	2.86 x 10 ⁴	4.18 x 10 ⁶	< 0.56	< 0.47
August	13184	< 6.94 x 10 ²	8.01 x 10 ³	1.87 x 10 ⁶	< 0.15	< 0.13
September	7734	< 5.15 x 10 ²	1.14 x 10 ⁴	5.84 x 10 ⁶	< 0.17	< 0.16
October	7340	< 5.95 x 10 ²	2.84 x 10 ³	1.47 x 10 ⁶	< 0.09	< 0.08
November	6530	< 8.23 x 10 ²	7.45 x 10 ³	3.45 x 10 ⁶	< 0.16	< 0.14
December	8434	< 9.00 x 10 ²	3.23 x 10 ³	4.95 x 10 ⁶	< 0.12	< 0.12
Average	8038	< 1.97 x 10³	2.49 x 10⁴	6.48 x 10⁶	< 0.45	< 0.39
Maximum Permissible Concentration (Former 1959 Radioactive Substances Regulations)		1.0 x 10 ⁴ (as ²²⁶ Ra)	1.0 x 10 ⁵ (as ⁹⁰ Sr)	4.0 x 10 ⁹	1.00	-
Activity Concentration Equivalent at ANSTO (WHO Guidelines for Drinking Water Quality)		1.25 x 10 ⁴ (as ²²⁶ Ra)	1.25 x 10 ⁵ (as ⁹⁰ Sr)	1.95 x 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. In 1998, the analytical method for gross alpha/beta determinations was changed from gas-proportional counting to liquid scintillation analysis. The procedure was modified in July 1998 to improve the detection limit for alpha emitters.
3. A mixture of unidentified beta-emitting nuclides, assumed to be all strontium-90 (ie. the worst possible case) when calculating the concentration quotient.
4. Concentration Quotient: the sum of the average monthly concentrations of alpha, beta and tritium radioactivity in the liquid effluent divided by the Maximum Permissible Concentration (MPC) or Activity Concentration Equivalent for that radionuclide. The relevant quotient term must be no greater than one to comply with the requirements of the former NSW Radioactive Substances Regulations (1959) or the WHO Guidelines for Drinking-Water Quality (1993).
5. All discharges for 1998 were below the former NSW Radioactive Substances Regulations MPC concentration limits and the Activity Concentration Equivalents at ANSTO (based on the WHO Guidelines for Drinking-Water Quality).

TABLE 22
NON-RADIOACTIVE COMPONENT OF LIQUID EFFLUENT
DISCHARGED TO THE SYDNEY WATER SEWER,
February 1995 – December 1998

Component mg/L	Observed Values 1995 - 1998		YEARLY AVERAGE ⁽¹⁾				AVERAGE 1995 to 1998	Standard for Acceptance mg/L ^(2,3)
	Minimum	Maximum	1995	1996	1997	1998		
Suspended Solids	5	84	30.5	23	22	22	24	200
pH	6.8	8.3	7.4	7.2	7.3	7.6	7.4	7 – 10
Ammonia	< 0.01	52.2	20.8	17.8	16.0	10.7	16.3	50
BOD	< 2	110	< 25	36	23	12	< 24	85 ⁽⁴⁾
Grease	< 5	59	< 20	14	13	12	< 14	50
Chromium	0.03	4.40	0.62	1.34	1.36	1.18	1.1	3

Notes:

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

TABLE 23a

ESTIMATED EFFECTIVE DOSES FROM LHSTC AIRBORNE DISCHARGES, 1998

Receptor Location	Percent of site dose constraint ⁽¹⁾	Percent of annual public dose limit ⁽²⁾	Effective dose 1998 mSv/yr
Nearest resident	0.8	0.25	0.0025
LHSTC Library	1.7	0.50	0.0050
LHSTC Building 9	1.7	0.52	0.0052
LHSTC Main gate	1.2	0.35	0.0035
Stevens Hall Motel	3.2	0.95	0.0095
LH Waste Service (tip)	0.5	0.15	0.0015
BMX track	0.3	0.08	0.0008
Woronora Valley	0.3	0.08	0.0008
At 1.6 kilometre radius from HIFAR			
NORTH	2.3	0.68	0.0068
NNE	2.6	0.79	0.0079
NE	1.6	0.48	0.0048
ENE	1.4	0.42	0.0042
EAST	0.9	0.27	0.0027
ESE	0.9	0.28	0.0028
SE	1.1	0.34	0.0034
SSE	0.7	0.20	0.0020
SOUTH	0.3	0.10	0.0010
SSW	0.3	0.09	0.0009
SW	1.4	0.42	0.0042
WSW	0.9	0.27	0.0027
WEST	0.4	0.12	0.0012
WNW	0.4	0.11	0.0011
NW	0.6	0.19	0.0019
NNW	1.0	0.31	0.0031
At 4.8 kilometre radius from HIFAR			
NORTH	0.7	0.22	0.0022
NNE	0.4	0.11	0.0011
NE	0.4	0.11	0.0011
ENE	0.3	0.09	0.0009
EAST	0.2	0.05	0.0005
ESE	0.1	0.04	0.0004
SE	0.2	0.07	0.0007
SSE	0.2	0.07	0.0007
SOUTH	0.1	0.03	0.0003
SSW	0.1	0.02	0.0002
SW	0.4	0.11	0.0011
WSW	0.2	0.06	0.0006
WEST	0.1	0.03	0.0003
WNW	0.1	0.03	0.0003
NW	0.2	0.05	0.0005
NNW	0.3	0.08	0.0008

Notes:

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

TABLE 23b

ESTIMATED EFFECTIVE DOSES FROM LHSTC AIRBORNE DISCHARGES, 1997

Receptor Location	Percent of site dose constraint ⁽¹⁾	Percent of annual public dose limit ⁽²⁾	Effective dose 1997 mSv/yr
Nearest resident	1.1	0.32	0.0032
LHSTC Library	2.3	0.70	0.0070
LHSTC Building 9	2.2	0.67	0.0067
LHSTC Main gate	1.6	0.48	0.0048
Stevens Hall Motel	4.4	1.32	0.0132
LH Waste Service (tip)	0.5	0.15	0.0015
BMX track	0.3	0.08	0.0008
Woronora Valley	0.4	0.12	0.0012
At 1.6 kilometre radius from HIFAR			
NORTH	2.5	0.75	0.0075
NNE	2.8	0.84	0.0084
NE	2.2	0.68	0.0068
ENE	2.0	0.59	0.0059
EAST	1.1	0.34	0.0034
ESE	0.8	0.23	0.0023
SE	1.0	0.31	0.0031
SSE	0.7	0.22	0.0022
SOUTH	0.3	0.10	0.0010
SSW	0.4	0.11	0.0011
SW	1.2	0.36	0.0036
WSW	0.9	0.28	0.0028
WEST	0.4	0.12	0.0012
WNW	0.4	0.12	0.0012
NW	0.5	0.19	0.0019
NNW	1.1	0.34	0.0034
At 4.8 kilometre radius from HIFAR			
NORTH	0.7	0.22	0.0022
NNE	0.5	0.14	0.0014
NE	0.5	0.15	0.0015
ENE	0.4	0.12	0.0012
EAST	0.2	0.07	0.0007
ESE	0.1	0.04	0.0004
SE	0.2	0.06	0.0006
SSE	0.2	0.07	0.0007
SOUTH	0.1	0.02	0.0002
SSW	0.1	0.03	0.0003
SW	0.3	0.09	0.0009
WSW	0.2	0.06	0.0006
WEST	0.1	0.03	0.0003
WNW	0.1	0.03	0.0003
NW	0.2	0.05	0.0005
NNW	0.3	0.09	0.0009

Notes:

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

TABLE 24
ANNUAL EFFECTIVE DOSES TO ADULTS
FROM NATURAL SOURCES

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

Notes:

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